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## Spatial Analysis of Atmospheric Carbon Oxides and Their Effect on Air Temperature over Iraq

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### ABSTRACT

This study focused on the concentration of carbon oxides (CO and CO<sub>2</sub>) and temperature in Iraq, using satellite remote sensing data from 2003 to 2024. It showed hot and cold spots in different locations in Iraq, and these spots are the result of the standard deviation of both carbon dioxide and temperature, showing the strong and weak correlation. The analysis of CO revealed spatial variations, with a strong correlation coefficient of approximately 0.63 in Basra and a significance level of 0.01. In Baghdad, the correlation reached 0.73, but not at a significant level, despite the standard deviation of CO being approximately 3.787. This CO is a product of fuel combustion, transportation, and other activities. Conversely, there was a weak, positive correlation between temperature and carbon dioxide. Hot spots emerged in Maysan Wasit, showing strong positive and positive correlations between temperature and carbon dioxide, with correlation coefficients of 1.208 and 1.134, respectively. Cool spots were also found in the north, exhibiting a moderate to weak positive correlation between temperature and carbon dioxide, resulting in negative deviations for both carbon oxides and temperature. This is attributed to the vegetation cover characteristic of the northern regions. This indicates that, over time, without alternative energy sources such as renewables, carbon oxides will have a significant impact on future temperatures in Iraq due to human activity and the burning of fuels, oil and gases.

**Keywords:** Carbon Oxides; Air Temperature; Spatial Correlation; Iraq

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## 1. Introduction

Climate change is one of the issues facing planet Earth in the 21<sup>st</sup> century due to the increasing concentration of greenhouse gases, which in turn causes changes in global temperatures<sup>[1]</sup>. Based on socioeconomic scenarios for these gases, this increase is expected to continue at the Earth's surface<sup>[2]</sup>. In 1750, the concentration of carbon dioxide in the atmosphere was estimated at about (278 ppm), but it rose to 419.3 ppm in 2023<sup>[3]</sup> due to deforestation, land-use change, and increased human activities. In 2024, it reached 421 ppm, and it is projected to reach between 670 and 940 ppm by 2100<sup>[4,5]</sup>. To find successful ways to mitigate and adapt, it is essential to understand the dynamics of climate change and its relationship to air pollution<sup>[6]</sup>.

And spatial variability in atmospheric CO<sub>2</sub> is shaped by multiple interacting factors, including vegetation cover, where studies indicate that vegetation affects the distribution of CO<sub>2</sub> because plants absorb CO<sub>2</sub> during photosynthesis, leading to spatial variations in atmospheric gas concentrations vegetation functions as a carbon sink<sup>[7,8]</sup>, it is also affected, latitude, geographic position, because of regional surface processes and differences in climate, CO<sub>2</sub> concentrations show geographic heterogeneity and latitudinal gradients. Geographical location is particularly important because, rather than a homogeneous distribution across latitudes, spatial clustering of CO<sub>2</sub> is frequently linked to anthropogenic activities and landscape features<sup>[9,10]</sup>.

Recent years in Iraq have shown a marked increase in temperatures. From 1981 to 2020, the average annual temperature rose by approximately 1.8 °C, exceeding the global average. This is due to changing rainfall patterns, increased heat waves, and more frequent dust storms, which threaten health, economic, water, and social development<sup>[11]</sup>. So, Iraq constitutes a climate-sensitive region due to its unique geographical, political, and industrial characteristics, making it a crucial area for analyzing these interactions<sup>[12]</sup>.

The change in temperature and the increase in carbon oxides resulting from human activities, including the burning of biomass, gas, and oil, have led to a lack of spatial and temporal understanding of the interaction between these pollutants and rising temperatures in Iraq, due to environmental and population variations<sup>[13]</sup>. Carbon oxides primarily absorb infrared radiation. As the Earth's surface temperature rises, they emit thermal radiation in the form of infrared

waves. These gases absorb some of this radiation and convert it back into heat energy, which is then released into the atmosphere or the Earth's surface<sup>[14]</sup>. In the presence of carbon dioxide and carbon monoxide, carbon dioxide acts as a climate regulator in the atmosphere and plays a crucial role in regulating Earth's temperature<sup>[15]</sup>.

### 1.1. Climate Change and Temperature Trends in Iraq

Numerous studies have demonstrated significant spatial variation in carbon dioxide concentrations, with the highest levels found over urban and industrial areas, particularly in Baghdad, Basra, and oil production facilities in southern Iraq<sup>[16]</sup>. Its seasonal impact is more pronounced during the winter months when plants absorb less moisture and fuel consumption for heating increases<sup>[17]</sup>. The study showed<sup>[18]</sup> that carbon monoxide pollution is associated with incomplete combustion processes and has a shorter atmospheric lifetime, along with a strong and positive correlation with several buildings in Dubai. Comparing these studies in the Middle East with Iraq reveals that countries have experienced a decrease in carbon monoxide levels in recent years due to improvements in combustion and emission technologies. Therefore, Iraq is considered among the countries with relatively high levels, a consequence of conflicts in environmental management systems<sup>[19]</sup>.

The vulnerability of Iraq to climate change has been the subject of extensive research and the rate of warming has accelerated since the 1980s<sup>[20]</sup>. Specifically, they reported that the mean annual temperatures increased by 0.2–0.3 °C/decade from 1950–1990 and 0.4–0.5 °C/decade from 1990–2020. The Intergovernmental Panel on Climate Change (IPCC) has identified Iraq as a climate change “hotspot”, indicating that the country has experienced above-average warming rates. demonstrated that the southern and western regions of Iraq experienced accelerated warming relative to the northern regions. This discrepancy can be attributed, at least in part, to the urban heat island effect, which has been shown to exacerbate the rate of warming in urban areas<sup>[21]</sup>. Nighttime temperatures increased at a faster rate than did daytime temperatures across central and southern Iraq<sup>[22]</sup>. Future projections of the daily temperature mean indicate that under the high-emissions scenario, Iraq could experience annual average temperature increases of 4.5–6

°C by 2100, with summer increases likely to exceed 7 °C in some areas. The increase in temperatures in Iraq is expected to exceed the projected global increase 1.5 °C<sup>[23]</sup>.

