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Sulfur Dioxide (SO_2) Anthropogenic Emissions Distributions Over Iraq (2000-2009) Using MERRA-2 Data

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ABSTRACT

The Sulfur dioxide (SO_2) is a colorless air pollutant cannot be been seen with naked eyes. The fossil fuels burning, of coal, oil and gas, biomass combustion. are the largest sources of SO_2. Sometimes SO_2 Pollution reaches hazardous levels near coal-fired plants, oil refineries, and industrialized areas. This study analyzed the trend, spatial and temporal distributions of anthropogenic SO_2 emissions in Iraq from January 2000 to December 2009. The monthly SO_2 was analyzed and investigated using the time series and trends over six stations: Baghdad, Mosul, Basra, Muthanna, Babylon, and Kirkuk were conducted using the data set. The results show clear reductions in SO_2 values from 2002 to 2006, and the SO_2 values increase from 2006 to 2009 over all stations. The annual trend analyses show positive results over Baghdad, Muthanna, and Babylon, and negative results over Basra, Mosul and Kirkuk. Large differences in SO_2 values were over Basra, Kirkuk and Babylon, and slight differences over Baghdad, Mosul and Muthanna. The monthly SO_2 anthropogenic emissions values show relatively constant over most stations, and the only fluctuation was over Babylon and Kirkuk during the study. The higher SO_2 values were observed in winter and spring than in the summer. This study confirmed the satellite observations efficiently show the spatial and temporal variations of SO_2 for the considered study area.

KEYWORDS: Sulfur dioxide; MERRA data; remote sensing; Iraq; anthropogenic.

الخلاصة

ان غاز ثاني اوكسيد الكبريت هو من الغازات الملوثة العديمة اللون الناتج عن الوقود الاحفوري والبراكين والمخلفات البشرية واحتراق الكتل الحيوية في هذه الدراسة تم الاعتماد على بيانات من MERRA-2 للفترة (كانون الثاني 2000- كانون الاول 2009) لغاز ثاني اوكسيد الكبريت لست محطات فوق العراق (بغداد، الموصل، البصرة، المثنى، بابل وكركوك). حيث حللت هذه الدراسة الاتجاه والتوزيع المكاني والزماني لثاني اوكسيد الكبريت البشري المنشأ وحللت الاتجاه والسلاسل الزمنية للست محطات كذلك تم فحص وتحليل تقلبات الغاز. حيث اظهرت هذه الدراسة التقلبات الموسمية لهذا الغاز، وأوضحت النتائج انخفاضًا واضحًا في قيم ثاني أكسيد الكبريت من عام 2002 حتى عام 2006، وزادت قيم ثاني أكسيد الكبريت خلال عام 2006 إلى عام 2009 في جميع المحطات. تظهر تحليلات الاتجاهات السنوية نتائج ايجابية في بغداد والمثنى وبابل، ونتائج سلبية على البصرة والموصل وكركوك. كانت هناك اختلافات كبيرة في قيم ثاني أكسيد الكبريت فوق البصرة وكركوك وبابل، واختلاف طفيف في بغداد والموصل والمثنى. ولوحظت قيم أعلى من ثاني أكسيد الكبريت في الشتاء والربيع عنها في الصيف. تظهر القيم الشهرية لانبعاثات ثاني أكسيد الكبريت البشرية المنشأ ثباتًا نسبيًا في معظم المحطات، والتذبذب الوحيد كان فوق بابل وكركوك خلال فترة الدراسة.. أكدت هذه الدراسة أن فعالية ملاحظات الأقمار الصناعية تظهر التغيرات المكانية والزمانية لثاني أكسيد الكبريت لمنطقة الدراسة المدروسة.

