International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 12 No. 2, 2026
https://www.theaspd.com/ijes.php

Relationship Between Stratospheric and Tropospheric Ozone Over Iraq

Zainab M. Abbood

Department of Atmospheric Sciences, College of Science, Mustansiriyah University, Baghdad, Iraq.
zainabatmo@uomustansiriyah.edu.iq

Abstract
The total ozone in the column is concentrated about 90% in the stratosphere, while about 10% is found in the troposphere. Global ozone values range from 200 to 500 Dobson's with the average being around 300 Dobson's. The data was taken from the European Centre for Medium- Range Weather Forecasts for hourly and monthly averages for the three years 2005, 2015, and 2025 Over Iraq as Total Column Ozone (TCO), Relative Humidity (RH), Temperature (T), Solar Radiation (SR), Ozone Troposphere, Ozone Stratosphere and Ultraviolet Radiation (UV) for the period 3 years (2005, 2015, and 2025). The resulted showed the highest ozone values are generally found in Mosul, followed by Baghdad and then Rutba, with the lowest values in Basra. The difference between stations is very small, indicating that the spatial distribution of ozone in Iraq is relatively uniform. This may be due to: varying solar radiation or weather conditions (temperature, wind). Southern regions like Basra have slightly lower values, possibly due to: high humidity or industrial activities and their chemical impact. Furthermore, the values fall within a narrow range (~ 0.006 to 0.0067 kg/m²), indicating the relative stability of the ozone layer over Iraq during these years. Also, the highest inverse correlation between temperature and ozone stratosphere in the Mosul station was (-0.776, p<0.05) and the lowest inverse correlation between UV and ozone stratosphere in the Basra was (-0.04, p<0.05). Also, the highest positive correlation between relative humidity and ozone stratosphere in the Mosul station was (0.692, p<0.05).
Keywords: *Stratospheric Ozone; Tropospheric Ozone; Total Colum Ozone; Ultraviolet Radiation; ECWMF; Iraq.*

1 Introduction

One type of secondary air pollution is tropospheric O_3. It is created by chemical processes rather than being released directly into the atmosphere. When there is bright sunlight and high temperatures, these effects become more noticeable [1]. O_3 has significant oxidizing qualities in the near-surface layer and is essential to the development of photochemical air pollution. Tropospheric O_3 with a radiative forcing of (0.47) W/m² and range of (±0.23) W/m². O_3 functions as a greenhouse gas by trapping infrared (IR) radiation emitted from the Earth's surface, thereby contributing to atmospheric warming [2]. Through its impact on important processes within the troposphere–stratosphere system, such as atmospheric dynamics, thermodynamic structure, radiative balance, and chemical interactions, it plays a critical role in climate and environmental variability [3]. Beyond its impact on air quality, O_3 has a major global impact on ecosystem functioning and agricultural output [4]. Because of its detrimental effects on health, it is categorized as a hazardous air pollutant. Certain meteorological circumstances, such as high temperatures, low wind speeds, and low relative humidity, are generally linked to elevated O_3 concentrations [5]. The O_3 layer, is a part of the Earth's stratosphere that absorbs the bulk of the Sun's UV radiation. It has a higher concentration of O_3 than other regions of the atmosphere, but still being small compared to other gases in the stratosphere. The O_3 layer peaks at 8 to 15 parts per million, while the average quantity in the Earth's atmosphere is about 0.3 parts per million. Although its thickness varies seasonally and geographically, the ozone layer is generally found in the lower stratosphere, between 15 and 35 kilometers above ground. The O_3 layer's thickness varies throughout the world, but it is typically thicker toward the poles and thinner near the equator [8]. The O_3 layer gradually vanishes, but generally speaking, its upper limit happens when air becomes too thin for UV radiation to form much O_3, and its lower limit is when produced O_3 blocks enough UV light to stop most ozone synthesis. Research indicates that October has the lowest O_3 levels in the United States, while April and May have the highest. Although the total amount of O_3 increases from the tropics to higher latitudes, concentrations of O_3 are higher in high northern latitudes than in high southern latitudes. Before anthropogenic O_3 depletion, spring ozone columns at high northern latitudes averaged 450 DU and occasionally exceeded 600 DU. at contrast, the Antarctic had a usual maximum of

400 DU. Due to the northern hemisphere's extensive mountain ranges and more pronounced temperature differences between land and ocean, the polar vortex was weaker and the Brewer-Dobson circulation was stronger [9]. The O_3 hole phenomenon has caused the distance between high northern and southern latitudes to rise since the 1970s. The spring months of March and April see highest ozone levels over the Arctic, while summer months of September and October see the lowest levels over the Antarctic [10, 11].
The main objective of this study is to examine the relationship between stratospheric O_3 and tropospheric O_3 over Iraq: Kethireddy et al. (2014) and Chiang et al. applied geostatistical interpolation methods to investigate the spatial distribution of stratospheric O_3 using satellite observations. Their studies confirmed the efficiency of combining remote sensing data with GIS-based kriging techniques to model O_3 spatial variability. These methodological approaches are relevant to the present study, which similarly employs spatial interpolation to analyze stratospheric O_3 distribution over Iraq [12]. Chang, K.-L., Guillas, S., & Fioletov, V. E. (2015) is among the first to use spatial interpolation techniques (such as Kriging and SPDE) to accurately map the global total O_3 distribution based on ground station data. The results showed that the distribution of O_3 clearly varies by latitude and seasons [13]. Coates, J., Mar, K. A., Ojha, N., & Butler, T. M. (2016), studied the influence of anthropogenic and climatic factors on the temporal trends of O_3 in Europe. The researchers came to the conclusion that although regulations have decreased main pollutants, O_3 formation is nevertheless impacted in some places by variations in sun radiation and temperature patterns [14]. A study published by Gomez-Leal et al. (2019), focused on the role of O_3 in the climate system and its relationship with the Earth's ability to provide suitable conditions for life. The researchers relied on climate models to measure the impact of changing O_3 levels on surface temperature and humidity. The results showed that O_3 is an essential element of the climate balance, as its change leads to a clear difference in temperature and humidity, which is directly reflected in the stability and viability of the environment [15]. Li, X., Li, Y. J., Ma, Q. M., Chen, J., Chen, F., Yang, X. Y., & Wang, Q. J. (2019). dealt with the spatial and temporal analysis of the total and tropospheric O_3 over China using OMI and AERONET satellite data. The results showed that O_3 values in the north-eastern regions increased during spring, with a pronounced decrease in summer, reflecting the significant influence of climatic factors and human activities in the variability of O_3 [16]. Boleti et al. (2020) used a multi-temporal analytical strategy backed by statistical evaluations over a two-decade period to investigate long-term O3 variability across Europe. According to their findings, long-distance air mass transport and industrial emissions were the main causes of increases in O3 concentrations during particular times, while regional climate variability and the use of pollution control measures were linked to declines [17]. With an emphasis on tropical and mid-latitude areas, Ravishankara et al. (2020) examined the global relationship between O3 depletion and climate change. According to their research, anthropogenic substances like chlorofluorocarbons (CFCs) and climate-related feedback mechanisms like stratospheric cooling and changes in air circulation have an impact on ozone variability. The study also showed that, especially in certain areas, rising greenhouse gas concentrations may impede the O3 layer's recovery [18]. Al-Ataby et al. (2021) used OMI data from 2003 to 2015 to examine temporal variations in the total ozone column (TOC) across a number of Iraqi cities, including Baghdad, Mosul, and Basra. According to their investigation, O3 levels clearly varied seasonally and geographically, peaking in the spring and falling in the summer, particularly in the north [19].

2 Method

2.1 Research Location

This study was conducted in Iraq, focusing on four stations: Mosul, Rutba, Baghdad, and Basra. These stations were chosen because of their diverse environments in terms of population, topography, and geographical characteristics (mountainous, desert, and temperate). This allowed for differentiation between the stations in terms of pollution levels and their relationship to weather factors, using time series analysis and mathematical statistics [20].

2.2 Research Design

This research used a data collection and processing methodology, plotting the data as time series. Statistical functions were used to illustrate the relationships between variables, and maps were used to demonstrate spatial analysis and identify the most influential stations using flowchart. As shown the Figure 1.

International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 12 No. 2, 2026
https://www.theaspd.com/ijes.php

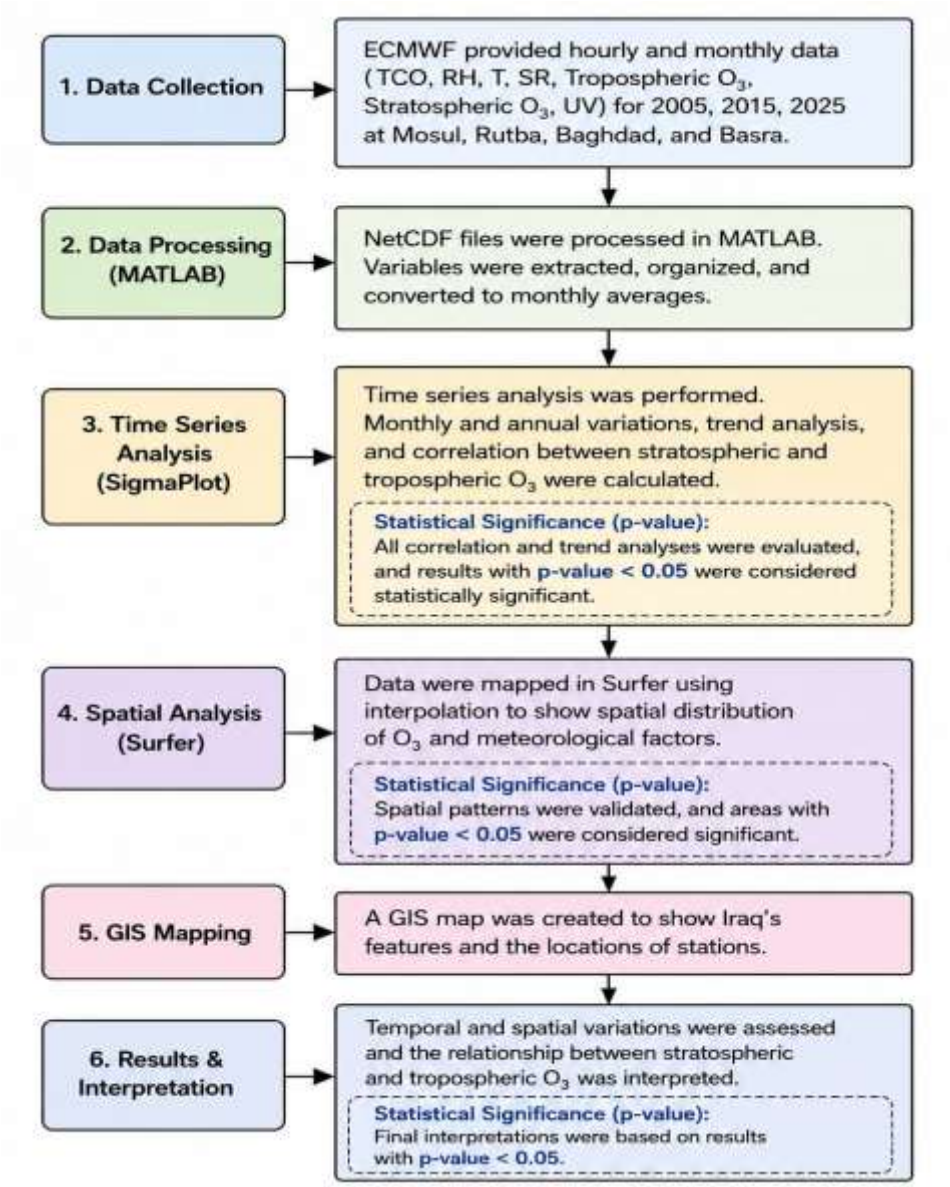


Figure 1. Stages of Research and Development.