Using remote sensing techniques, studies analyzing the spatial and temporal patterns of air pollutants have seen significant development in recent years. These include the spatial and temporal distribution of air quality across the Red Sea<sup>[24]</sup>, the use of geoweighted regression (GWR) to analyze the spatial instability of air pollution pollutants from smog in China<sup>[25]</sup>, and the use of spatial autocorrelation analysis (SACA) to determine the concentrations of carbon monoxide and nitrogen dioxide associated with forest fires in Turkey in 2021<sup>[26]</sup>. In areas with limited ground infrastructure, remote sensing methods have become increasingly important for environmental monitoring. Satellite instruments, such as the Tropospheric Monitoring Instrument (TROPOMI), the Moderate Resolution Imaging Spectroradiometer (MODIS), and the Airborne Infrared Radiometer (AIRS), have enabled the monitoring of atmospheric composition at both regional and global levels. In Karbala, central Iraq, satellite technologies from atmospheric monitoring services are used in conjunction with available ground-based measurements to analyze air quality and study the relationship between climate variables and the air pollution index for the period

2021–2024<sup>[27]</sup>.

## 1.2. Research Objectives

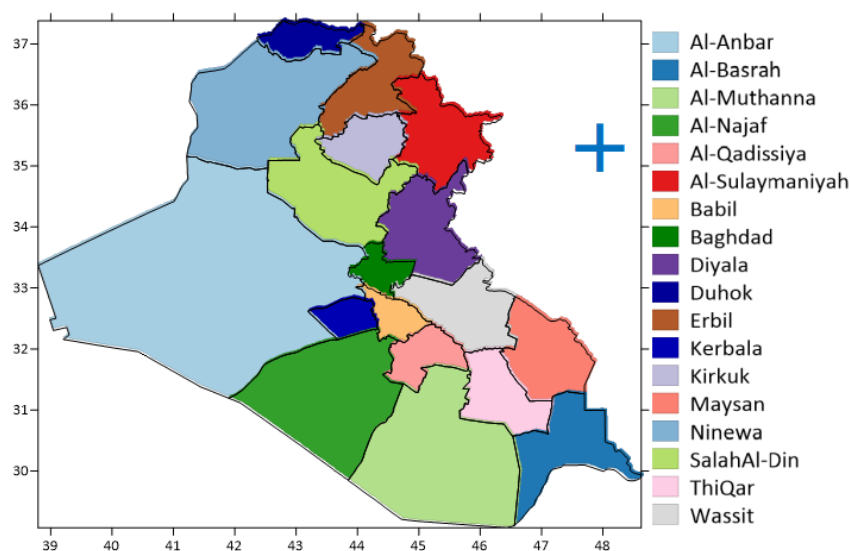
The objectives of the present investigation are as follows:

1. Spatial analysis of carbon monoxide and carbon dioxide concentrations in Iraq for the periods 2003–2024 and 2003–2016, respectively.
2. Spatial analysis of air temperature (2 m).
3. Illustrating the relationships between air temperature and both carbon monoxide and carbon dioxide, illustrated by hotspots and cold spots.
4. Proposing recommendations for integrated climate change management strategies and air quality standards in Iraq.

## 2. Methodology

### 2.1. Area Study

The study covered Iraq, which is located between latitudes 29 and 37.8 north and longitudes 39 and 49 east, covering 18 regions, as shown in **Figure 1**<sup>[28]</sup>.



**Figure 1.** Area Study.

### 2.2. Data Sources

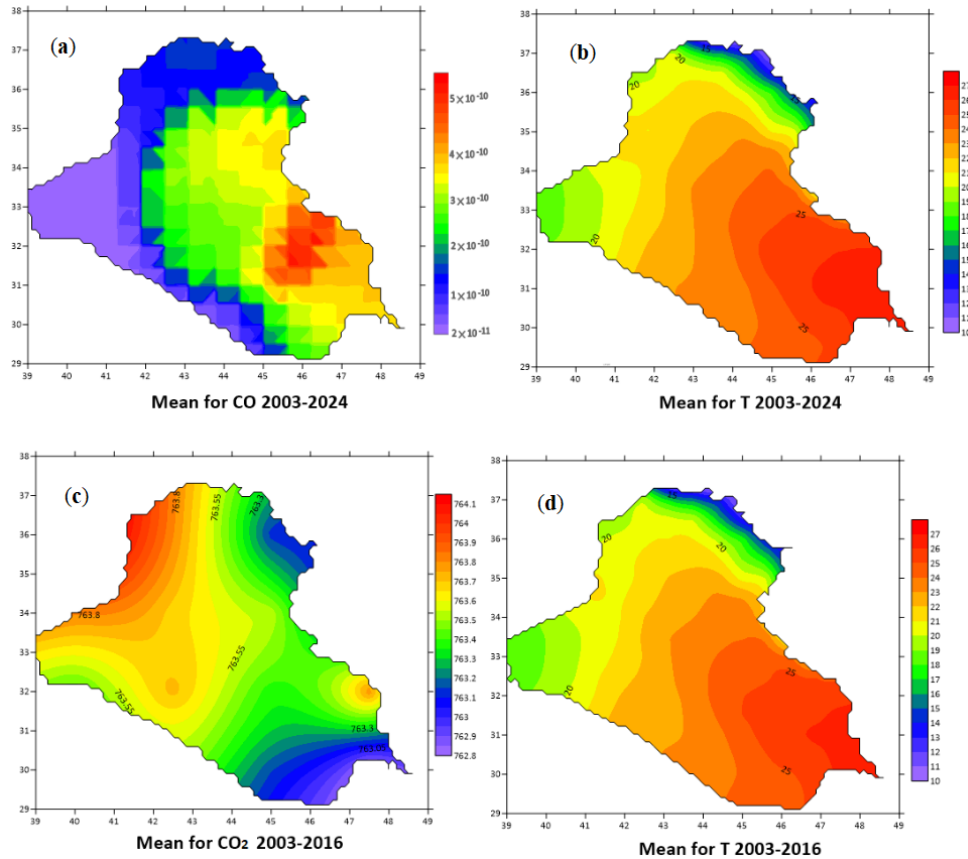
The Merra-2 model was used for both air temperature above 2 m in °C and carbon monoxide flow ( $\text{kg m}^{-2} \text{s}^{-1}$ ) during the period 2003–2024, whereas carbon dioxide data

in ppm were used for the period 2003–2016 of AIRS remote sensing<sup>[29]</sup>.