INTRODUCTION

The SO_2 is a trace gas regulated by the United States Environmental Protection Agency (EPA) as harmful to health [1] . It is one of the pollution components with a particulate matter diameter of 2.5µm (PM 2.5) produced by motor vehicle combustion emissions [2]. SO_2 leads to acid rain and, when oxidized in the atmosphere, produces sulfate aerosols (SA), which have an impact on the global radiation budget and cloud microphysics in the lower troposphere. The wet and dry deposition efficiently eliminated SO_2 (1-3 days), resulting in primarily localized effects. Stratospheric SA, on the other hand, has a substantially longer lifetime (months to years) and is capable of being transferred over large distances [3]. Exposure to 100 ppm is highly hazardous to human beings.

Several investigations demonstrated changes in pulmonary functioning following SO_2 exposure ranging from 0.4 to 3.0 ppm. [2]. The fossil fuels by power plants and other industrial facilities are the largest source of SO_2 in the atmosphere. Also, the emissions from industrial processes, extracting metal from ore, volcanoes, locomotives, ships, other vehicles and heavy equipment that use fossil fuels with a high sulfur content [4]. In Iraq, transportation and electric power generation (especially local generators) sectors significantly contribute to air pollution, causing high environmental problems [5]. Furthermore, the continuous burning of oil fields co-produces natural gas, resulting in high levels of pollutants connected to the worsening of Iraq's air quality. Air quality is also deteriorating as a result of the use of low-quality fuel in transportation and power generation, industrial facility emissions, dust storms, open garbage burning, and an increase in illegal logging [6]. Recently, the remote sensing observations show a high increase in pollution levels over the Asian continent, especially in East Asia, due to the emissions originating from coal combustion. Asian sulfur emissions are now equal to the emissions of North America and Europe combined [7, 8]. The profound changes in global SO_2 emissions over the last decades have had a large impact on air quality, atmospheric deposition, and the radioactive forcing of sulfate aerosols. The effects of air pollution on the environment and human health have given rise to international and national legislation on the subject [9]. Even though the ground-based observations and aircraft are able to make good measurements of the tropospheric Gases concentrations, but still not able to supply large-scale global or regional coverage. The remote sensing technique provides a continuous measurement to overcome a lack of meteorological data at both global and regional scales [10] . Only space observations allow such observations with a reasonably short time period, by its good global coverage, to analyze the human activities' effects on the GHG and climate changes [11]. The greenhouses emissions are increased due to excessive use of oil heating during the winter and spring seasons, Several studies had analyzed the GHG's distributions using different satellites data [12, 13]. The Modern Era Retrospective Analysis for Research and Applications, Version 2 (MERRA-2) data set offers a variety of information useful for weather and climate investigations. We employ MERRA-2 (surface) measurements with resolutions of (0.625° x 0.5°) to track Anthropogenic SO_2 over our defined targets [14]. The purpose of this study is to analyze the monthly and annual hotspots emissions, and monthly distribution of SO_2, and evaluate its long term-trends over Iraq using MERRA-2 data for the decade (2000-2009). The findings aid in identifying hotspots for regional SO_2 emissions across the research area.

Study Area

Iraq is located in the western part of Asia, 39°-49° E longitudes and 29°- 38° N latitudes [15]. Its population is more than 40 million, and total area is 438320 Km^2 as shown in Figure 1.

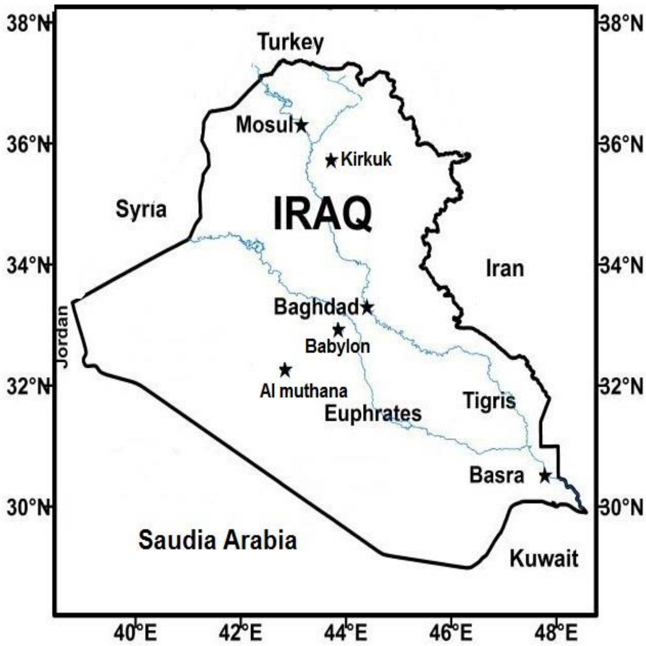

Figure 1. The study area [15].

