Spaceborne Nitrogen Dioxide Observations from the Sentinel-5P TROPOMI over Turkey [†]

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Abstract: With rapid population growth, both urbanization and transportation affect air pollution, population health, and global warming. A number of air pollutants are released from industrial facilities and other activities and may cause adverse effects on human health and the environment. One of the biggest air pollutants, nitrogen dioxide (NO_2), is mainly caused by the combustion of fossil fuels, especially from traffic exhaust gases. Over the years, air pollution has been monitored using satellite remote sensing data. In this study, we investigate the relationship of the tropospheric NO_2 retrieved from the recently launched Sentinel-5 Precursor, a low-earth-orbit atmosphere mission dedicated to monitoring air pollution equipped with the spectrometer Tropomoi (Tropospheric Monitoring Instrument), and the population density over Turkey. For this purpose, we use the mean value of the NO_2 collected from July 2018 to January 2019 and the statistic population data from 2017. The results showed a significant correlation of higher than 0.72 between the population density and the maximum NO_2 values. For future studies, we recommend investigating the correlation of different air pollutants with population and other factors contributing to air and environmental pollution.

Keywords: air pollution; remote sensing; Sentinel-5 Precursor; nitrogen dioxide; Tropomoi

1. Introduction

The main causes of air pollution include economic development, urbanization, energy consumption, transportation and motorization, as well as the rapid increase of urban population. As the world population is rising, it is greatly increasing humanity's impact on the Earth's natural environment. In 2018, the global population was estimated to be 7.5 billion, with most people living in urban areas. Population growth has a negative impact on the quality of the environment and human health [1,2]. The biggest air pollutants encountered in our daily life are particulate matter (PM), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), ozone (O_3), carbon monoxide (CO), and carbon dioxide (CO_2) [3]. NO_2 is an important component of urban air pollution and a precursor to ground-level ozone, particulate matter, and acid rain [4]. The major source of NO_2 is the burning of fossil fuels such as coal, oil and gas. About 80% of the nitrogen dioxide in cities comes from motor vehicle exhaust. Other sources of NO_2 are petrol and metal refining, electricity generation from coal-fired power stations, other manufacturing industries and food processing.

Satellite observations of tropospheric NO_2 have been conducted since 1995 [5] by the Global Ozone Monitoring Experiment (GOME) satellite instrument, designed to observe the various gases in the Earth's stratosphere and troposphere. The latest launched satellite by the European Space
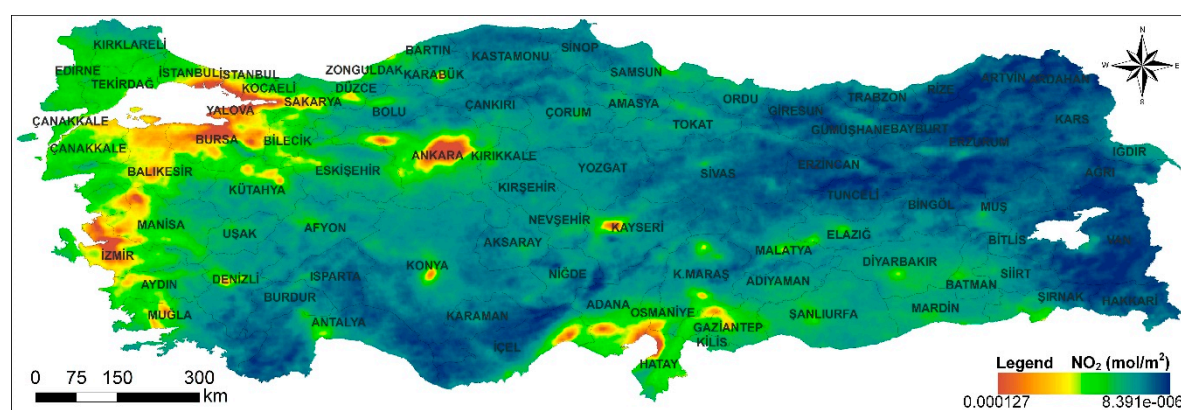
Agency (October, 2017), Sentinel-5 Precursor (Sentinel-5p), is a low-earth-orbit atmosphere mission dedicated to monitoring air quality and air pollution.

The Copernicus Program managed by the European Space Agency provides a number of Earth observation satellites intended for mapping and monitoring both the physics and chemistry of the Earth. One of the biggest Earth observation programs, Sentinel, contains different satellites. The Sentinel-5p is equipped with the spectrometer Tropomoi (Tropospheric Monitoring Instrument) which senses in the ultraviolet, visible, near and short-wavelength infrared to monitor ozone (O_3), methane (CH_4), formaldehyde (HCHO), carbon monoxide (CO), nitrogen dioxide (NO_2) and sulfur dioxide (SO_2) [6]. All data (near-real-time, offline and reprocessed) is freely accessible via the Copernicus Open Access Data Hub.