Carbon monoxide (CO) is a toxic gas with a short life span in the troposphere. It is detected from incomplete com-

bustion of fossil fuels, burning of biomass, and oxidation of methane and other hydrocarbons<sup>[30]</sup>. **Figure 2a** shows the analysis of average carbon monoxide gas concentrations for the period 2003–2024. It showed a spatial correlation with higher temperatures in Maysan, Thi-Qar, and Wasit, extending to AL-Basrah, as shown in **Figure 2b**. The CO levels are gradually declining in the northern regions of the

country. However, an analysis of carbon dioxide gas data from 2003–2016 revealed a distinct increase in the north-eastern regions. This increase is evident from the observed proliferation of vegetation in this area, suggesting a potential relationship with changes in temperature. However, further analysis, as depicted in **Figure 2c,d**, indicates that this increase may not directly affect the temperature in Iraq.



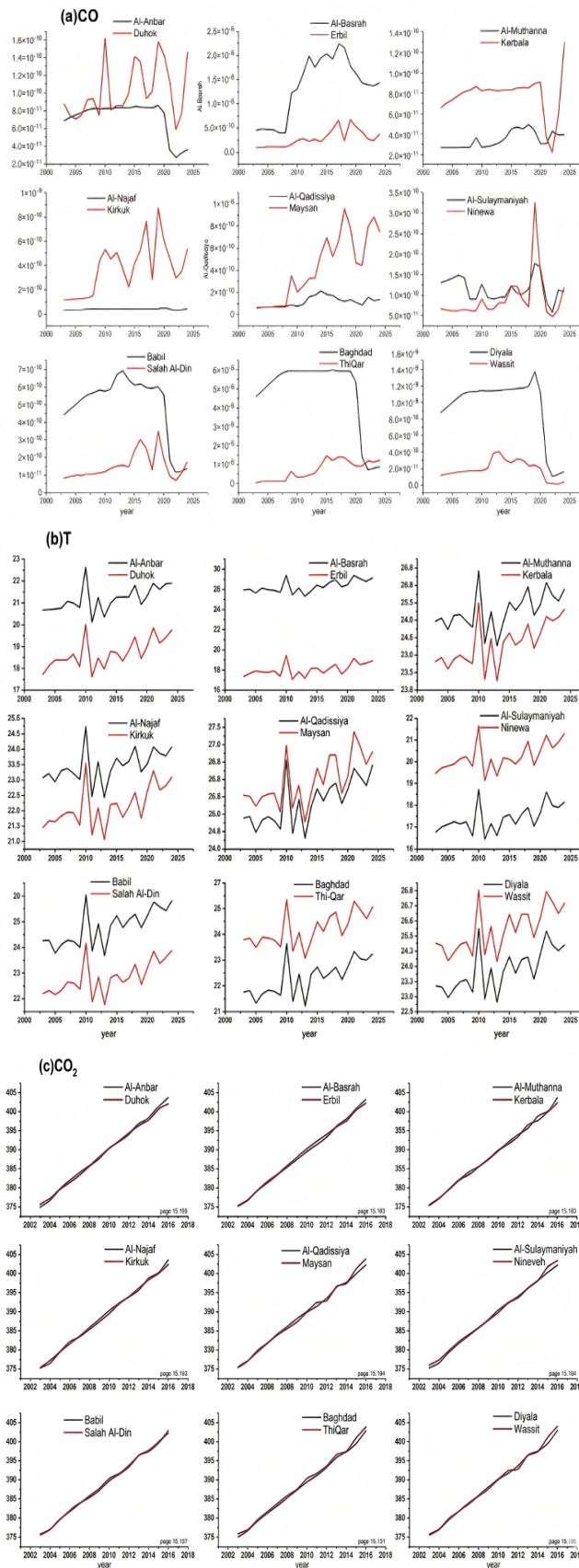
**Figure 2.** (a) Temperature mean (°C) distribution; (b) average carbon monoxide ( $\text{kg m}^{-2} \text{s}^{-1}$ ) distribution during the period (2003–2024); (c) temperature mean (°C) distribution; (d) average carbon dioxide (ppm) distribution during the period (2003–2016).

### 2.3. Time Series Analysis

The time series analysis of 18 regions in Iraq shows the carbon monoxide levels in **Figure 3a**, indicating that the AL-Basrah and Baghdad regions have the highest quantities of carbon monoxide gas flow resulting from fuel combustion and other activities, as **Figure 3b**, shows the temperatures and indicates that there is a noticeable increase over time, with the highest temperatures recorded in AL-Basrah and Baghdad between 25 and 28 °C annually, and **Figure 3c**, shows the quantities of carbon dioxide gas for each region, indicating an increase in its annual concentration, which may be similar in all regions, with a slight difference between one

region and another.

Simple regression analysis, as shown in **Table 1**, revealed a significant increase in carbon dioxide concentrations across all regions, with the annual increase ranging from 2.10 to 2.14 parts per million (ppm) at a statistical significance level. The analysis also indicated a clear warming trend in surface temperatures across most regions, with annual increases ranging from 0.04 to 0.08 °C, also at a statistical significance level in several areas. Analysis of the temporal trend for carbon monoxide (CO) showed clear spatial variation. While some regions exhibited statistically significant trends, the majority did not, indicating that CO exhibits a weak and spatially irregular trend.