Summer temperatures in much of the country average around 40 °C and frequently surpass 48 °C, while Winter temperatures seldom exceed 21 °C (69.8 °F) with maxima around 15 to 19 °C (59.0 to 66.2 °F) and night-time lows 2 to 5 °C (35.6 to 41.0 °F). Precipitation is often low; most localities receive less than 250 mm/year, with the most rain falling during the winter. Except in the far north, summer rainfall is uncommon. Northern mountainous regions experience frigid winters with occasional severe snowfall, resulting in extensive flooding [16, 17]. Where six different sites were studied as shown in Table 1.

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Table 1. Study areas, latitude, longitude, and altitude above sea level

Study areas	Latitude (N)	Longitude (E)	Altitude above sea level (m)
Baghdad	44.4	33.3	34
Mosul	43.1	36.31	223
Basra	47.7	30.52	5
Muthanna	45	32	220-70
Babylon	44.4	32.5	350
Kirkuk	44.3	35.5	35

MATERIALS AND METHODS

Data collection

Monthly data set of SO_2 from MERRA-2 model with spatial resolutions of 0.5×0.625 were downloaded for the period from January 2000 to December 2009 over Iraq. In order to better assess, the SO_2 distribution data was analyzed over six stations spread throughout Iraq; Baghdad, Mosul, Basra, Muthanna, Babylon and Kirkuk. GIS software kriging interpolation technique was used to generate the monthly SO_2 map distributions. The information was obtained from the website (https://nasa.gov/reanalysis/MERRA-2). Monthly mean SO_2 data and annually averaged monthly MERRA-2 SO_2 time series were utilized in this study to assess long-term SO_2 variability at each of the six stations. Radiosonde data, which were principally utilized to evaluate the MERRA-2 product, were downloaded for free from the National Climatic Data Centre's (NCDC) Integrated Global Radiosonde Archive (IGRA) ver. 2, which is accessible at (www.ncdc.noaa.gov) [9].

RESULTS AND DISCUSSION

Figure 2 Shows the annual anthropogenic SO_2 emissions for the period 2000-2009 over the six stations. The SO_2 values from 2000 to the middle of 2002 were almost constant over all stations, and decrease from the end of 2002 till the end of 2005. There was an increase in SO_2 values from 2006 to 2009 over all stations. The highest values of SO_2 were recorded over Basra and Kirkuk while moderate values were recorded in Baghdad and Babylon. The lowest values of SO_2 were recorded over Mosul and Muthanna. Large differences in SO_2 values were over Basra, Kirkuk and Babylon while slight differences were over Baghdad, Mosul and Muthanna. These increase in SO_2 values may be due to increased population, increased traffic, and the expansion and establishment of various industrial plants such as petrochemical plants, oil refineries, burnt natural gas flames, fertilizer: plants, paper and pulp mills, power production stations, and industrial workshops [18].

Figure 3 visualizes the average monthly SO_2 anthropogenic emissions values for the period 2000-2009 over the six stations. Noted the SO_2 values are relatively Constant over Baghdad, Mosul, Basra, and Muthanna, and fluctuated over Babylon and Kirkuk during the study period. In Babylon, the higher values were in October and the lowest values in June, while over Kirkuk the highest values were in January and February, and the lowest values were in May and June. The results also indicate the average monthly SO_2 was higher in the winter and spring than its values in the summer. All of this was ascribed to variations in weather conditions (Especial wind speeds and directions, humidity, and air temperature) [18], topographic and SO_2 sources. The weather on all scales essentially effects on transport and dilution of air pollutants. Meteorology determines what happens to air pollutants once they begin to emit from their source until they are identified at a certain site. Wind and temperature patterns have a considerable impact on air pollution dilution. Pollutants discharged into the atmosphere are transported as a function of the local (average) wind direction.