2.3 Statistical Used

2.3.1 Spearman Rank

This research employed Spearman's Rank Correlation Coefficient is a non-parametric statistical measure used to determine the strength and direction of the relationship between two variables based on the ranking of their values, rather than the original values [21, 22]. It is denoted by the symbol ρ or rs and relies on comparing the ranking of data for each variable, making it suitable for analyzing both linear and nonlinear relationships, provided they have a monotonic direction. The importance of Spearman's coefficient lies in several aspects, including: analyzing nonlinear relationships [23, 24]. Also, it is used when the relationship between variables is not linear, which is common in environmental studies, such as the relationship between ultraviolet radiation and ozone. No requirement for a normal distribution making it suitable for climatic and environmental data. Resistance to outliers because the calculation is based on ranking, the impact of outliers is less significant compared to other coefficients. Ease of Interpretation It gives a value between (-1 and +1), making it easy to interpret the strength and direction of the relationship: Alternatively, it can be quicker to find using the formula [25, 26].

$$r_s = 1 - \frac{6\sum_{i=1}^{n} d_i^2}{n(n^2-1)} \quad (1)$$

The value of rs can be evaluated for significance if n is big by computing the quantity of ts, which is provided by the following equation

$$t_s = r_s\sqrt{\frac{n-2}{1-r_s^2}} \quad (2)$$

Where n is the number of pairs and d is the difference between the ranks of each pair of items. Keep in mind that this becomes an approximation of rs if any of the rankings are tied, and the more tied ranks there are, the less accurate it is [27, 28].

2.4 Data Collection Techniques

The European Center for Medium-Range Weather Forecasts provided the dataset, which included hourly and monthly averaged values over Iraq. The analyzed variables comprised Total Column Ozone (TCO), Relative Humidity (RH), Temperature (T), Solar Radiation (SR), tropospheric O_3, stratospheric O_3, and Ultraviolet Radiation (UV). The study covered a 3year period (2005, 2015, and 2025) across major Iraqi stations, namely Mosul, Rutba, Baghdad, and Basra, as illustrated in Figure 2 and Table 1. To display seasonal influences, this data was transformed into monthly rates. (ECMWF) provided the meteorological and O_3 data utilized in this study in NetCDF format (nc). The necessary variables, such as the stratospheric and tropospheric ozone concentrations across Iraq also meteorological data were extracted and arranged using MATLAB software after the NetCDF files were converted and processed. SigmaPlot software was then used to do a time series analysis on the prepared data. The statistical relationship between stratospheric and tropospheric ozone was examined using correlation coefficients and trend analysis, and monthly and annual variations were examined [20]. The data was also plotted using Surfer software to illustrate the temporal and spatial distribution for meteorological factors and O_3 produced using interpolation techniques. Together with the correlation coefficient, the p-value was computed. The probability that the observed link happened by chance under the null hypothesis is represented by the p-value. In this investigation, a significance threshold of 0.05 was chosen. Consequently, a meaningful association between the variables under study was suggested by results with p-values less than 0.05 ($p < 0.05$), whereas no statistically significant relationship was shown by results with p-values greater than 0.05. Also, a map was created using GIS to illustrate the features and nature of Iraq.

Table 1. Meteorological station used in the study [19].

No.	Station	Longitude (degree)	Latitude (degree)	Elevation (meter)
1	Mosul	43.15	36.31	223
2	Rutba	40.28	33.03	222
3	Baghdad	44.4	33.3	32
4	Basra	47.78	30.52	2

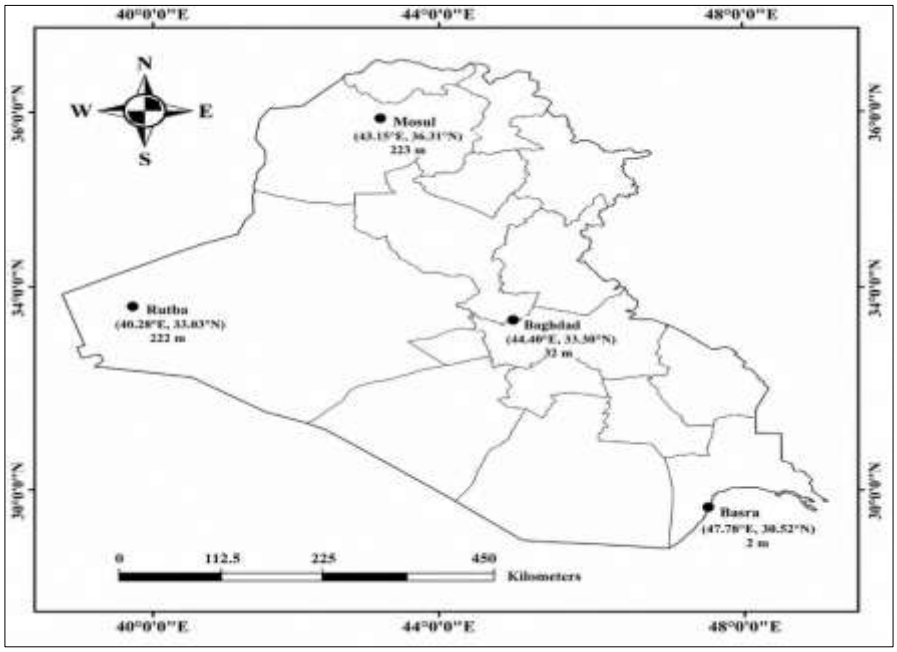


Figure 2. The location of study area.

2.5 Data Analysis

Data analysis employed various methods and timeframes to understand the nature of ozone activity in the troposphere and stratosphere over time and its relationship to atmospheric conditions at different locations. The analysis revealed two distinct effects: one cooling and the other warming the atmosphere. The data collection, presentation, analysis, and conclusions provided valuable insights that contribute to promoting radiation balance, environmentally conscious behaviors, and pollution reduction.

3 Result and Discussion

3.1 Spatiotemporal Annual Distribution of Total Column Ozone, Ozone troposphere, and Ozone Stratosphere in Iraq for 3 years (2005, 2015, and 2025)

Figure 3, the spatiotemporal distribution of total column ozone (TCO) over Iraq for the years 2005, 2015, and 2025 reveals a consistent latitudinal gradient, with higher values observed in the northern regions and lower values in the southern parts of the country. Large-scale meteorological processes, such as the Brewer–Dobson circulation, which promotes the poleward movement of ozone-enriched air masses from tropical regions, can account for the observed distribution. As a result, northern Iraq often has greater O_3 levels than the country's middle and southern regions. The spatial distribution shows a consistent pattern even if the research covers non-consecutive years, suggesting that geographic variables are the key determinant of O_3 fluctuation. However, there are slight variations in O_3 concentrations across the years under study, especially over central regions, indicating some interannual variability. Variations in climatic circumstances, such as T, SR, and atmospheric circulation dynamics, are probably linked to these changes. On the other hand, higher temperatures and increased photochemical activity, which encourage O_3 loss mechanisms, may be connected to the relatively lower O_3 concentrations found in southern Iraq. Additionally, isolated abnormalities found in some regions, particularly in the 2025 distribution, may indicate changes in vertical O_3 exchange processes or temporary atmospheric impacts.

International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 12 No. 2, 2026
https://www.theaspd.com/ijes.php

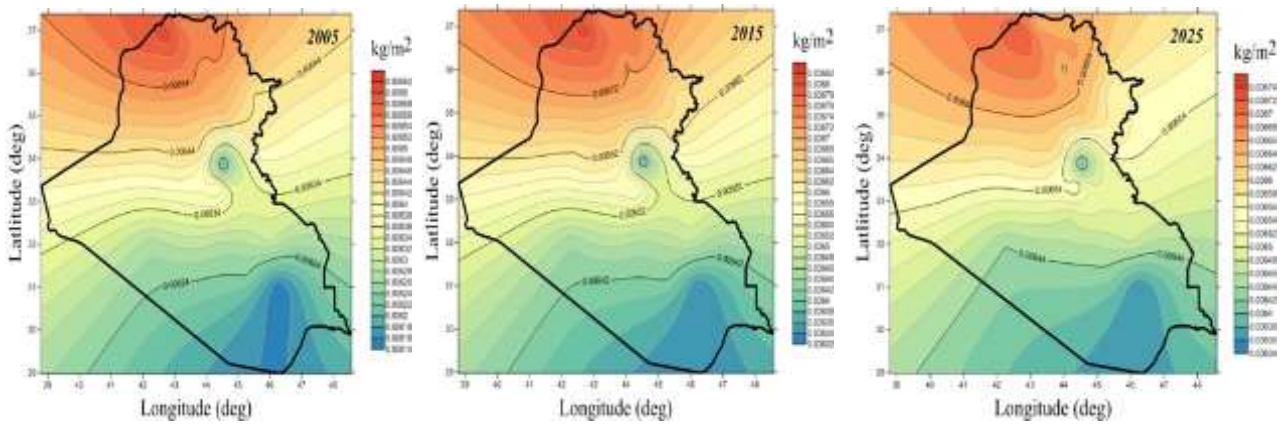


Figure 3. Annual distribution of TCO in Iraq for the year 2005 2015, and 2025.

In comparison to TCO, Figure 4, shows significant geographical and temporal variability in the tropospheric O_3 spatiotemporal distribution across Iraq for the years 2005, 2015, and 2025. While lower concentrations are more prevalent in the central and southwestern regions, O_3 levels are typically higher in the northern and eastern regions. The combined impacts of photochemical production, the presence of precursor pollutants (such NO_x and VOCs), and air transport processes are what cause this regional contrast. The regional pattern was comparatively uniform in 2005, exhibiting a slow shift toward the east with rising O_3 concentrations. The distribution grew more erratic in 2015, with discernible improvements in the northeast, which could be linked to higher emissions from human activity and more potent photochemical reactions. By 2025, the O_3 distribution showed more complicated characteristics, such as an isolated low zone inside inland regions, indicating the impact of changing horizontal transport pathways and atmospheric circulation. Tropospheric O_3 is significantly influenced by local environmental factors, including T, SR, and emission intensity, in contrast to total column O3. The differences between years show how important anthropogenic activities and weather variations are in shaping O_3 distribution patterns over Iraq.