**Figure 3.** Time series for each of the 18 regions in Iraq: (a) Carbon monoxide ( $\text{kg m}^{-2} \text{s}^{-1}$ ) 2003–2024, (b) Temperature ( $^{\circ}\text{C}$ ) 2003–2024, (c) Carbon dioxide (ppm) 2003–2016.

**Table 1.** Simple regression analysis of variables over time.

Region	CO <sub>2</sub>		Temperature		CO	
	Slope	p-Value	Slope	p-Value	Slope	p-Value
Al-Anbar	2.14	0	0.05	0.01	$-1.6 \times 10^{-12}$	0.01
AL-Basrah	2.13	0	0.06	0.001	$6.5 \times 10^{-11}$	$7.2 \times 10^{-4}$
Al-Muthanna	2.12	$1.1 \times 10^{-16}$	0.04	0.01	$8.0 \times 10^{-13}$	$7.8 \times 10^{-4}$
Al-Najaf	2.12	$1.1 \times 10^{-16}$	0.04	0.03	$1.5 \times 10^{-13}$	0.37
Al-Qadissiya	2.1	0	0.07	$4.1 \times 10^{-4}$	$3.9 \times 10^{-12}$	0.01
Al-Sulaymaniyah	2.11	0	0.05	0.01	$-1.0 \times 10^{-12}$	0.30
Babil	2.1	0	0.08	$1.5 \times 10^{-4}$	$-1.4 \times 10^{-11}$	0.02
Baghdad	2.1	$1.1 \times 10^{-16}$	0.08	$3.2 \times 10^{-4}$	$-1.7 \times 10^{-10}$	0.01
Diyala	2.1	$1.1 \times 10^{-16}$	0.07	$7.9 \times 10^{-4}$	$-3.0 \times 10^{-11}$	0.02
Duhok	2.1	0	0.07	0.001	$1.8 \times 10^{-12}$	0.1
Erbil	2.11	0	0.05	0.01	$1.8 \times 10^{-11}$	$4.9 \times 10^{-4}$
Kerbala	2.1	0	0.07	$5.9 \times 10^{-4}$	$-1.0 \times 10^{-13}$	0.9
Kirkuk	2.1	0	0.06	0.004	$2.0 \times 10^{-11}$	0.003
Maysan	2.11	$8.3 \times 10^{-15}$	0.07	0.001	$4.1 \times 10^{-11}$	$5.5 \times 10^{-8}$
Ninewa	2.11	$1.1 \times 10^{-16}$	0.06	0.01	$3.1 \times 10^{-12}$	0.12
Salah Al-Din	2.1	$1.1 \times 10^{-16}$	0.06	0.001	$4.4 \times 10^{-12}$	0.1
Thi Qar	2.13	$1.1 \times 10^{-16}$	0.06	0.002	$6.7 \times 10^{-11}$	$4.4 \times 10^{-7}$
Wassit	2.11	$9.3 \times 10^{-15}$	0.08	$4.2 \times 10^{-4}$	$-2.9 \times 10^{-12}$	0.4

## 2.4. Local Spatial Autocorrelation Tools and Analysis

GeoDa spatial correlation software was used for bivariate local Moran's (Bivariate LISA):

Moran's I equation<sup>[31]</sup> is as follows:

$$I = \frac{N \sum_{i=0}^n \cdot \sum_{j=0}^n w_{ij} (x_i - \bar{x})(x_j - \bar{x})}{\left(\sum_{i=0}^n \cdot \sum_{j=0}^n w_{ij}\right) \sum_{i=0}^n (x_i - \bar{x})^2} \quad (1)$$

where  $N$  is the number of observations (points or polygons),  $\bar{x}$  is the mean of the variable,  $x_i$  is the variable value at a particular location,  $x_j$  is the variable value at another location, and  $w_{ij}$  is a weight indexing location of  $i$  relative to  $j$ <sup>[32]</sup>.

The spatial correlation between the two variables of temperature (°C) and carbon monoxide (CO kg m<sup>-2</sup> s<sup>-1</sup>) is used, and the spatial correlation between the two variables of temperature and carbon dioxide (CO<sub>2</sub> ppm) is used again to find "hot spots" (high-high)-high-value areas with comparable neighbors and "cold spots" (low-low) for low-value areas with similar neighbors, high-value locations with low-value neighbors (high-low) and low-value locations with high-value neighbors (low-high)-using the bivariate local Moran relationship for dispersion and LISA. The following connection indicates the significance level of the  $p$  value for geographical outliers from the following relationship:

$$I_i^B = cx_i \sum_j w_{ij} y_j \quad (2)$$

## 2.5. Study Limitations

Despite the importance of the results, several limitations must be carefully considered when interpreting the data. A clear assessment of the study and its scope is required, including the small spatial sample size ( $N = 18$ ). This limited sample size restricts the statistical analysis. The study relied on temporal aggregation of the MERRA-2 reanalysis data, the sole source of data used in the analysis. While widely used and scientifically reliable, the outputs of the MERRA-2 reanalysis are model-dependent, and the accuracy of the inferred variables may be difficult to assess, increasing the uncertainty in the results. This is further compounded by the absence of field observations or independent datasets such as ERA5 or station-based measurements to validate the findings.

The original data were collected on an annual mean timescale. This results in the loss of short-term temporal dynamics, although it is beneficial for long-term patterns. This may obscure important interactions between atmospheric carbon dioxide concentrations and temperature variability. Consequently, the study may not adequately detect transient or nonlinear time-related interactions. And in this study, a correlation-based analytical framework was used. Although statistically significant correlations were found between temperature and carbon oxide concentrations, a causal relationship cannot be inferred due to the correlation-based nature of

the study methodology. Consequently, the results cannot be considered evidence of a direct causal relationship. Rather, these results demonstrate overall statistical variability that may be influenced by shared patterns or extraneous variables.