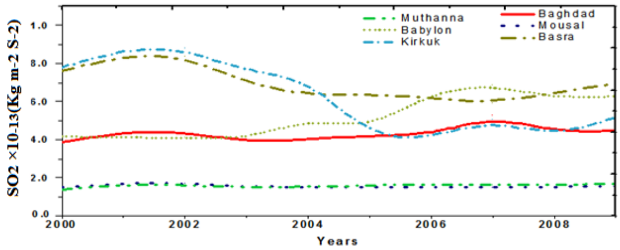

Figure 2. The annual SO_2 values over Baghdad (red line), Mosul(royal), Basra (dark yellow), Muthanna (green line) Babylon (olive line), and Kirkuk (blow line) during January 2000 to December 2009.

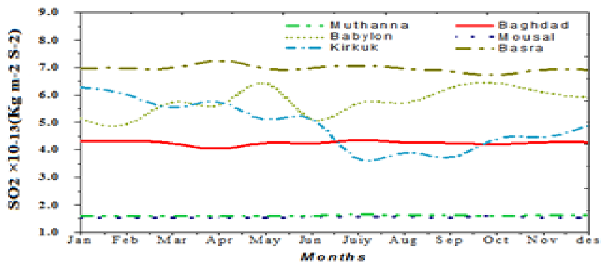

Figure 3. The average monthly SO_2 for Baghdad (red line), Mosul(royal), Basra (dark yellow), Muthanna (green line) Babylon (olive line), and Kirkuk (blow line) during (January 2000 to December 2009)

Annual Long-Term So2 Trend Analysis

The mean annually of SO_2 over is presented in Figure 4, for the six stations during the period 2000-2009. Several factors contributed to the gradual increase in SO_2 levels observed during the study period, including: an increase in the city's population, high traffic levels, and the expansion and establishment of several industrial plants, including petrochemical plants, oil refineries, burned natural gas flames, fertilizer plants, paper and pulp mills, power generation stations, and industrial workshops. Increased population growth[18]. In presence of clouds, the SO_2 is rapidly taken up into the liquid phase and converted to H_2SO_4 with short SO_2 lifetime (few hours). In the case of a decrease the water vapor percentage, as the percentage of OH decreases, then SO_2 age and quantity increases in the atmosphere. The air pollutants concentration levels are related directly to pollutants emission and meteorological conditions. The linear growth rate for the stations were -0.02%, 0.1%, 0.2%, 0.3%, -0.1%, and 0.3% in Baghdad, Mosul, Basra, Muthanna, Babylon, and for Kirkuk, respectively. These ratios are relative to the average values. The results were calculated and arranged in Table 2.

Table 2. The locations of the mean annual, maximum, minimum, and trend of SO_2 values (Anthropogenic) during 2000-2009.

Stations	Latitude (N°)	Longitude (E°)	Mean of Annual	Maximum $SO_2 \times 10^{-13}$ Kg m^{-2} S^{-2}	Minimum $SO_2 \times 10^{-13}$ Kg m^{-2} S^{-2}	Trend $SO_2 \times 10^{-13}$ % per year
Baghdad	44.4	33.3	4.24	4.4	3.9	-0.02
Mosul	43.1	36.3	1.56	1.7	1.4	0.1
Basra	47.7	30.5	6.96	8.5	5.8	0.2
Muthanna	45	32	1.61	1.7	1.4	0.3
Babylon	44.4	32.5	5.59	8.1	1.01	-0.1
Kirkuk	44.3	35.5	4.99	8.6	3.3	0.3

