Journal of Environmental Studies

Vol. 47, No. 2, Summer 2021

Journal Homepage: www.Jes.ut.ac.ir
Print ISSN: 1025-8620 Online ISSN 2345-6922

Sulfur Dioxide (SO2) Monitoring Based on MetOp-A/GOME-2 Sensor Observations in the Troposphere of Iran

Document Type
Research Paper

Received
February 28, 2021

Accepted
May 31, 2021

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DOI: 10.22059/JES.2021.329512.1008222

Abstract

Sulfur dioxide (SO_2) is one of the most important air pollutants, and increasing its concentration can cause the spread of cardiovascular, respiratory, lung function, chronic bronchitis, lung cancer and death. In this study, the concentration of SO_2 between 2007 and 2020 in the troposphere of Iran, which is one of the countries with high SO_2 emissions in the world, was estimated. To achieve this goal, the concentration of SO_2 column in the troposphere of Iran was analyzed using GOME-2 sensor data from MetOp-A satellite. GOME-2 is a MetOp-A satellite-based sensor that can measure daily SO_2 concentrations on a global scale. Based on the results, The mean concentration of SO_2 in the Iranian troposphere was 28.5 µg/m³ and the maximum and minimum values were estimated to be 200.9 µg/m³ and 1.70 µg/m³ with a standard deviation of 15.9 µg/m³, respectively. Spatially, Khuzestan province has the highest average concentration of SO_2 in Iran, followed by Ilam, Bushehr, Tehran, Alborz, Gilan, Mazandaran and south of Kerman. The analysis of the time series of tropospheric distribution of SO_2 (2007-2020) shows a decreasing trend of SO_2 in the troposphere of Iran, so that its average from 35 µg/m³ in 2007 to 26 µg/m³ in 2020 (9µg/m³ or (25%) decreased. The results of seasonal distribution showed that the maximum and minimum of SO_2 occur in cold and warm seasons, respectively. On the other hand, October and September (cold months of the year) had the highest, and Jotun and July (warm months of the year) had the lowest monthly distribution. The higher concentration of SO_2 in the cold period of the year is due to the more active emission foci and the prevailing meteorological conditions in this period.

Keywords: Sulfur dioxide, Pollutant, GOME-2 sensor, Meteorological conditions, Iran

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Introduction

Today, industrialization, urbanization, and population growth have polluted the environment. As a result, many major cities around the world face a number of environmental problems, most notably air pollution. As a result, exposing citizens to polluted air in large cities is inevitable. The short-term and long-term health effects of air pollution have been proven in the twentieth century. Therefore, there are concerns about the effects of air pollution on human health in developed and developing countries. Sulfur dioxide (SO_2) is one of the most important air pollutants that can threaten human health and cause respiratory problems, headaches, dizziness and previous attacks. SO_2 is the predominant sulfur oxide in the atmosphere, which is non-flammable, non-explosive and colorless, and at concentrations above 3 ppm has a pungent odor and can be fatal. Airway narrowing, bronchospasm, severe cough, eye and respiratory tract irritation, decreased respiratory function and shortness of breath, decreased respiratory depth, and ultimately exacerbated cardiovascular and respiratory complications from the health effects attributed to SO_2 It counts. This pollutant in combination with hydroxide and reducing the pH of precipitation, falls in the form of acid rain on the ground and acidifies water and soil, with adverse environmental consequences. On the other hand, SO_2 plays an important role in atmospheric chemistry, especially air pollution, and is one of the most important Photochemical smoke fog. SO_2 can also alter the earth's radiative balance through photochemical interactions by radiation induction. Therefore, it has a great ability to create climate change by disrupting the energy balance of the Earth system and changing the mechanism of cloud formation. SO_2 is released into the atmosphere through natural and human resources. Volcanic eruptions are the main natural source of SO_2. More than 80 percent of the world's SO_2 production comes from fossil fuels, 85 percent of which are generated by power plants. Among the non-combustible sources, oil refineries, copper smelters and cement factories are among the most prominent sources of this gas production. The growing need for continuous or instantaneous analysis of air compositions and the study of air pollutants in remote locations through laboratory and terrestrial methods is almost impossible. Remote sensing methods have made it possible to evaluate various types of air pollutants at desired time intervals due to their extensive spatial coverage and high time separation. It is estimated that more than 15 sensors are continuously active in monitoring air pollution and atmospheric chemistry and provide the necessary data to those interested. Therefore, many studies have been performed using remote sensing techniques to monitor SO_2. The GOME-2 sensor, which was placed on the MetOp-A satellite on October 19, 2006 for data collection of several important gases (O3, NO_2, CO_2, CO, SO_2,), is the basis of research. There was a lot of SO_2 monitoring. Good horizontal resolution along with daily time resolution make this sensor suitable for long-term monitoring purposes. According to the Global Atmospheric Research Database, Iran is the world's largest producer of SO_2 after China, the United States, India, Saudi Arabia, Russia, South Africa, Indonesia and Kazakhstan. SO_2 contamination in Iran has been reported by foreign and domestic researchers. The results of these studies showed that the level of SO_2 emission in some parts of Iran is dangerous. However, although SO_2 has been studied from several aspects in Iran, but due to the health risks to people living in contaminated areas, there are still many questions about temporal-spatial distribution, trends, hotspots, Its spatial differences and similarities are present in the troposphere of Iran. Therefore, the focus of the present study is to analyze the concentration of SO_2 in Iran between 2007 and 2020 using the observations of the GOME-2 sensor of the MetOp-A satellite to answer the questions. Quantifying and evaluating SO_2 emissions and detecting spatio-temporal fluctuations is not only important for environmental protection and citizens' health, but can also help policymakers develop policies to reduce pollution and manage air quality.