Temperature and carbon dioxide data were analyzed over different time periods. Given the variations in atmospheric and climatic processes over time, this variability in temporal coverage may lead to biases and significant differences in the estimated relationships. Furthermore, the study did not account for a number of potential variables. It is well established that temperature fluctuations are significantly influenced by factors including latitude, altitude, and urbanization, which may affect the observed correlations regardless of atmospheric CO and CO<sub>2</sub> concentrations. When these factors are excluded from the model, residual effects may emerge, meaning that part of the observed correlation may be due to human or geographical factors and not solely to the influence of carbon oxides. In light of these limitations, the results of this study should be interpreted with caution. Future research will benefit from larger spatial samples, validation of data from multiple sources, consistent time coverage, and the inclusion of additional explanatory variables within multivariate or causal modeling frameworks. Such improvements would enhance the robustness of the conclusions and improve our understanding of the complex interactions between atmospheric carbon monoxide and carbon dioxide and temperature fluctuations.

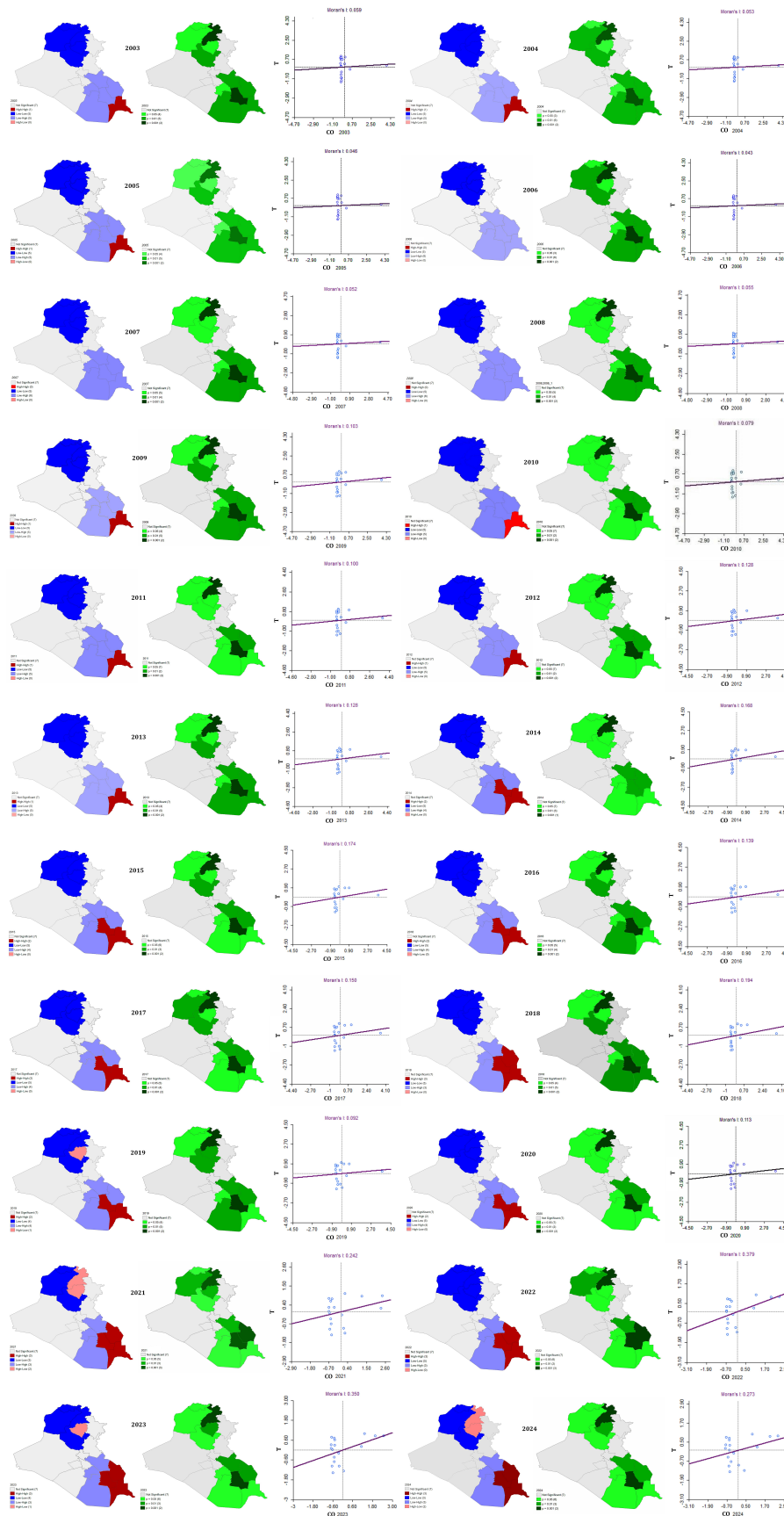
### 3. Results and Discussion

Partial analysis of daily temperature and carbon monoxide concentration data for the period from 2003 to 2024 revealed a weak positive correlation in some northern regions of Iraq and a negative correlation in others. Spatial correlation analysis for each year identified a hotspot in AL-Basrah in 2003. The emergence of these hotspots coincided with elevated carbon monoxide concentrations, suggesting a corresponding rise in temperature. Statistical significance was found at levels between 0.05, 0.01, and 0.001. In contrast, Baghdad recorded higher carbon monoxide concentrations and temperatures compared to AL-Basrah. Autocorrelation between these two variables was observed, although it was