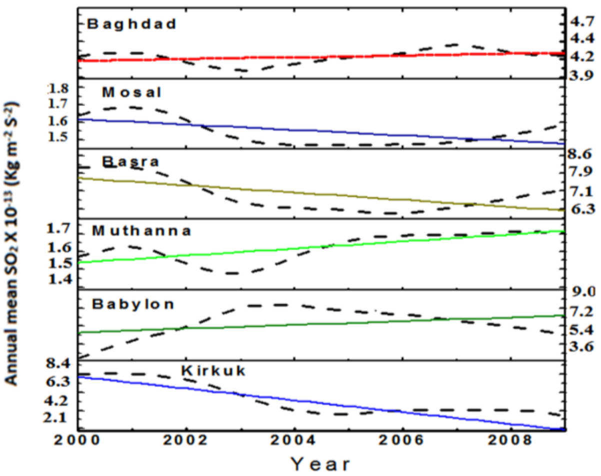

Figure 4. Annual SO_2 trend values over six stations Baghdad (red line), Mosul (royal), Basra (dark yellow), Muthanna (green line) Babylon (olive line), and Kirkuk (blow line) during 2000-2009.

Annual Analysis of Long-Term SO_2 Values over The Study Areas

Figures 5 and 6 show the mean annual SO_2 obtained from MERRA-2 data from January 2000 to December 2009. The regional fluctuation of SO_2 values was observed over much of Iraq, with small changes in spatial patterns for each season depending on terrain and weather conditions. The highest levels were recorded throughout the winter and autumn seasons (September, October, November, December, January and February) Figure 5 shows that more fuel is consumed for indoor heating in the north and northeast, as well as in the Muthanna desert. Moreover, the inversion layer, which is rather prominent during the winter season, traps more pollutants in the ambient air, as does the generally calmer conditions in dry months due to the predominance of windless days, which enhance the buildup of pollutants. As a result, the seasonality of emissions from neighboring power plants should be considered. Increased fuel use in buildings with higher or lower temperatures is likely to lead to increase SO_2 concentrations for air pollution, Where the highest value was over Basra in April 2001 (7.24482×10^{-13}) Kg m^{-2} s^{-2}. SO_2 concentrations increased with the decrease in wind speed and temperature. The weather acts on the conveyance and dilution of air at all scales in space and time. Wind speed is more pronounced in the summer. Pollutants and has diverse effects on the air quality that we measure and experience. Meteorology describes what happens to air pollutants from the time they are emitted from their source until they are detected at some point. Wind Local wind and temperature patterns have a considerable impact on the dilution of air pollutants. Pollutants discharged into the atmosphere are transported in accordance with the

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direction of the local wind. Dust storms are the most significant source of air pollution in Muthanna. The oil sector is the primary cause of air pollution in Kirkuk. The main sources of air pollution in Baghdad include emissions from electric power generation, the Al-Dura oil refinery, and motor vehicles.

Figure 6 shows that SO_2 values are comparable in March and April (Spring). However, in June, July, and August (summer), the amount of SO_2 pollutants decreases due to the increase in wind speed which transports pollutants to a place far away from the source, Wind speed is more pronounced in the summer.