Using data from the Sentinel-5p, in this paper, we investigate the relationship between the NO_2 and the population statistics at the territory of Turkey. For that purpose, we use six-month average NO_2 values from 2018 and population statistics from 2018.

2. Data and Methods

The Sentinel-5p satellite was successfully launched on 13 October 2017, and the NO_2 data were released on 10 July 2018. Using the Google Earth Engine tools, the average NO_2 values over Turkey in the period of 10 July 2018–10 January2019 (Figure 1) were downloaded and statistically processed. Thus, the data were processed together and according to the provinces in Turkey. For all 81 provinces in Turkey, we extracted the minimum, maximum, mean, and sum of the NO_2.

Figure 1. NO_2 data taken from the Sentine-5p Tropospheric Monitoring Instrument (Tropomoi).

Afterwards, the results of the statistical analyses were correlated with the population data of every province in Turkey and regression analyses were performed. The population data were taken from the official Turkey population webpage [7] (Figure 2). According to the population statistics, it has been recorded that Turkey's total population in 2018 is approximately 82 million people, which is more than 10 million greater than the statistical data in 2017.
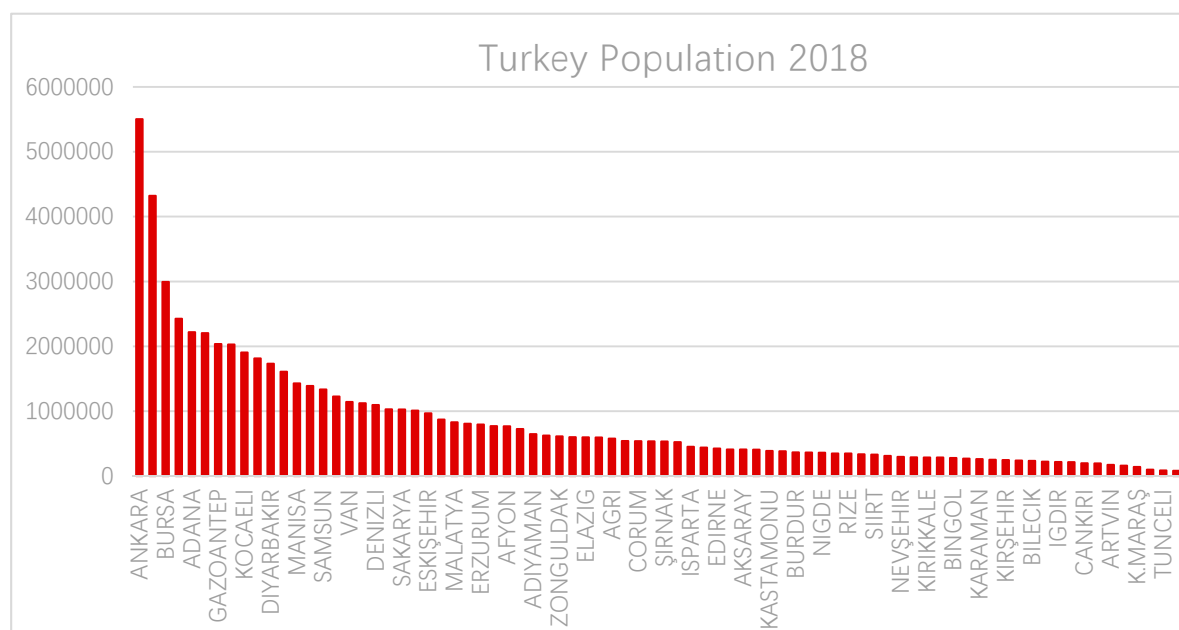
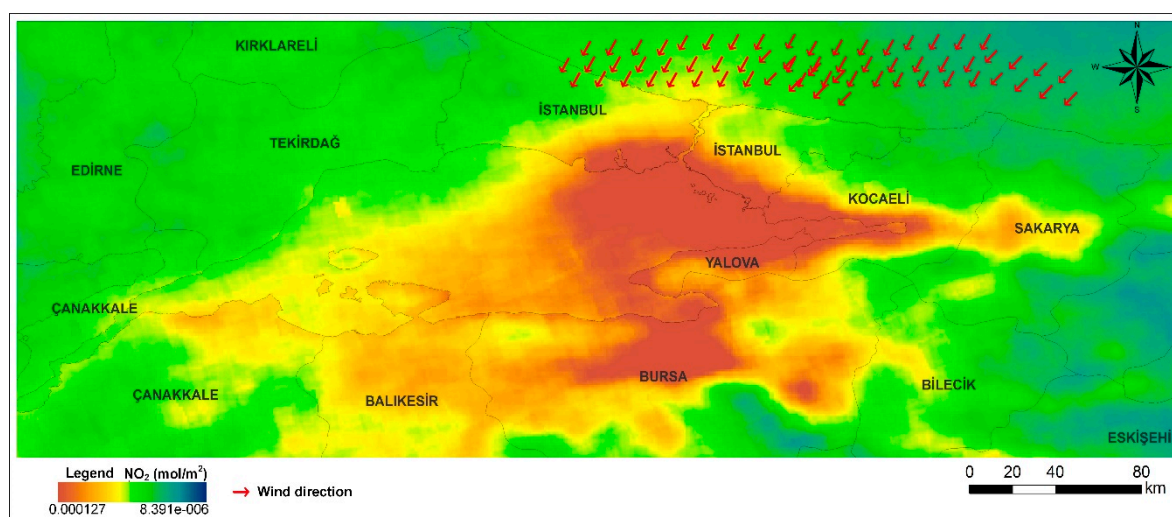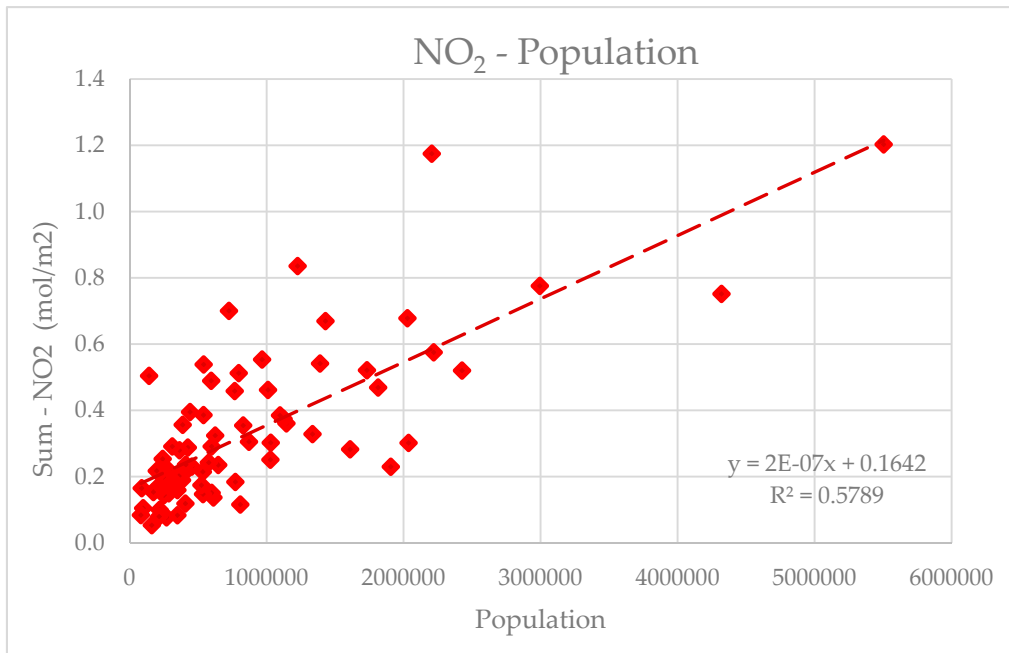**Figure 2.** Turkey's population in 2018.