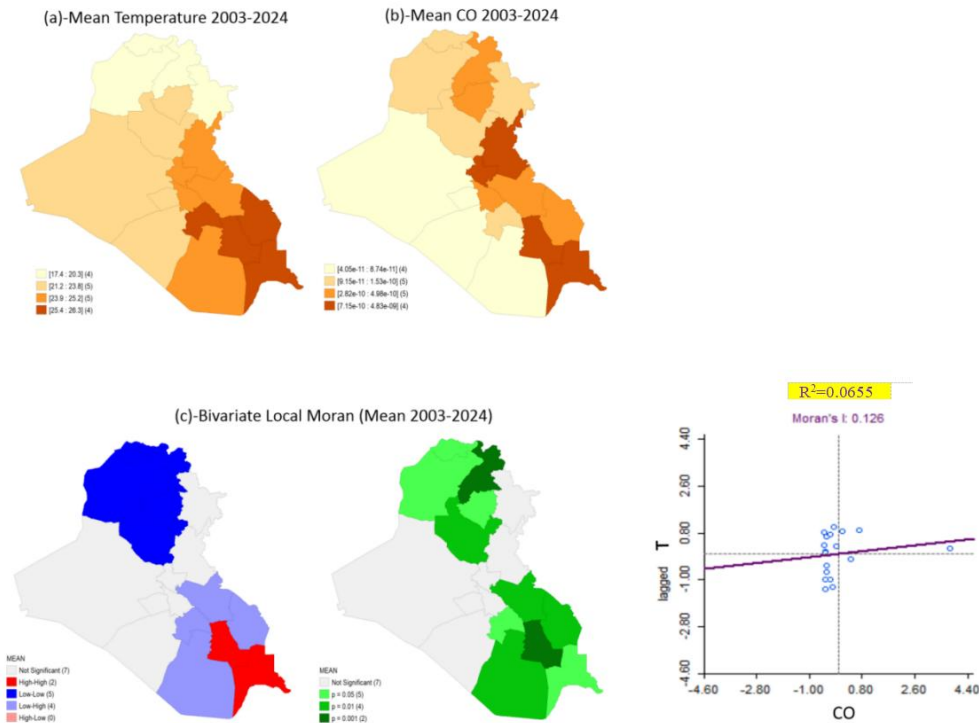
not statistically significant.

As previously mentioned, the northern regions of the country, specifically the governorates of Dohuk, Nineveh, Erbil, Kirkuk, and Salah al-Din, are characterized by cold spots. This is due to a decrease in temperature coinciding with a decrease in CO, showing a weak positive correlation, as illustrated in the LISA analysis (see **Table 2**). This pattern remained consistent in 2004 and 2005, while the effect of carbon monoxide on temperature showed a negative correlation in the Iraqi regions from 2006 to 2008. Specific hotspots emerged from AL-Basrah to Thi-Qar, extending into Maysan Governorate during the years 2021–2024, as shown in **Figure 4c**. **Figure 5** illustrates the annual average from 2003 to 2024, showing the spatial variation in both temperature and carbon monoxide concentration, highlighting the large hotspots in AL-Basrah and Thi-Qar and the cold hotspots in the northern regions, as previously mentioned.

**Figure 6** illustrates the relationship between carbon dioxide concentration and temperature, showing a clear spatial correlation each year. The hotspots of 2003 in Al-Qadissiya Governorate are highlighted, indicating a strong autocorrelation between the two variables. Conversely, the stations in Salah al-Din and Nineveh showed a slight effect on average temperatures, despite their high carbon dioxide concentrations, indicating a negative correlation. Cold hotspots with a weak positive correlation were observed in the stations of Dohuk, Erbil, and Kirkuk, along with a noticeable decrease in average temperatures and carbon dioxide concentration. Conversely, the high temperatures and low carbon dioxide concentrations in Al-Muthanna, Wassit, AL-Basrah, Thi Qar, and Maysan Governorates demonstrate a negative autocorrelation with a significant level of  $p$ -value = 0.05. During the year 2004, a direct correlation was observed due to the large concentration of hot spots, which were represented at each of the stations in Al-Muthanna, Wassit, Al-Qadissiya, and Maysan. Concurrently, a decrease in CO<sub>2</sub> concentrations was observed in AL-Basrah and Thi-Qar, with a clear increase in daily temperature rates. Additionally, an increase in the CO<sub>2</sub> concentration was observed in Ninewa, with a decrease in temperature and the presence of cold spots in the areas of Duhok, Al-Sulaymaniyah, Kirkuk, Erbil, and Salah al-Din.



**Figure 4.** Bivariate local Moran correlations between the mean temperature ( $^{\circ}\text{C}$ ) and atmospheric carbon monoxide (CO) ( $\text{kg m}^{-2} \text{s}^{-1}$ ) concentration, with significance levels of  $p = 0.05, 0.01$  and  $0.001$ , for the period extended from 2003 to 2024.

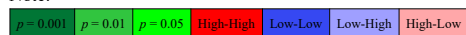


**Figure 5.** (a) Spatial distribution of the mean temperature, (b) spatial distribution of average carbon monoxide, (c) bivariate local Moran correlation between the mean temperature (°C) and atmospheric carbon monoxide CO (kg m<sup>-2</sup> s<sup>-1</sup>) from 2003–2024.

**Table 2.** Bivariate local Moran correlation between temperature (°C) and atmospheric carbon monoxide (kg m<sup>-2</sup> s<sup>-1</sup>) from 2003–2024.