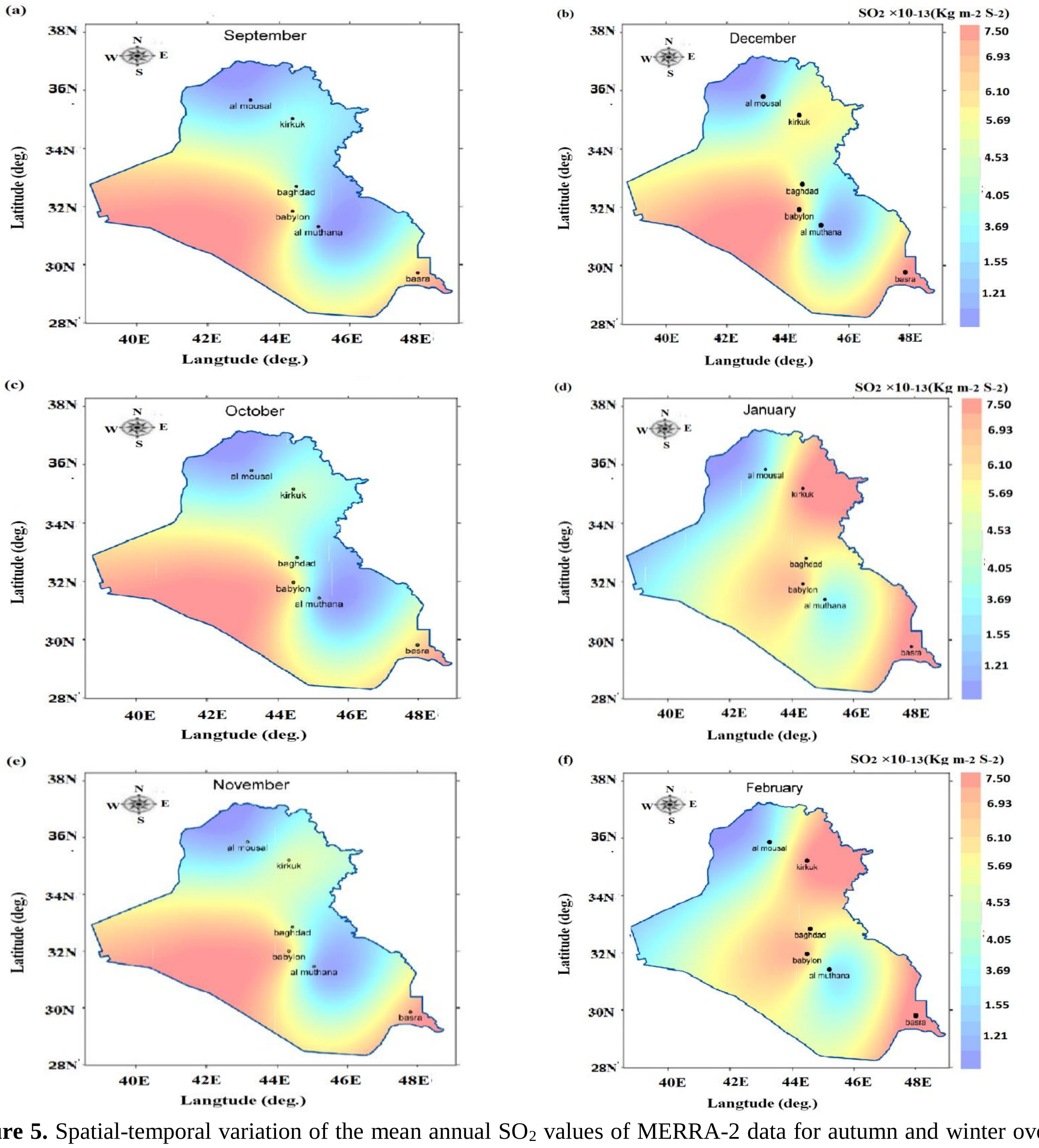

Figure 5. Spatial-temporal variation of the mean annual SO_2 values of MERRA-2 data for autumn and winter over the six stations for the period (2000-2009).