Materials and Methods

MetOp-A (from the MetOp series of satellites) is the first polar orbiting satellite and the most advanced European satellite observation satellite, which was launched on October 19, 2006 to increase the accuracy of weather forecasting and better understanding of climate change. MetOp-A satellite is equipped with sen$_{so}$rs (IASA, ASCAT, AMSU-A, MHS, ANHRR, GRAS, HIRS, A-DCS, SARSAT, SEM-2, GOME-2) for different parameters Such as temperature, humidity, wind direction and speed, ozone level and air pollutants, it captures information from three terrestrial, atmospheric and ocean spaces with unparalleled accuracy and quality and provides it to those interested. One of the most important sensors of this satellite, which measures air pollutants such as SO_2, is the GOME-2 sensor. The GOME-2 sensor covers a wide range from 240 to 790 nm, with a spectral resolution of 0.26 to 0.51 nm and has an equatorial the time of the passing of 9:30 local time in the Sun-Orbit. The spatial resolution or size of each pixel of this sensor for the main channels is in the form of 80 × 40 km and scan width of 1920 km and 40 × 40 km with scan width of 960 km, which covers the whole world on a daily basis. The use of GOME-2 sensor SO_2 products, due to good spectral resolution and optimal calibration compared to similar instruments, has been the basis of numerous studies in the world in the direction of atmospheric SO_2 monitoring. In this study, the tropospheric SO_2 observations of the Gome-2 sensor in the period of 2007-2020 were used. The data used is an estimate of the weight of SO_2 in micrograms per cubic meter of tropospheric air, expressed in micrograms per cubic meter (µg/m³). This data was extracted from the website (http://www.temis.nl) with monthly and spatial separation of 40 × 40 km and after applying quality control and necessary processing, it was converted into monthly, seasonal and annual values. The number of cells with the above spatial resolution for the GOME-2 sensor in Iran is 1030 pixels. Accordingly, the dimensions of the arrays created are 168 × 1030 for the months and 56 × 1030 for the seasons, respectively. The data used, which is digital and the value of SO_2 is a numerical value per pixels, was converted into network data and data tables by applying geostatistical algorithms in specialized software environment (Arc GIS, ENVI) Necessary was extracted and analyzed as a raster based on the geographical border of Iran.