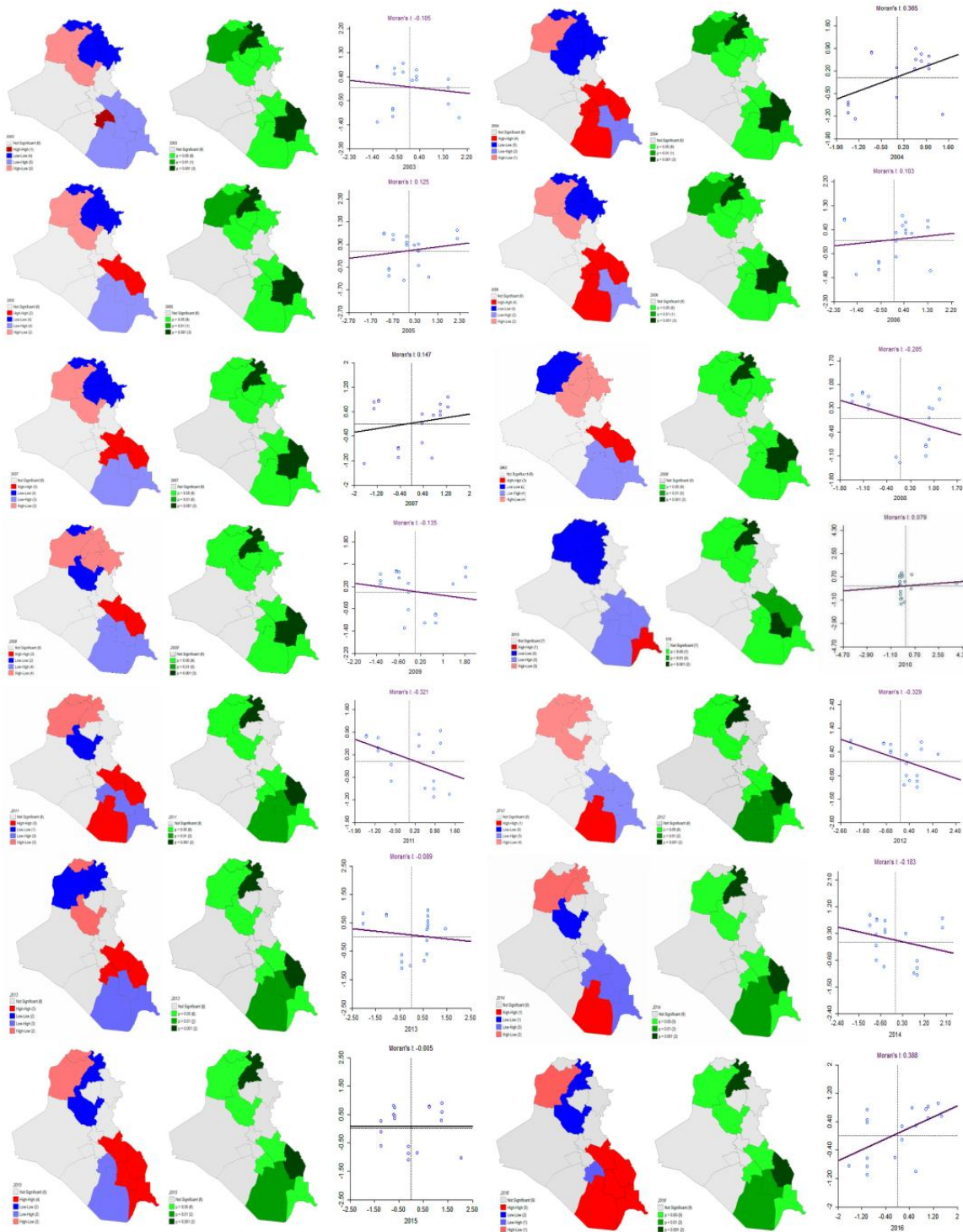
Region	Mean 2003–2024 for CO and Temperature			
	Bivariate Local Moran		LISA_I	LISA_P
	CO	T		
Al-Anbar	-0.464	0.075	-0.035	0.477
AL-Basrah	0.686	0.922	0.633	0.014
Al-Muthanna	-0.489	0.810	-0.396	0.01
Al-Najaf	-0.493	0.335	-0.165	0.19
Al-Qadissiya	-0.422	0.653	-0.275	0.025
Al-Sulaymaniyah	-0.425	-0.461	0.196	0.068
Babil	-0.084	0.302	-0.025	0.158
Baghdad	3.787	0.193	0.733	0.292
Diyala	0.400	-0.208	-0.083	0.313
Duhok	-0.437	-1.374	0.600	0.031
Erbil	-0.277	-0.980	0.271	0.001
Kerbala	-0.451	0.037	-0.016	0.488
Kirkuk	-0.186	-1.272	0.236	0.012
Maysan	-0.145	1.014	-0.147	0.003
Ninewa	-0.447	-1.005	0.449	0.014
Salah Al-Din	-0.392	-0.707	0.277	0.01
Thi Qar	0.110	0.878	0.097	0.001
Wassit	-0.273	0.725	-0.198	0.004

Note:



As shown in **Figure 6**, there is an increasing trend in temperature in the southern regions associated with an increasing carbon dioxide concentration in the northern regions. However, the increasing amounts of CO<sub>2</sub> in southern Iraq due to the combustion of biomass and the difference in its concentration

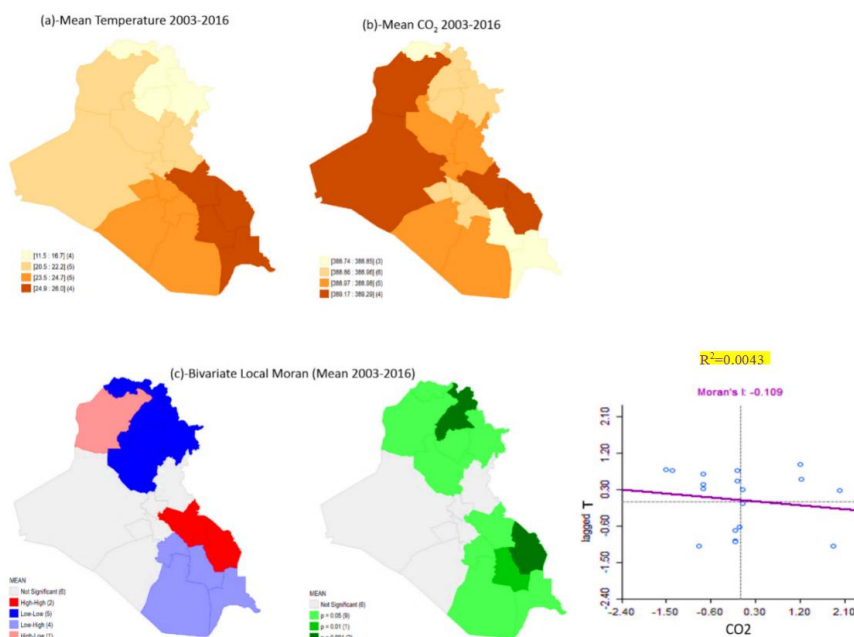
from year to year in 2010 demonstrated that CO<sub>2</sub> was slightly lower than its concentration in 2016. In general, the positive relationship was statistically significant at different significance levels and appeared more clearly in southern Iraq as a result of the increase in CO<sub>2</sub> concentrations in southern regions of Iraq.