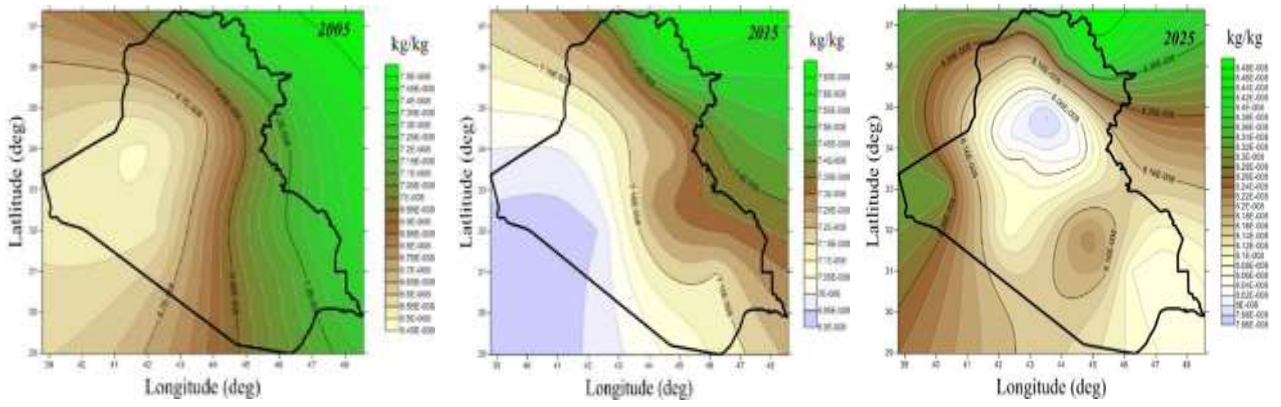


Figure 4. Annual distribution of Ozone Troposphere in Iraq for the year 2005 2015, and 2025.

Figure 5, the spatiotemporal distribution of stratospheric O_3 over Iraq for the years 2005, 2015, and 2025 shows a relatively stable and well-organized pattern compared to tropospheric O_3. The middle part of the country had greater O_3 concentrations, as well as chronically high amounts in the eastern parts. This is linked to large-scale atmospheric dynamics, not local surface activities. The low temporal fluctuation observed between the years analyzed shows that stratospheric O_3 is driven by the Brower-Dobson circulation, which moves O_3 from tropical production areas to higher latitudes. Furthermore, jet stream activity and temperature fluctuations in the stratosphere influence O_3 redistribution and concentration. Stratospheric

O_3, unlike tropospheric O_3, is regulated by photochemical equilibrium and air circulation rather than anthropogenic sources. The little differences observed over the years are most likely due to changes in atmospheric dynamics and seasonal or interannual variability, rather than major long-term trends.

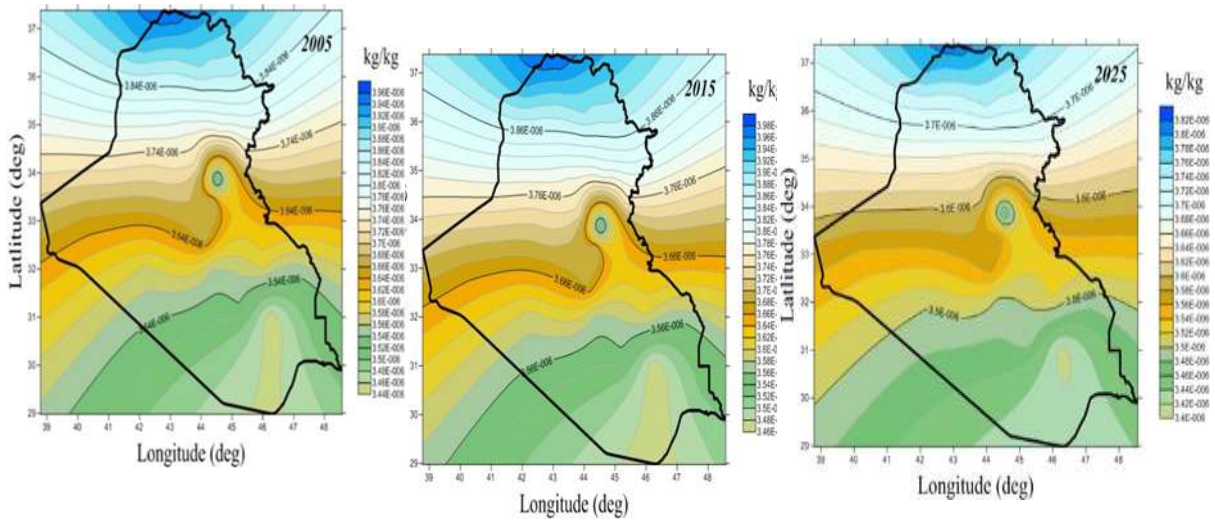


Figure 5. Annual distribution of Ozone Stratosphere in Iraq for the year 2005 2015, and 2025.

3.2 Spatiotemporal Annual Distribution of RH in Iraq (2005, 2015, 2025)

The spatiotemporal distribution of relative humidity (RH) over Iraq in 2005, 2015, and 2025 is shown in Figure 6 as a constant regional gradient with significant temporal variability. Geographically, RH levels are steadily higher in Iraq's northern regions and progressively lower in its center and southern regions. The northern regions are frequently associated with lower temperatures, higher elevation, and an increasing impact of Mediterranean air masses, whilst the southern regions are characterized by drier weather, higher temperatures, and less moisture available. In 2005, there was a noticeable north-to-south gradient and moderate RH values across the country. The southern areas have the lowest humidity, while the center region has intermediate values. RH has somewhat grown by 2015, especially in the northern and northeastern regions. The central region exhibits localized increases despite the geographical distribution remaining static, most likely as a result of changes in air circulation and moisture transport patterns. The same pattern continues in 2025 even though RH in central and southern Iraq is generally lower than in prior years. Despite a minor geographical decrease, humidity levels are still somewhat greater in the northern parts. Rising temperatures and increased evaporation rates, which lower the amount of moisture in the atmosphere, may be connected to this decline. Compared to 2005 and 2025, the humidity levels in 2015 were noticeably greater.

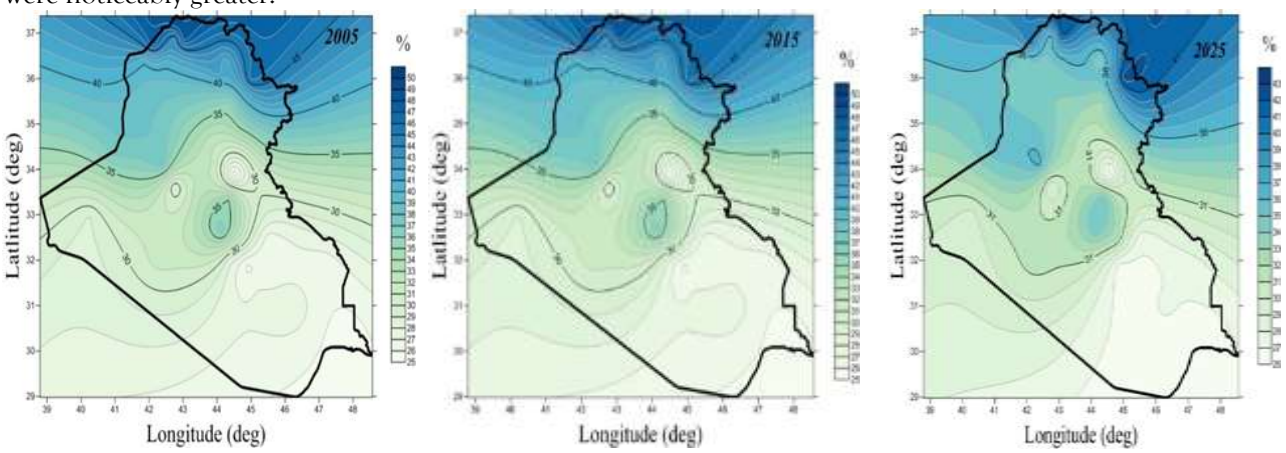


Figure 6. Annual distribution of RH in Iraq for the years 2005, 2015, and 2025.

International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 12 No. 2, 2026
https://www.theaspd.com/ijes.php

3.3 Spatiotemporal Annual Distribution of T in Iraq (2005, 2015, 2025)

The spatiotemporal distribution of T over Iraq for the years 2005, 2015, and 2025 as shown in Figure 7 demonstrates temporal analysis that is certainly increasing. There was a huge increase in 2015 compared to 2005, notably in the southern regions. In 2025, when this trend persisted with a significant extension of high T regions, the consequences of climate change and the rising heat intensity over time became evident. The distribution of T in Iraq appears to vary significantly, according to the spatial study. They are highest in the country's south and gradually decrease as one travels north. Numerous elements, including location, altitude, and surface features, contribute to this. The results demonstrate that temperatures have been gradually increasing over time, with hotter locations spreading throughout Iraq, particularly in the southern and central parts of the country. The geographical variance also shows how climate and geography influence heat dispersion.

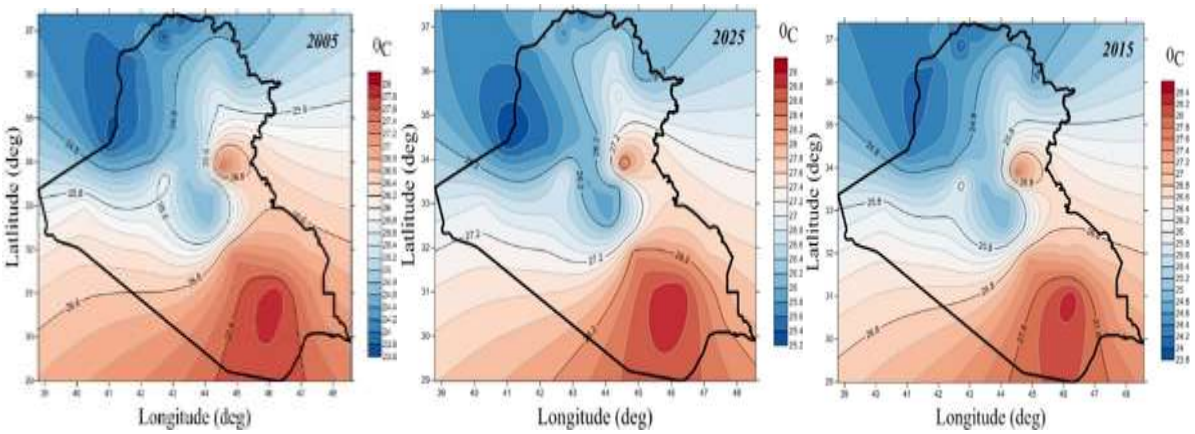


Figure 7. Annual distribution of T in Iraq for the years 2005, 2015, and 2025.