Figure 3. NO$_2$ over Istanbul and its surroundings and wind directions over the Black Sea.

Istanbul is the most populated city in Turkey with more than 15 million people, and it contains more than 20% of the population of Turkey. Because of the specific geographical position of Istanbul, it has been excluded from the statistical analyses. However, the NO$_2$ values have been taken into consideration, and the area around the city has been additionally analyzed. Since Istanbul is surrounded on both the north and south by sea (Black Sea and Marmara Sea), the wind direction takes on an important role in terms of the air pollution and air quality [8]. Thus, as shown in Ruso et al. [9], the average wind direction in the Black Sea and Marmara Sea region is north–east south–west (Figure 3).
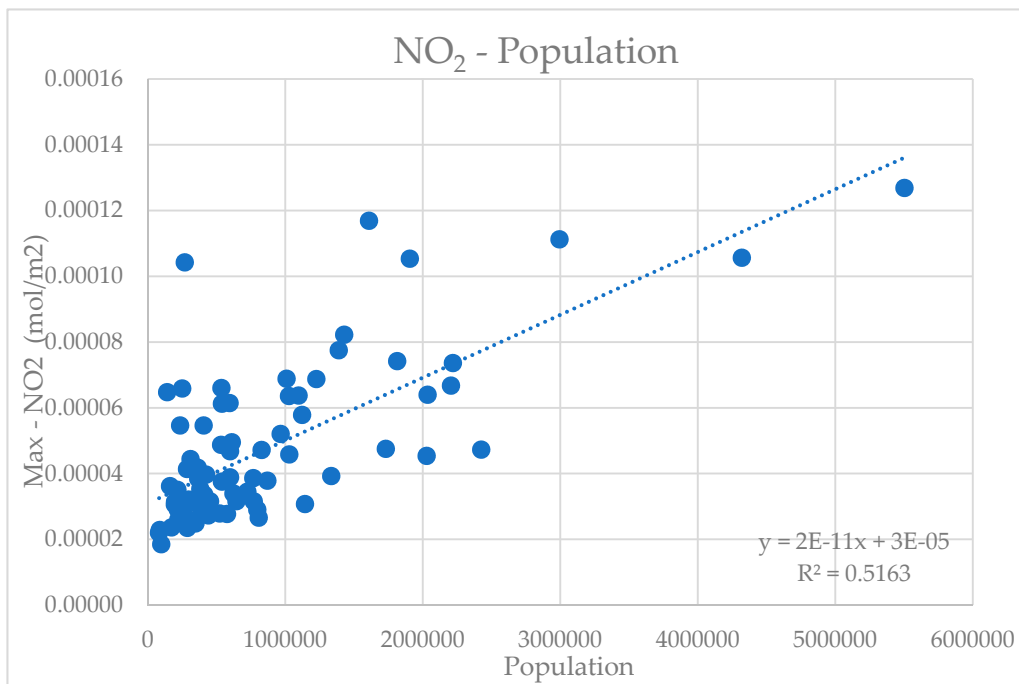
3. Results

The results of the statistical analyses are presented in Figure 4 and Figure 5. Additionally, the correlation coefficient between the summary and the maximum value of the NO$_2$ and the population statistics of every province in Turkey have been calculated. The correlation between the maximum value of NO$_2$ and the population is r = 0.72, while the correlation between the summary of the NO$_2$ and the population statistics is r = 0.76, which shows a strong linear relationship between the NO$_2$

and the population. On the other hand, the coefficient of determination (R^2) shows positive moderate correlation between the population and the summary ($R^2 = 0.58$) (Figure 4) and maximum ($R^2 = 0.52$) (Figure 5) NO_2 values, meaning that more than 50% of the NO_2 can be explained by the linear relation with the population statistics.

Figure 4. Relationship between the summary of NO_2 amounts and population statistics.

Figure 5. Relationship between the maximum NO_2 amount and population statistics.

4. Discussion

Istanbul, one of the world's mega cities and the biggest city in Turkey, is surrounded on both the north and south by the Black Sea and Marmara Sea, respectively. The wind direction takes on an important role in terms of the air pollution and air quality [8] due to the urban structure, the predominant wind direction in the city and the possible wind transport of pollutants to neighboring

cities. Thus, as shown in Ruso et al. [9], the average wind direction in the Black Sea and Marmara Sea region is north–east south–west. As shown in Figure 3, air pollutants from Istanbul are carried to north–east south–west wind directions over the Marmara Sea.

The positive relationship between the population and the NO_2 was expected, as NO_2 is one of the most important components of urban air pollution and a precursor to ground-level ozone, particulate matter, and acid rain [4]**,** and the major source of NO_2 is the burning of fossil fuels such as coal, oil and gas. About 80% of the nitrogen dioxide in cities comes from motor vehicle exhaust. That means that along with the population growth, NO_2 also rises, which was also proven in this paper using remote sensing data from the Sentinel-5p sensor. This remote sensing data can be further used to mitigate air pollution and improveme the air quality. In comparison with other satellite remote sensing sensors for monitoring air quality, Sentinel-5p has better spatial and spectral resolution, allowing the users to be able to observe smaller areas such as single cities.

5. Conclusions

In this study, we investigated the relationship of the tropospheric NO_2 retrieved from the recently launched Sentinel-5 Precursor, a low-earth-orbit atmosphere mission, dedicated to monitoring air pollution and equipped with the spectrometer Tropomoi, and the population density over Turkey from 2018. For this purpose, the mean value of NO_2 collected from July 2018 to January 2019 and the statistic population data from 2017 were used. The results showed a significant correlation of higher than 0.72 between the population density and the maximum NO_2 values. For future studies, we recommend investigating the correlation of different air pollutants with population and other factors contributing to air and environmental pollution.

Author Contributions: Authors contributed equally to this paper.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

The following abbreviations are used in this manuscript:
NO_2: Nitrogen dioxide
PM: Particulate matter
SO_2: Sulfur dioxide
NO_2: Nitrogen dioxide
O_3: Ozone
CO: Carbon monoxide
CO_2: Carbon dioxide
GOME: Global Ozone Monitoring Experiment
CH_4: Methane
HCHO: Formaldehyde

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