**Figure 6.** Bivariate local Moran correlations between temperature (°C) and atmospheric carbon dioxide (CO<sub>2</sub>) (ppm) concentrations, with significance levels of  $p = 0.05, 0.01$  and  $0.001$  from 2003 to 2016.

In **Figure 7**, the general averages of atmospheric gas concentrations and temperatures within the time series for the years 2003–2016 reveal a spatial relationship between the two variables, temperature and CO<sub>2</sub>. As illustrated in **Figure 6c**, the relationship manifested in the Wassit and Maysan re-

gions, as well as in the cold spots in the northern part of the country. **Figure 6a** shows that high temperatures are concentrated in AL-Basrah, Thi-Qar, Maysan, and Wassit. **Figure 6b** shows the concentrations of CO<sub>2</sub> in Anbar, Ninewa, Wassit, and Maysan; refer to **Table 3** for further details.

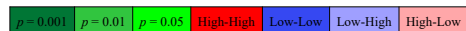


**Figure 7.** (a) Spatial distribution of the mean temperature, (b) spatial distribution of average carbon dioxide, (c) bivariate local Moran correlation between temperature (°C) and atmospheric carbon dioxide (CO<sub>2</sub> ppm) from 2003–2016.

**Table 3.** Bivariate local Moran correlation between temperature (°C) and carbon dioxide (CO<sub>2</sub>) (ppm) from 2003–2016.

Region	Mean 2003–2016			
	Bivariate Local Moran		LISA_I	LISA_P
	CO <sub>2</sub>	T		
Al-Anbar	1.997	0.290	0.579	0.192
AL-Basrah	-1.507	0.791	-1.192	0.019
Al-Muthanna	-0.068	0.779	-0.053	0.016
Al-Najaf	-0.068	0.508	-0.034	0.072
Al-Qadissiya	-0.745	0.699	-0.521	0.013
Al-Sulaymaniyah	-0.101	-0.715	0.072	0.037
Babil	-0.745	0.424	-0.316	0.071
Baghdad	0.047	0.295	0.014	0.205
Diyala	0.047	-0.049	-0.002	0.433
Duhok	-0.830	-1.089	0.903	0.041
Erbil	-0.101	-0.968	0.097	0.001
Kerbala	-0.745	0.318	-0.237	0.286
Kirkuk	-0.101	-0.999	0.100	0.043
Maysan	1.208	0.917	1.108	0.001
Ninewa	1.865	-1.090	-2.033	0.021
Salah Al-Din	-0.020	-0.624	0.012	0.023
Thi Qar	-1.371	0.766	-1.050	0.003
Wassit	1.234	0.570	0.703	0.023

Note:



A rise in temperatures in the southern regions of the country is accompanied by a rise in the concentration of carbon dioxide, due to the fact that these regions are witnessing a crowding of urban development and human activity and an abundance of means of transport that depend on traditional fuel, while the northwestern regions are affected by a slight concentration of carbon dioxide gas and consequently a decrease in temperatures. The northern regions, particularly

the Duhok governorate, are distinguished by their colder temperatures, which can be attributed to the presence of plant cover.

#### 4. Conclusions

Most studies indicate that the cause of climate change is the emission of greenhouse gases resulting from increased

human activity. In our current study, the spatial analysis of both carbon monoxide (CO) and carbon dioxide (CO<sub>2</sub>) with temperature revealed strong to weak positive correlations. The spatial distribution of these gases and their impact on temperature are significant. Using LASI for carbon monoxide and temperature, hotspots were identified in AL-Basrah and Thi Qar, showing a strong correlation. In the northern regions, characterized by vegetation cover, a weak positive correlation was observed, specifically in Kirkuk, Salah ad-Din, Ninewa, Duhok, and Erbil. In Wassit and Maysan, a strong correlation between temperature and CO<sub>2</sub> was found, reaching a statistically significant level. In the north of the country, a weak positive correlation was also observed, concentrated in Al-Sulaymaniyah, Kirkuk, Duhok, and Erbil. From this spatial analysis, we conclude that areas with oil fields and increased oil activity contribute to the emergence of hotspots, particularly in the southern regions. In contrast, northern regions are characterized by the emergence of cold spots due to a decrease in temperatures and CO<sub>2</sub> concentration, despite their vegetation cover, which naturally makes CO<sub>2</sub> concentration concentrated in these areas.

Although hotspots tend to coincide spatially with areas of intense oil activity, the current approach is based on correlations and does not allow for the inference of a causal relationship. The observed geographic relationships may be influenced by additional factors such as urbanization, elevation changes, latitudinal temperature gradients, and land cover characteristics. Therefore, hot and cold zone patterns should be interpreted as areas of shared spatial presence, not as direct evidence of causation. For example, colder areas in the north may result from relatively lower temperatures and distinct carbon dioxide distribution, which may be influenced by vegetation cover and spatial geography.

### **Recommendations for reducing greenhouse gas emissions in Iraq:**

- Reduce gas flaring and take urgent measures to collect flared gas for electricity generation.
- Increase renewable energy projects and provide financial support for the construction of solar power plants.

### **Author Contributions**

Initial conceptualization, data collection, graphical analysis, and writing the original draft in Arabic, H.M.B.M.;

review, editing and typesetting, M.A.J.; translation and scientific review, Z.H.A.A. All authors have read and agreed to the published version of the manuscript.

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Not applicable.

### **Data Availability Statement**

The datasets adopted in this study were collected and analyzed from Giovanni NASA, by the corresponding author are available upon request. The data supporting the results of this study are available in an Excel file format. If any raw data files in another format are needed, they are available upon request.

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### **Conflicts of Interest**

The authors declare no conflict of interest.

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