3.4 Spatiotemporal Annual Distribution of SR in Iraq (2005, 2015, 2025)

Figure 8, the spatiotemporal distribution of SR over Iraq for the years 2005, 2015, and 2025 show that the southern and western regions of Iraq record the highest SR values, while these values gradually decrease towards the northern and northeastern regions. This spatial variation is linked to several factors, most notably the clear atmosphere in the southern and western desert regions, the low cloud cover, and the low atmospheric humidity, which allow a greater amount of SR to reach the Earth's. In contrast, the northern regions are affected by higher altitude and mountainous terrain, as well as higher cloud cover and humidity, which reduces the intensity of SR. While a temporal variation, an upward trend in SR values is observed across the three years studied. In 2005, the distribution appears relatively moderate, with limited areas of low values in the central and northern parts of the country. While in 2015 values began to rise noticeably, with the area of high radiation expanding, particularly in the south and east, by 2025 values would reach their highest levels, with high radiation areas expanding significantly and low radiation areas decreasing noticeably.

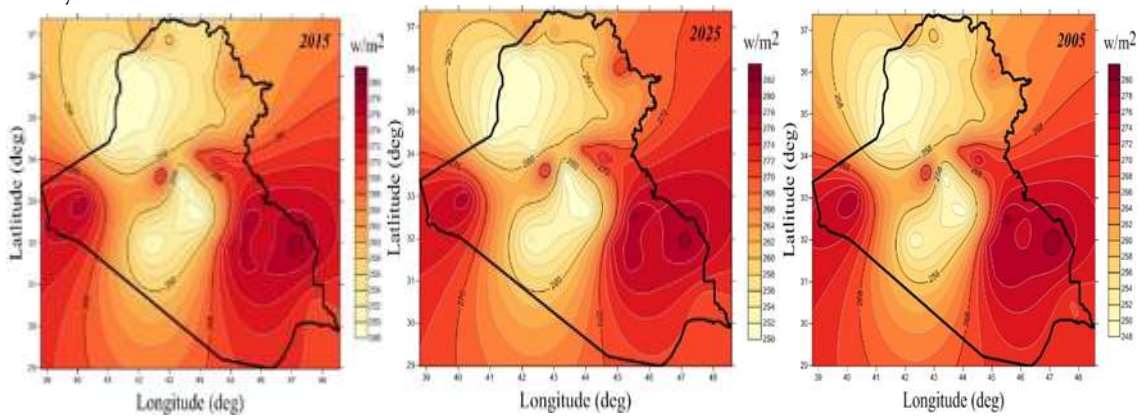


Figure 8. Annual distribution of SR in Iraq for the years 2005, 2015, and 2025.

3.5Spatiotemporal Annual Distribution of UV in Iraq (2005, 2015, 2025)

Figure 9, the spatiotemporal distribution of UV over Iraq for the years 2005, 2015, and 2025 show the southern and southeastern regions record the highest values, while intensity gradually decreases towards the northern and northwestern regions. A mix of meteorological and geographic elements, mainly the astronomical location, are responsible for this spatial variance. Due to their lower latitudes, the southern regions are more perpendicular to the sun's light, which increases UV intensity. The clarity of the atmosphere has a major impact on this distribution as well. The amount of UV light that reaches the Earth's surface is increased since there is less absorption and scattering in the southern regions due to lower humidity and less cloud cover than in the northern ones. Conversely, factors that restrict radiation intensity, like relatively higher elevations, frequent humid air mass passage, and a greater chance of cloud formation, all help to reduce the amount of incoming radiation in the northern latitudes. A comparison of the three years reveals slight changes in UV intensity and distribution over time, but no appreciable shifts in the overall pattern. With average values concentrated in the middle of the country, the distribution in 2005 is quite balanced. In 2015, there was a little increase in radiation intensity in the southern regions, which might be explained by either an increase in air clarity or a decrease in cloud cover. In 2025, the south exhibits a relative growth in the range of high values while the north continues to decline. This implies that the same climatic variables will continue to have an impact, with the potential for slow climate change consequences like rising temperatures and falling humidity.

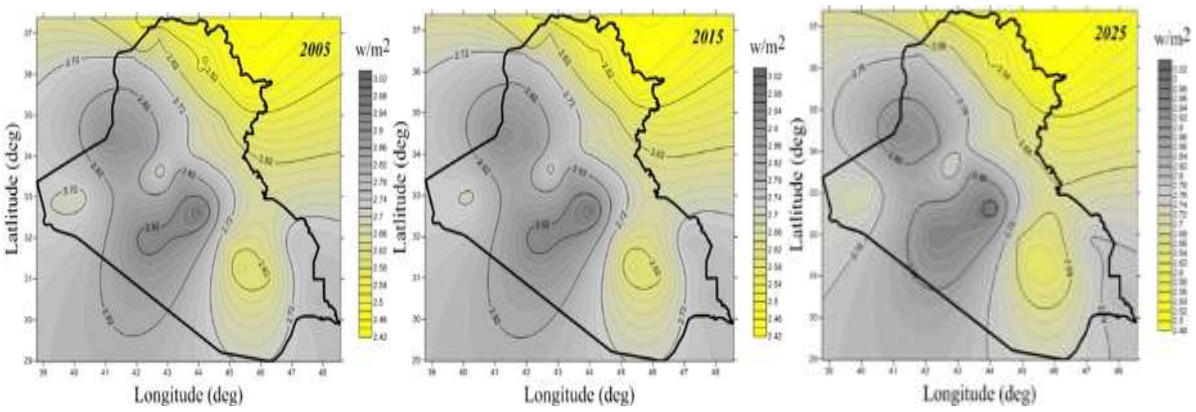


Figure 9. Annual distribution of UV in Iraq for the years 2005, 2015, and 2025.

3.6Temporal Analysis of TCO, RH, T and SR Over Some Iraq Station

The annual distribution of TCO values at all locations is shown in Figure 10, and they range around from 0.006 to 0.007 kg/m². This implies that there are no significant fluctuations or sharp drops in Iraq's O_3 content, which is within a relatively stable range. Location-wise, Mosul (north) has the highest values, followed by Baghdad and Rutba, while Basra (south) has the lowest values. Due to variations in atmospheric dynamics and air mass movement, the O_3 layer thickens comparatively as one approach northward, which is why this progressive increase reflects the influence of latitude. Temporally, a slight upward trend in O_3 values is observed from 2005 to 2015, with values rising similarly at all stations. This limited increase is expected to continue until 2025, with relatively stable differences between stations.

This gradual increase can be scientifically explained by the global improvement of the O_3 layer due to the reduced use of ozone-depleting substances (such as chlorofluorocarbons) and changes in atmospheric circulation that affect O_3 distribution and variations in solar radiation that affect O_3 formation and decomposition processes.

International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 12 No. 2, 2026
https://www.theaspd.com/ijes.php

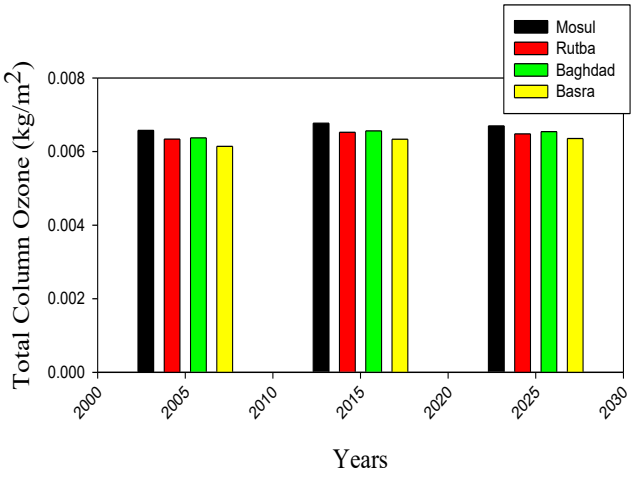


Figure 10. Annual behavior of ozone gas levels during the years 2005, 2015, and 2025 over Iraq.

Figure 11 annual distribution of RH in the stations of Mosul, Rutba, Baghdad, and Basra during the years 2005, 2015, and 2025 which shows a distinct variation in values over time. In comparison to 2005, RH rose dramatically in 2015 then falling once more in 2025. The results also showed a regular spatial gradient, with the highest humidity values recorded in Mosul, followed by Rutba, then Baghdad, while the lowest values were in Basra. This fluctuation is explained by regional variations in surface features, temperature, and proximity to bodies of water. All things considered, these findings show that RH in Iraq is highly impacted by climatic fluctuations and shows relative temporal instability with distinct geographical disparities between the north and south.

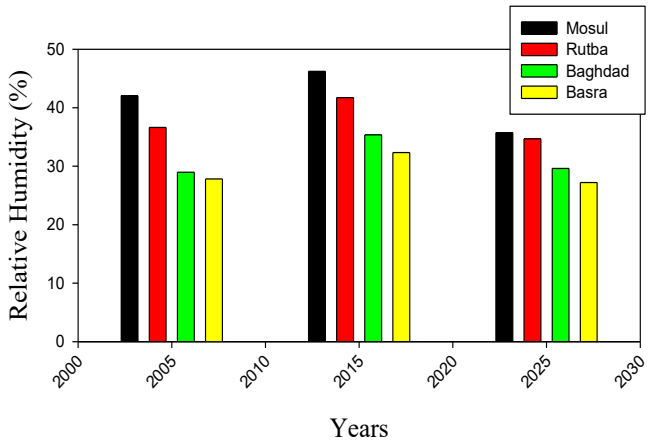


Figure 11. Annual behavior of relative humidity levels during the years 2005, 2015, and 2025 over Iraq.

The annual distribution of T in the stations of Mosul, Rutba, Baghdad, and Basra for the years 2005, 2015, and 2025 is depicted in Figure 12. All of Iraq's cities—Mosul, Rutba, Baghdad, and Basra—showed a steady rise in temperatures between 2005 and 2025, according to the data. This increase makes sense in the context of global climate change, which increases the buildup of greenhouse gases and exacerbates the greenhouse effect. However, this increase is directly related to solar radiation because greater temperatures are caused by more radiation reaching the Earth's surface, particularly in regions with clear skies like Iraq. Additionally, the lack of flora and growing desertification lead to less natural cooling, which exacerbates the rising temperatures. It is also interesting that geographical location accounts for the spatial variance in temperatures (greater in Basra and lower in Mosul), with hot, dry air masses affecting southern regions and more temperate climates in northern parts.

International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 12 No. 2, 2026
https://www.theaspd.com/ijes.php

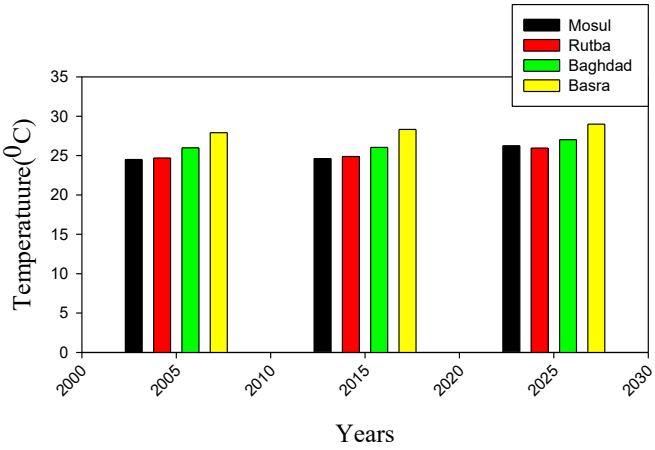


Figure 12. Annual behavior of temperature levels during the years 2005, 2015, and 2025 over Iraq.