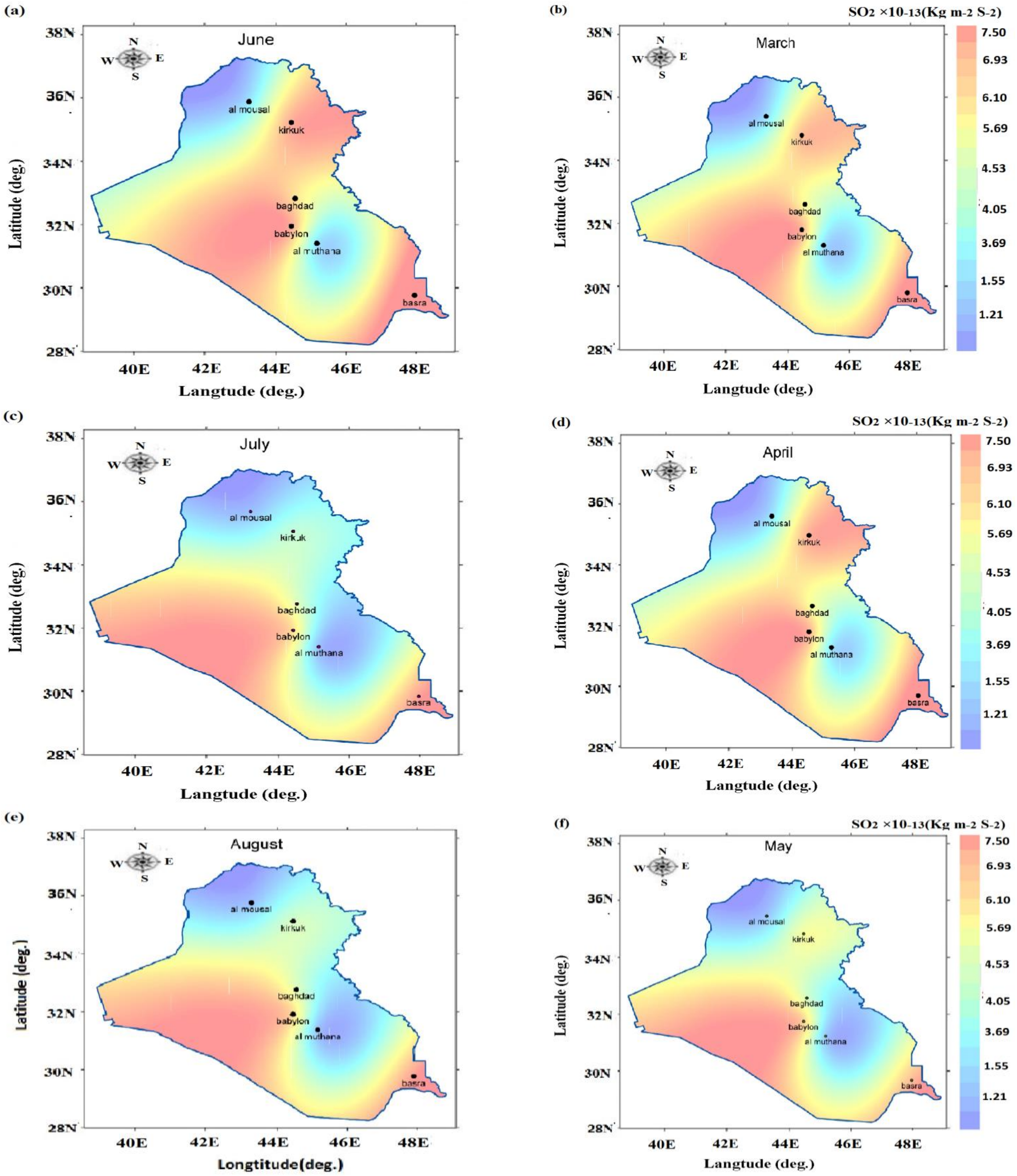

Figure 6. The mean annual SO_2 variation Spatial and temporal from MERRA-2 data for spring and summer over the six stations for period (2000-2009).

CONCLUSIONS

There is a clear reduction of SO_2 values from 2002 the beginning of USA occupation & invasion) till 2006, which led to the suspension and stopped most factories and reduction of human activities and transportation. The annual trend analyses show positive results over Baghdad, Muthanna, and Babylon, and negative results over Basra, Mosul and Kirkuk. The SO_2 values increase from 2006 to 2009over all stations. Large differences in SO_2 values were over Basra, Kirkuk and Babylon, and the slight difference over Baghdad, Mosul and Muthanna the monthly SO_2 anthropogenic emission values shows fluctuation over Babylon and Kirkuk during the study period, and higher SO_2 values compare to winter and spring compare to its values in the summer. All are attributable to changes in weather, topography, and SO_2 sources of SO_2. The MERRA-2 observations can detect an increase in the surface and troposphere SO_2 concentrations over various locations.

Disclosure and conflict of interest: The authors declare that they have no conflicts of interest.

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