Discussion of Results

The mean concentration of SO_2 in the troposphere of Iran was 28.5 µg/m³ and the maximum and minimum values were estimated to be 200.9 µg/m³ and 1.70 µg/m³ with a standard deviation of 15.9 µg/m³, respectively. Spatially, Khuzestan province has the highest average SO_2 concentration in Iran, followed by Ilam, Bushehr, Tehran, Alborz, Gilan, Mazandaran and southern Kerman. In Khuzestan province, the highest average concentration of SO_2 with a value of more than 100 µg/m³ is related to the southwest of Khorestan province (Abadan). Khuzestan province is one of the most important industrial areas in Iran, which is considered one of the most polluted areas in the world due to the establishment of oil, refinery, industrial and power plant facilities. The contribution of tropospheric SO_2 along with other pollutants in this province is significant. The amount of SO_2 over Tehran (the capital and largest metropolis of Iran) is also significant. Among the reasons for the high level of tropospheric SO_2 over Tehran, we can mention several factors, including geographical and human factors. The location of the city of Tehran in the semi-enclosed environment of the southern slope of the Alborz highlands, causes the Alborz mountains in the north and east to prevent air conditioning as a barrier and provide conditions for the persistence and continuity of tropospheric SO_2. The dominance of temperature inversion conditions and the continuous establishment of high-pressure systems are other climatic features of the region that create the conditions for intensifying air pollution in Tehran and surrounding areas in some days of the year. In addition to the natural factors mentioned, the establishment of factories and industries in the city (especially in the west and southwest), power plants and refining companies can be added to the amount of tropospheric SO_2. The coastal area of northern Iran (Mazandaran and Gilan provinces) has a high population density due to the location of Neka power plant on the one hand and on the other hand due to the favorable weather conditions and relatively favorable infrastructure development. In addition, the location of this area in the ranks of tourism target areas, creates a high volume of traffic and increases the concentration of SO_2 in this area. Other areas also experience relatively high concentrations of SO_2 during the year due to their industrial nature, dilapidated fleet, and the existence of cement plants and power plants based on diesel or fuel oil (southern Kerman province). These areas are contaminated with tropospheric SO_2 according to air quality standards. Analysis of the tropospheric SO_2 time series during 168 consecutive months (2020-2007) shows the decreasing trend of SO_2 emission in the surface troposphere of Iran. The decrease in tropospheric SO_2 concentration in Iran has occurred while Iran joined the Kyoto Protocol in 2005 and has announced cooperation in reducing greenhouse gases in various sectors of energy, oil and gas, agriculture, natural re$_{so}$urces and forestry. On the other hand, the analysis of annual SO_2 fluctuations in Iran shows that its concentration is related to crude oil production (the primary form of energy production in Iran). The decreasing trend of SO_2 concentration showed a significant relationship (R^2 = 71%) with the decrease in Iran's crude oil production, which intensified in recent years (2015-2020) with US oil sanctions and hindered Iran's oil trade.

Conclusions

SO_2 is one of the most important pollutants that causes irreparable damage to the environment, climate and human health in the present age. Today, due to the increasing development of industries and factories and the excessive consumption of fossil fuels, the concentration of air pollutants, especially SO_2, has increased and has caused many problems for human health. The aim of the present study is to estimate the spatio-temporal distribution of tropospheric SO_2 in Iran using the observations of the GOME-2 sensor of the MetOp-A satellite during the years 2007-2020. The results showed; The average tropospheric SO_2 in Iran is 28.5 µg/m³, among which, the highest/lowest values observed are 200.9 µg/m³ and 1.7 µg/m³, respectively, with a standard deviation of 15 µg/m³ It has been. In terms of spatial distribution, the highest concentration of tropospheric SO_2 pollutant over a continuous range from northwest of Kermanshah province to the west of Hormozgan province and the provinces of Tehran, Alborz, Gilan, Mazandaran, Isfahan and south of Kerman province. Among the mentioned areas, the highest concentration of tropospheric SO_2 is related to the southwest of Khuzestan province (Abadan) with a long-term average of up to 120 µg/m³ and its release in all months and seasons of the year has a high concentration. The analysis of the time series of the average monthly tropospheric SO_2 distribution during 168 consecutive months (2007-2020) shows a decreasing trend of tropospheric SO_2 trend in Iran. The average of this gas has decreased by 25% from 35 µg/m³ in 2007 to 26 µg/m³ in 2020. Analysis of the output related to the seasonal average of SO_2 distribution showed that the seasonal maximum of SO_2 occurs in autumn (31 µg/m³) and its seasonal minimum occurs in summer with 26 µg/m³. The highest average monthly SO_2 emissions were observed in October, November and January (cold months of the year) and the lowest in June and July (warm months of the year), respectively. Higher SO_2 concentrations in the colder months and seasons of the year, on the one hand due to more active sources of emissions such as higher fuel oil consumption, increased traffic volume, increasing the amount of fossil fuel consumption to provide Heating of residential and service spaces and on the other hand due to the prevailing meteorological conditions in this period of the year (occurrence of the phenomenon of temperature inversion and reduction of the thickness of the atmospheric boundary layer). The study of the spatial distribution of tropospheric SO_2 concentration also indicates its significant spatial differences in the geographical area of Iran. The difference is due to the heterogeneous distribution of tropospheric SO_2 production and emission centers in Iran. Because industrial areas and oil-rich areas are often located in the western and southern half of Iran. Therefore, due to the heterogeneous spatial distribution of SO_2 emission centers in the geographical area of Iran, the distribution of the pollutant in different areas is different.