The SR values at the stations of Mosul, Rutba, Baghdad, and Basra throughout the years 2005, 2015, and 2025 vary annually, as shown in Figure 13. The findings show that solar radiation values gradually increased between 2005 and 2025, showing a moderate rising trend across all regions examined. A relative rise in atmospheric clarity or a reduction in the effects of radiation-scattering elements like cloud cover or aerosols during specific times, which permits more SR to reach the Earth's, could account for this tendency. According to the data, Baghdad and Basra have higher SR values than Mosul and Rutba. Numerous geographic and climatic factors are responsible for this, including: Astronomical location: Due to their lower latitudes, Baghdad and Basra experience a greater angle of solar radiation incidence. In comparison to the north, the center and southern regions have lower cloud cover densities. the effects of dust storms and humidity, which might differ in frequency and intensity between areas. Rutba, on the other hand, took comparatively low readings when in a desert. This could be because suspended dust in the atmosphere scatters and absorbs solar energy, lowering the net radiation that reaches the planet. Mosul also displayed average values, probably because it is more vulnerable to Mediterranean weather systems and experiences more cloud cover in some seasons.

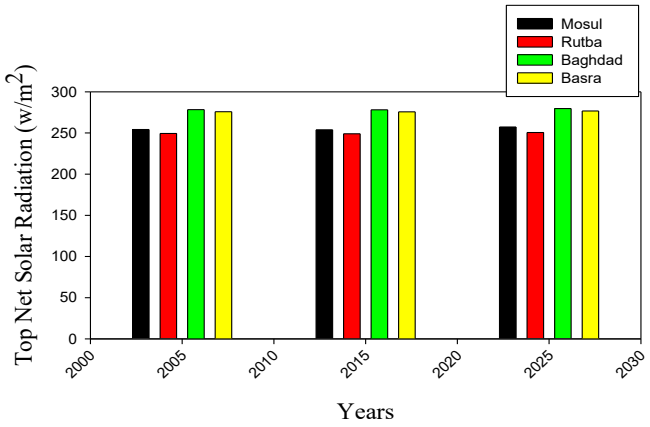


Figure 13. Annual behavior of solar radiation levels during the years 2005, 2015, and 2025 over Iraq.

Figure 14, shows annual variation in UV values in the stations of Mosul, Rutba, Baghdad, and Basra during years 2005, 2015, and 2025. The UV is relatively stable over time, with a slight tendency to increase during the years 2005, 2015, and 2025. Temporal Variation the slight increase in UV values in 2025 compared to 2005 may be attributed to: Limited changes in ozone layer thickness, as any decrease even a small one allows more UV radiation to pass through. A relative improvement in atmospheric clarity during certain periods, which increases radiation penetration. Fluctuations in aerosol (dust) concentration, which is an important factor in radiation absorption and scattering. While spatial variation: the results show a clear and relatively stable spatial variation between cities: Baghdad records the highest UV radiation values, attributed to its

geographical location and relatively high atmospheric clarity. This is followed by Rutba, which is affected by an open desert climate and low cloud cover. Although Mosul and Basra record comparatively lower levels, this is because of regional factors as air mass differences in the north (Mosul) or humidity in the south (Basra). This variation reflects the influence of Latitude and angle of incidence of solar radiation Clouds and humidity Dust storms and air pollutants.

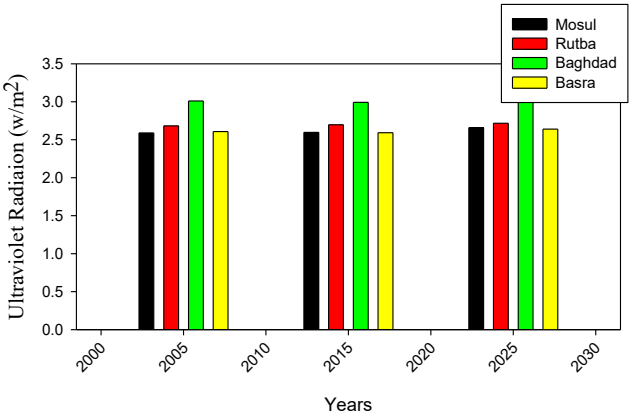


Figure 14. Annual behavior of ultraviolet radiation levels during the years 2005, 2015, and 2025 over Iraq.

Figure 15, shows annual variation in ozone troposphere and ozone stratosphere values in the stations of Mosul, Rutba, Baghdad, and Basra during the years 2005, 2015, and 2025. Analysis of O_3 data over Iraq reveals a clear difference in O_3 behavior between the troposphere and stratosphere, both temporally and spatially. This reflects the different physical and chemical processes dominant in each layer. Temporally, tropospheric O_3 levels at all stations (Mosul, Rutba, Baghdad, and Basra) during the years 2005, 2015, and 2025 show a steady increase without sharp fluctuations. This is explained by the fact that ozone in this layer is a secondary pollutant created by SR induced photochemical reactions between NOx and VOCs. This increases the efficiency of these processes and makes it susceptible to changes in human activity, such as increased vehicle traffic, urban growth, and industrial activity, as well as the impact of rising T. As a result, the temporal increase amply illustrates how human activity and climate change are increasingly affecting the urban environment in Iraq. In contrast, stratospheric O_3 exhibits a distinct temporal trend, with values rising sharply between 2005 and 2015 before either staying mostly constant or slightly dropping by 2025. This pattern demonstrates the dynamic nature of the stratosphere, where large-scale processes like the Prior-Dobson circulation and global atmospheric circulation, as well as the balance between chemical breakdown and photosynthesis, affect O_3. The sluggish global recovery of the O_3 layer once the usage of O_3 depleting substances is decreased, which results in values stabilizing over time rather than continuously rising, can also be linked to this behavior. There are noticeable spatial variations in the tropospheric O3 distribution in Iraqi cities. Mosul frequently reports the highest values as compared to other stations, followed by Baghdad and Rutba, while Basra shows relatively lower amounts. This fluctuation can be explained by the influence of geographic location and local climate. In addition to mild temperatures that encourage O_3 buildup, northern regions like Mosul are impacted by the inflow of contaminated air masses from outside. Baghdad is an example of an intermediate situation because of a variety of regional sources of pollution. Despite its oil activities, Basra may have lower O_3 concentrations or less buildup than other areas because of its high humidity and the impact of its coastal environment. Stratospheric O_3, on the other hand, clearly shows geographic homogeneity throughout all cities, with values seeming to be fairly comparable and displaying very slight variations. This is due to the fact that O_3 in this layer is dispersed throughout a large region and is not immediately impacted by local sources. Rather, it minimizes spatial variability across various areas within Iraq by largely relying on latitude and major atmospheric circulation patterns.

International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 12 No. 2, 2026
https://www.theaspd.com/ijes.php

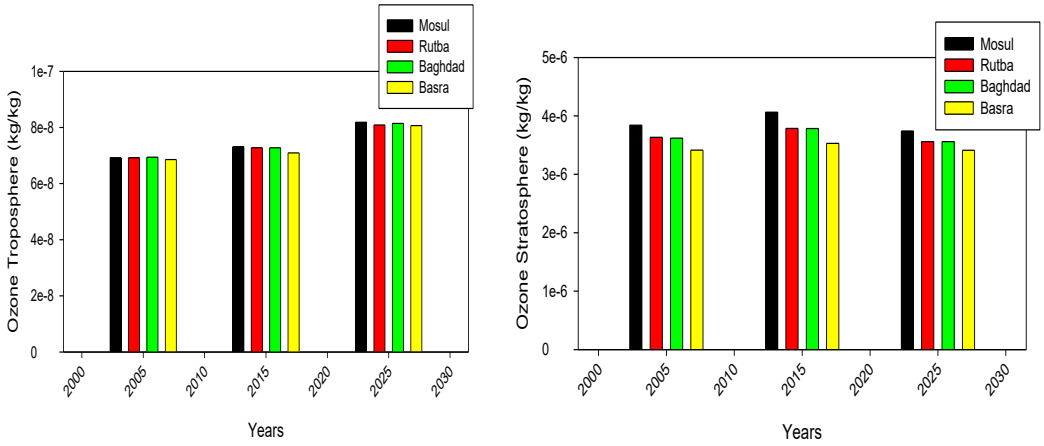


Figure 15. Annual behavior of ozone (troposphere and stratosphere) levels during the years 2005, 2015, and 2025 over Iraq.

3.7 Analysis distribution of TCO, RH, T, and SR for 3 years 2005, 2015, and 2025 over Iraq

Figure 16 illustrates four monthly time relationships (January–December) for four Iraqi stations: Mosul, Rutba, Baghdad, and Basra. These relationships include ozone levels, temperature, relative humidity, and solar radiation.

- **TCO:** Highest values are found in winter and early spring (January–March). It gradually decreases, reaching its lowest point in autumn (September–October). Then it rises again with the onset of winter. Explanation: Ozone is inversely related to temperature and solar radiation. Increased heat and radiation in summer lead to the chemical decomposition of ozone, while it is more stable in winter.
- **T:** It gradually rises from winter, peaking in summer (July–August). Then it decreases towards winter. Basra and Baghdad record the highest temperatures, while Mosul experiences relatively lower temperatures. Explanation: This pattern is natural due to geographical location and the influence of solar radiation.
- **RH:** Highest values are found in winter (December–February). It decreases significantly in summer (June–August). Mosul has the highest humidity, and Basra the lowest, in the summer. Explanation: An inverse relationship with temperature; higher temperatures increase evaporation and decrease relative humidity.
- **SR:** Increases in winter, reaching its peak in summer. It decreases again in winter. Baghdad and Basra record higher values. Explanation: Due to clear skies and fewer clouds in summer, which increases the amount of radiation.

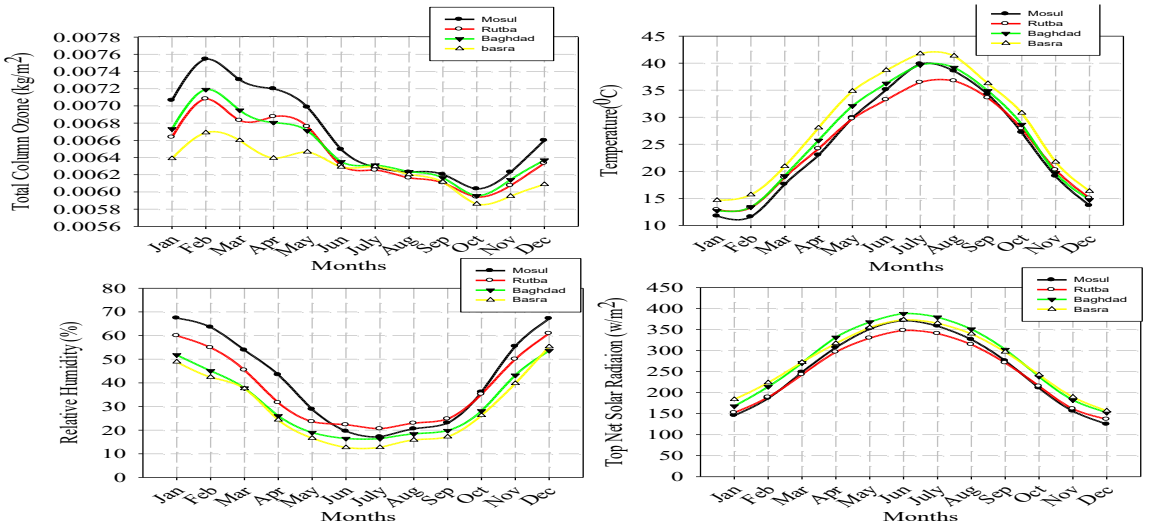


Figure 16. The monthly variation of TCO and Metrological factors in Mosul, Rutba, Baghdad, and Basra stations from 2005, 2015, and 2025.

International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 12 No. 2, 2026
https://www.theaspd.com/ijes.php

3.8 Analysis distribution of O_3 concentration (troposphere and stratosphere) and ultraviolet radiation for 3 years 2005, 2015, and 2025 over Iraq

The Figure 17, shows the spatial distribution of O_3 over Iraq shows a clear contrast between the troposphere and stratosphere. In the troposphere, O_3 is spatially heterogeneous, with relatively high values observed in the northern regions, followed by lower values in the central regions, and moderate to low values in the south. This variance is explained by both the function of dynamic forces like air mass movement and wind patterns, as well as local influences like pollution emissions and photochemical reactions. Topography may also have an impact on increased O_3 buildup in the northern regions. O_3 in the stratosphere, on the other hand, shows a more consistent pattern with a distinct north-south gradient, with the highest values found in the northern areas and progressively declining towards the south.

The distribution of O_3 in this layer is dominated by large-scale processes like Brewer-Dobson circulation and the impact of SR, while local causes have a less influence. Accordingly, it can be concluded that tropospheric O_3 is mainly affected by local factors and complex chemical processes, resulting in clear spatial variation, while stratospheric O_3 is subject to global dynamic mechanisms that result in a more regular and stable distribution. The results of the monthly variation in ultraviolet (UV) radiation showed a clear seasonal pattern. Values start low during winter (January–February), then gradually rise to peak during the spring and early summer months (May–June), before decreasing again with the onset of autumn. This pattern is help to the change in the angle of the sun's rays and the length of the day, with radiation intensity increasing when the sun is almost directly overhead during summer. The comparison between stations also showed that Rutba station recorded the highest UV radiation values, due to clear atmospheric conditions and few clouds. Basra, on the other hand, recorded relatively lower values due to high humidity and increased particulate matter in the air, while Baghdad and Mosul recorded average values. In general, it can be resulted that O_3 plays an important role in regulating UV radiation intensity. However, its effect is influenced by a range of other climatic factors such as clouds, dust, humidity, and aerosols, which vary from one region to another within Iraq, leading to spatial and temporal variations in radiation intensity.

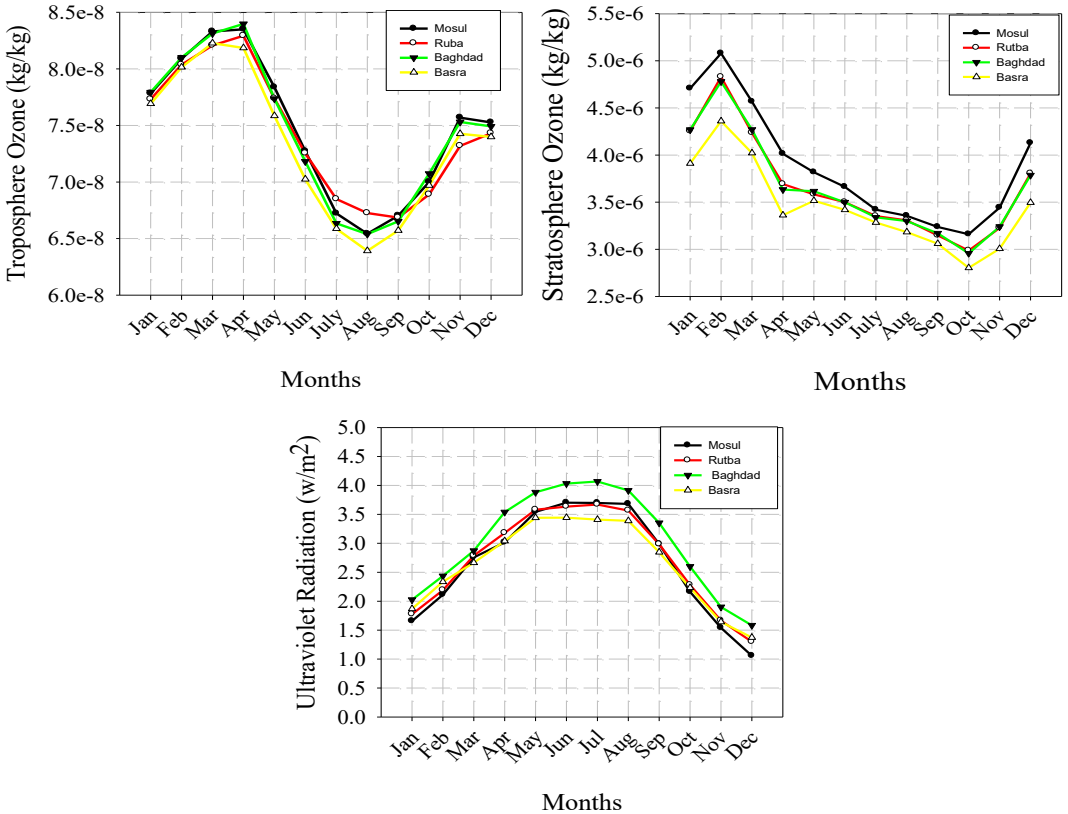


Figure 17. The monthly variation of O3 concentration (troposphere and stratosphere) and ultraviolet radiation in Mosul, Rutba, Baghdad, and Basra stations for years 2005, 2015, and 2025.

International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 12 No. 2, 2026
https://www.theaspd.com/ijes.php

3.9 The relationship between ozone and meteorological factor over Iraq

Figure 18, the interaction between T and O_3 concentration (troposphere and stratosphere) was analyzed in four Iraqi cities (Mosul, Rutba, Baghdad, and Basra), distinguishing between tropospheric and stratospheric O_3. At every location, the results clearly demonstrate an inverse association between T and stratospheric O_3. The concentration of O_3 in the stratosphere continuously drops with increasing T. Changes in stratospheric thickness and vertical mixing are two atmospheric dynamic processes that are responsible for this phenomenon. Increased atmospheric instability, which can spread O_3 and lower its concentration in particular areas, is frequently linked to higher temperatures. Moreover, elevated T may result in a rise in the concentration of O_3 in the stratosphere. Tropospheric O_3, has extremely low concentrations and little relationship to T. This almost constant pattern implies that tropospheric O_3 levels in these data are not solely influenced by T. Rather, photochemical reactions involving SR and primary pollutants including (NOx) and (VOCs) are the main sources of tropospheric O_3 production. Although tropospheric O_3 concentrations are somewhat higher in Baghdad and Basra, probably as a result of a wider T range and more severe weather, spatial comparisons show a consistent overall pattern across all cities. Overall, the findings show that T has a major impact on stratospheric O_3, but photochemical processes rather than direct thermal influences are the main drivers of tropospheric O_3.

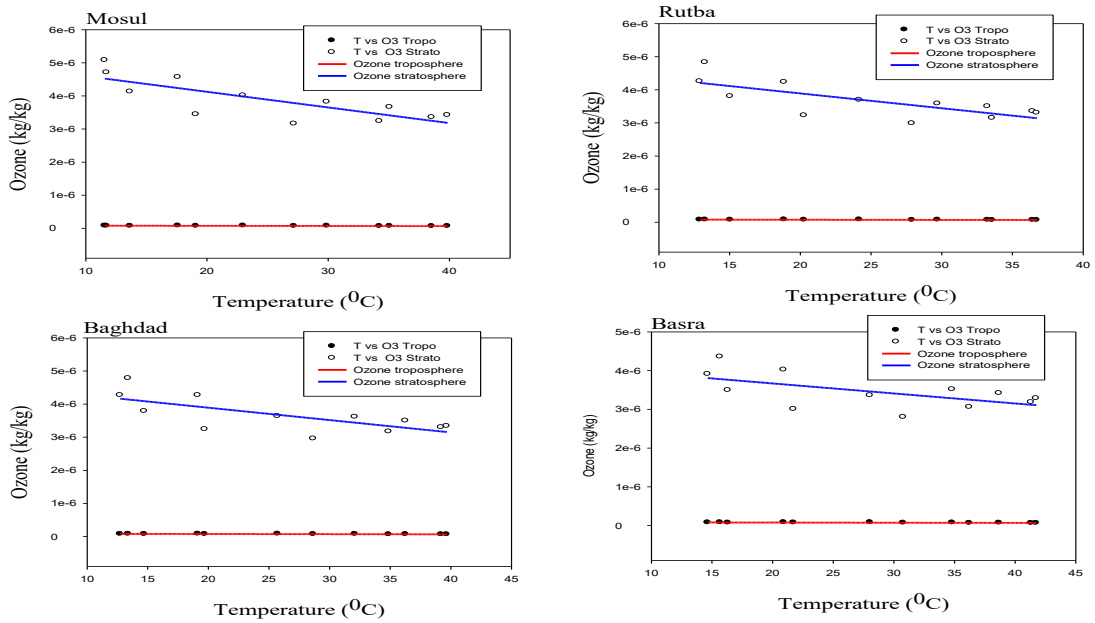
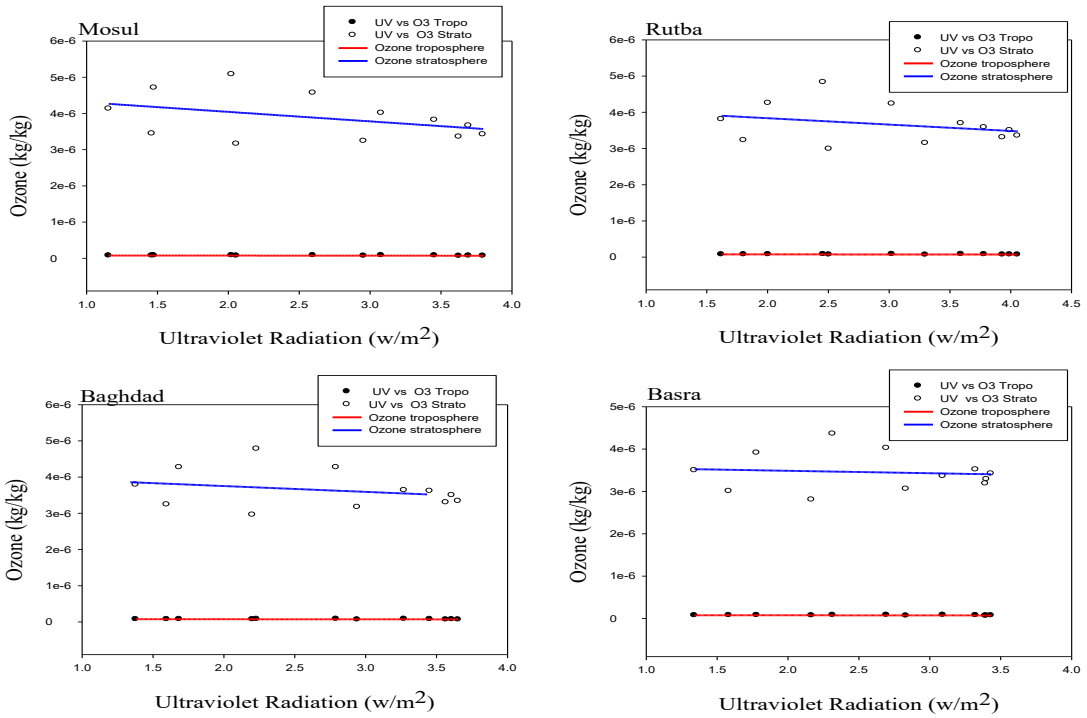


Figure 18. The monthly relationship between meteorological factors and ozone spearman coefficient (O_3 Troposphere and O_3 Stratosphere) for 3 years over Iraq.

The stratosphere and troposphere exhibit different behaviors in the interaction between ultraviolet (UV) energy and O_3 concentrations. UV radiation and stratospheric O_3 are clearly inversely correlated; as UV levels rise, O_3 concentrations fall, mostly as a result of photodissociation mechanisms. Because its synthesis is controlled by intricate photochemical interaction include precursor pollutants like NOx and VOCs rather than UV radiation alone, tropospheric O_3 does not show a substantial direct link with UV radiation.

International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 12 No. 2, 2026
https://www.theaspd.com/ijes.php

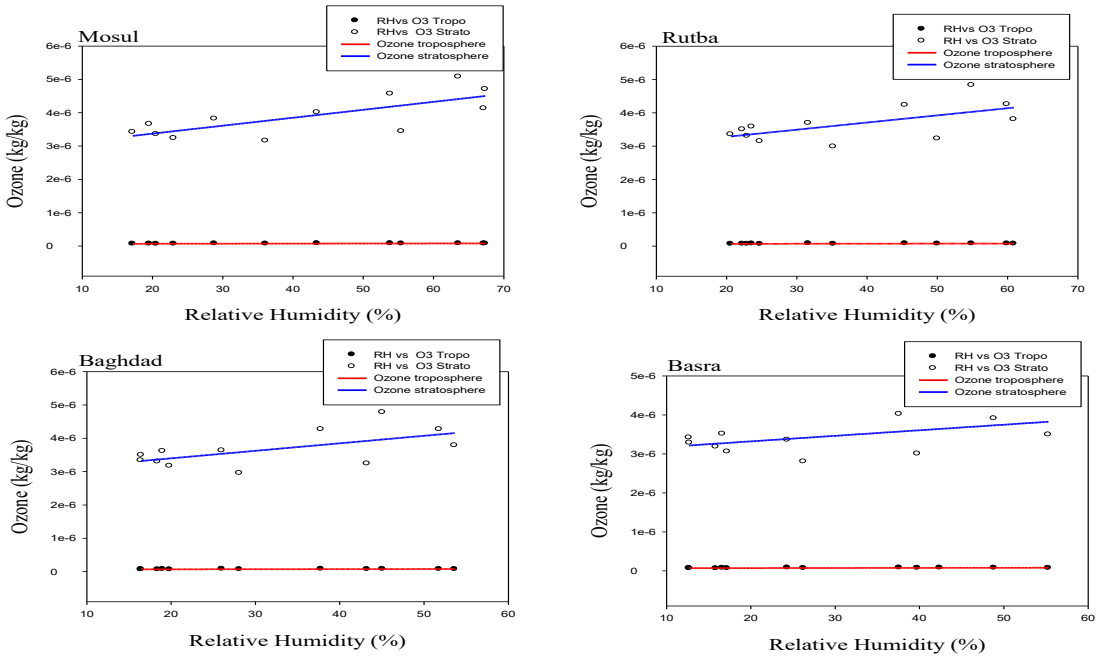


Followed Figure 18.

In the troposphere and stratosphere of all the cities under study (Mosul, Rutba, Baghdad, and Basra), the correlation between RH and O_3 concentrations shows unique patterns. The findings show a weak but steady positive correlation between stratospheric O_3 and RH, with O_3 concentrations generally rising slightly as RH rises. The vertical movement and distribution of O_3 in the higher layers of the atmosphere are influenced by atmospheric dynamics and moisture-related processes, which may be the cause of this behavior.

Tropospheric O_3, on the other hand, has extremely low concentrations and no discernible relationship with RH. The very consistent trend indicates that tropospheric O_3 fluctuation is not only controlled by RH. Rather, in addition to SR, complicated photochemical reactions involving precursor pollutants like nitrogen oxides (NOx) and volatile organic compounds (VOCs) are what mostly control tropospheric O_3. Overall, the results point to a small positive correlation between RH and stratospheric O_3, indicating the importance of air transport and environmental factors rather than direct chemical regulation, and a limited direct impact on tropospheric O_3.

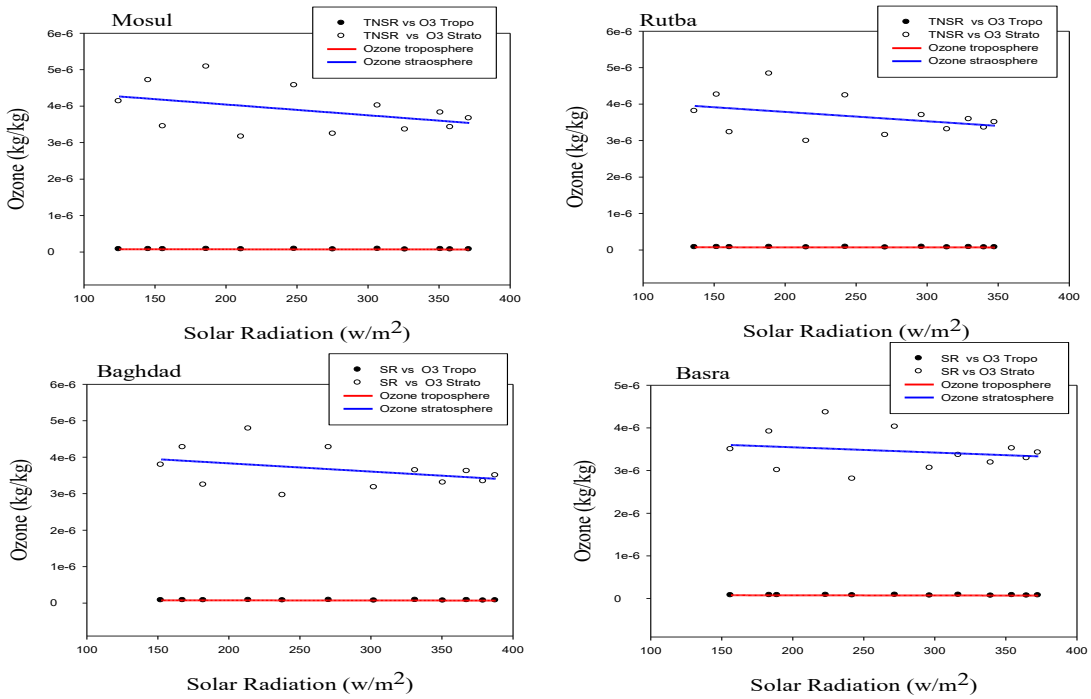
International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 12 No. 2, 2026
https://www.theaspd.com/ijes.php



Followed Figure 18.

The relationship between solar radiation and O_3 concentration in the troposphere and stratosphere at four significant Iraqi stations as Mosul, Rutba, Baghdad, and Basra is depicted in the image. The nature of the physical and chemical mechanisms controlling O_3 distribution in the atmosphere is reflected in the temporal and spatial variance in this relationship. The graph's downward slope shows that stratospheric O_3, which makes up the majority of the O_3 column overall, shows a minor decrease tendency with rising solar radiation at all sites. Higher solar radiation levels, particularly in the ultraviolet spectrum, can speed up the photodegradation of O3 molecules or change the dynamic equilibrium of the atmosphere, which can occasionally cause a decrease in the relative concentration of O3. However, this relationship is still non-linear and is influenced by other factors such as vertical and horizontal atmospheric transport. Conversely, O3 concentrations in the troposphere are far lower than those in the stratosphere and either stay relatively steady or slightly decrease as solar energy increases. This demonstrates how local chemical factors have a bigger impact than sunlight. Tropospheric O3 formation is primarily caused by complex chemical reactions between nitrogen oxides and volatile organic compounds in the presence of sunlight. Decomposition mechanisms, however, may limit or balance this process, producing values that are rather stable. The Mosul station's data exhibit significant regional variance, indicating its susceptibility to changing climatic factors such air masses and seasonal variations. In contrast, the Rutba station exhibits more consistent behavior due to its desert environment and lack of direct human influenceBaghdad, on the other hand, has a discernible level of variability that reflects the impact of urban activity and pollution emissions on chemical processes in the troposphere. The coastal environment and high humidity, which may change the speeds of chemical reactions and pollutant transmission, are likely responsible for Basra's slightly lower levels and relatively more constant behavior.

International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 12 No. 2, 2026
https://www.theaspd.com/ijes.php



Followed Figure 18.

Table 2. The relationship between meteorological factors and ozone over Iraqi Stations for the 3 years 2005, 2015, and 2025.

Stations	Spearman rho			Simple linear regression	
	Parameter	R	Correlation degree	P-value	Interpretation of relationship
Mosul	$O_{3\ Troposphere}$ vs T	-0.678	Middle inverse	0.0001<	Linear
	$O_{3\ Stratosphere}$ vs T	-0.776	High inverse	0.0001<	Linear
	$O_{3\ Troposphere}$ vs UV	-0.315	Low inverse	0.0001<	Linear
	$O_{3\ Stratosphere}$ vs UV	-0.399	Low inverse	0.0001<	Linear
	$O_{3\ Troposphere}$ vs RH	0.580	Middle positive	0.0001<	Linear
	$O_{3\ Stratosphere}$ vs RH	0.692	Middle positive	0.0001<	Linear
	$O_{3\ Troposphere}$ vs SR	-0.29	Low inverse	0.0001<	Linear
	$O_{3\ Stratosphere}$ vs SR	-0.399	Low inverse	0.0001<	Linear
Rutba	$O_{3\ Troposphere}$ vs T	-0.699	Middle inverse	0.0001<	Linear
	$O_{3\ Stratosphere}$ vs T	-0.713	High inverse	0.005	Linear
	$O_{3\ Troposphere}$ vs UV	-0.301	Low inverse	0.0001<	Linear
	$O_{3\ Stratosphere}$ vs UV	-0.273	Low inverse	0.0001<	Linear
	$O_{3\ Troposphere}$ vs RH	0.469	Middle positive	0.005	Linear
	$O_{3\ Stratosphere}$ vs RH	0.497	Middle positive	0.0001<	Linear
	$O_{3\ Troposphere}$ vs SR	-0.252	Low inverse	0.0001<	Linear
	$O_{3\ Stratosphere}$ vs SR	-0.301	Low inverse	0.0001<	Linear
Baghdad	$O_{3\ Troposphere}$ vs T	-0.734	High inverse	0.0001<	Linear
	$O_{3\ Stratosphere}$ vs T	-0.657	Middle inverse	0.0001<	Linear
	$O_{3\ Troposphere}$ vs UV	-0.350	Low inverse	0.0001<	Linear
	$O_{3\ Stratosphere}$ vs UV	-0.175	Very low inverse	0.0001<	Linear
	$O_{3\ Troposphere}$ vs RH	0.538	Middle positive	0.0001<	Linear
	$O_{3\ Stratosphere}$ vs RH	0.476	Middle positive	0.0001<	Linear

	$O_{3\ Troposphere}$ vs SR	-0.336	Low inverse	0.0001<	Linear
	$O_{3\ Stratosphere}$ vs SR	-0.273	Low inverse	0.0001<	Linear
Basra	$O_{3\ Troposphere}$ vs T	-0.727	High inverse	0.0001<	Linear
	$O_{3\ Stratosphere}$ vs T	-0.552	Middle inverse	0.0001<	Linear
	$O_{3\ Troposphere}$ vs UV	-0.315	Low inverse	0.093	Non-Linear
	$O_{3\ Stratosphere}$ vs UV	-0.0420	Very low inverse	0.084	Non-Linear
	$O_{3\ Troposphere}$ vs RH	0.510	Middle positive	0.0001<	Linear
	$O_{3\ Stratosphere}$ vs RH	0.336	Low positive	0.0001<	Linear
	$O_{3\ Troposphere}$ vs SR	-0.322	Low inverse	0.0001<	Linear
	$O_{3\ Stratosphere}$ vs SR	-0.140	Very low inverse	0.0001<	Linear

3.10 Limitations and Future Suggestions

Limitations:

The study's reliance on a particular time period may have limited its ability to capture long-term shifts in the link between stratospheric and tropospheric ozone.

Accuracy of Satellite Data: Due to cloud or dust conditions in Iraq's atmosphere, satellite readings may contain mistakes or uncertainties.

Absence of Ground-Based Monitoring Stations: The validation of satellite data is impacted by the scarcity of ground-based ozone monitoring data in Iraq.

influence of additional climatic variables, such as dust and wind speed, which were not included in the study.

Spatial Variability: Because different parts of Iraq have distinct pollution sources and climates, the connection between stratospheric and tropospheric ozone may differ.

Insufficient analysis of direct vertical transit

Specialized dynamic models were not used to examine Stratosphere-Troposphere Exchange Events.

Future Recommendations:

Do a long-term investigation: Analyze long-term ozone climatic patterns over Iraq using data from several decades.

Combine satellite and ground-based observational data: To increase the precision of findings, create a national ozone monitoring network.

Examine seasonal effects: Examine how tropospheric and stratospheric ozone relate to one another throughout the year.

Utilize sophisticated chemical and climatic models: To comprehend the processes of ozone movement between atmospheric layers, use chemical transport models like WRF-Chem or GEOS-Chem.

Examine the effects of climate change: Determine how ozone dynamics over Iraq are affected by rising temperatures and climate change.

Examine stratospheric-tropospheric transport events: Pay particular attention to locating and assessing ozone transport events from the stratosphere to the troposphere and how they affect air quality.

Add more pollutants to the study: Examine how ozone interacts with aerosols, carbon monoxide (CO), and nitrogen oxides (NOx).

Regional comparison: To comprehend the regional features of ozone distribution, compare Iraq's results with those of nearby Middle Eastern nations.

4 Conclusions

The country's northern regions have higher TCO concentrations, whereas the southern regions have lower concentrations. This pattern is caused by large-scale atmospheric circulation, particularly the Brewer–Dobson circulation, which transports ozone-rich air from tropical regions into higher latitudes. Also Stratospheric O_3 levels are rising in northern Iraq and falling in southern Iraq, following a very consistent and gradual pattern. This demonstrates the effects of large-scale atmospheric processes such as air mass movements and jet streams. In contrast, tropospheric O_3 shows an uneven distribution and the formation of closed regions with varying high and low values. This demonstrates how susceptible it is to local factors

like pollution emissions, human activity, and photochemical reactions. As The three-year spatiotemporal investigation of RH over Iraq shows a clear and consistent spatial gradient, with greater humidity levels centered in the country's north and progressively declining in its center and south. Compared to 2005 and 2025, 2015 has comparatively greater humidity levels, indicating a period of increased moisture availability. However, 2025 exhibits a widespread drop in RH, particularly over central and southern Iraq, which may be related to rising temperatures and increased evaporation rates. From 2005 to 2025, there was a steady rise in SR and T. Iraq's western and southern regions have the highest values. Over time, high-radiation areas grew. Numerous geographical and climatic conditions affected distribution. TCO, O_3 (troposphere and stratosphere) highest values are found in winter and early spring (January–March). It gradually decreases, reaching its lowest point in autumn (September–October). Then it rises again with the onset of winter. T, SR, UV it gradually rises from winter, peaking in summer (July–August). Then it decreases towards winter. Basra and Baghdad record the highest T, while Mosul experiences relatively lower T. RH highest values are found in winter (December–February). It decreases significantly in summer (June–August). Mosul has the highest humidity, and Basra the lowest, in summer. Tropospheric O_3 is a harmful pollutant that affects human health and the ecosystem, while stratospheric O_3 acts as a protective shield, protecting the Earth's surface from UV. There is a significant inverse correlation between (T, UV, SR) and O_3 (stratospheric and troposphere) over Iraq. A positive relationship exists between RH and O_3 (stratospheric and troposphere). The relationship between SR and O_3 concentration in both layers is not a simple, direct one, but rather the result of a complex interplay between radioactive, chemical, and dynamic processes in the atmosphere.

Stratospheric O_3 clearly dominates in terms of quantity and impact, while tropospheric O_3 remains more closely linked to human activities and local environmental conditions. As well as the highest inverse correlation between T and stratosphere O_3 in the Mosul station was -0.776 and the lowest inverse correlation between UV and stratosphere O_3 in the Basra was -0.04. In the stratosphere, the relationship between O_3 and T is linked to the absorption of (UV), which leads to air heating. However, increased T accelerates the chemical reactions that break down O_3 (such as the reaction of atomic oxygen with O_3). In the case of Mosul, the high value (-0.776) can be explained by these factors: As the T rises in the stratosphere, the chemical reactions that break down O_3 increase. O_3 concentration decreases. Mosul is located in a region affected by the movement of air masses and eddies (such as jet streams). Optimal air sometimes descends from higher layers (relatively ozone-poor but warm) or cold, ozone-rich air rises. In summer, high T cause O_3 to break down faster, while in winter, low T led to a greater accumulation of O_3. This reinforces the inverse relationship over time. The effect of UV: when O_3 levels decrease, more UV radiation penetrates the stratosphere. The weak relationship between stratospheric O_3 and UV in Basra is due to the influence of surface factors such as tropospheric O_3, airborne particles, and high humidity, which play an important role in modifying the intensity of UV reaching the surface, thus reducing its direct dependence on the concentration of stratospheric O_3.

Acknowledgment

I gratitude to Mustansiriyah University for providing scientific support for this study and to the European Center Medium Weather Forecasts (ECMWF) for providing the data utilized in this investigation.

References

[1] J. Lelieveld and F. J. Dentener, "What controls tropospheric ozone?," *Journal of Geophysical Research: Atmospheres,* vol. 105, pp. 3531-3551, 2000.

[2] M. P. Chipperfield, S. Bekki, S. Dhomse, N. R. Harris, B. Hassler, R. Hossaini, *et al.*, "Detecting recovery of the stratospheric ozone layer," *Nature,* vol. 549, pp. 211-218, 2017.

[3] I. H. Abdulkareem, A. D. Kosaj, T. A. Abbas, O. T. Al-Taai, Z. M. Abbood, and A. S. Hassan, "Nano impact of rainfall on soil temperature and soil moisture in Iraq for the period 2000-2022."

[4] Z. M. Abbood and O. T. Al-Taai, "Calculation of absorption and emission of thermal radiation by clouds cover," *ARPN Journal of Engineering and Applied Sciences,* vol. 13, pp. 9446-9456, 2018.

[5] Z. M. Abbood and O. T. Al-Taai, "Data analysis for cloud cover and rainfall over Baghdad city, Iraq," 2020.

[6] A. Banerjee, A. C. Maycock, A. T. Archibald, N. L. Abraham, P. Telford, P. Braesicke, *et al.*, "Drivers of changes in stratospheric and tropospheric ozone between year 2000 and 2100," *Atmospheric Chemistry and Physics,* vol. 16, pp. 2727-2746, 2016.

[7] Z. M. Abbood, M. H. Al-Jiboori, and O. T. Al-Taai, "Temporal and spatial analysis of particulate matter concentrations in Iraq," in *IOP Conference Series: Earth and Environmental Science*, 2023, p. 012018.

[8] Z. M. Abbood, O. T. Al-Taai, and W. G. Nassif, "Impact of wind speed and direction on low cloud cover over Baghdad city," *Current Applied Science and Technology,* pp. 590-600, 2021.
[9] O. T. Al-Taai and Z. M. Abbood, "Analysis of convective available potential energy by convective and total precipitation over Iraq," *Indian Journal of Ecology,* vol. 47, pp. 263-269, 2020.
[10] O. Al-Taai, Z. Abbood, and J. Kadhum, "Determination stability potential energy of thunderstorms for some severe weather forecasting cases in Baghdad city," *Journal of Green Engineering,* vol. 11, pp. 779-794, 2021.
[11] O. Al-Taai, S. A. Hashim, W. G. Nassif, and Z. M. Abbood, "Interference between total solar radiation and cloud cover over Baghdad City," in *Journal of Physics: Conference Series*, 2021, p. 012070.
[12] S. Payra, P. Gupta, A. Sarkar, R. Bhatla, and S. Verma, "Changes in tropospheric ozone concentration over Indo-Gangetic Plains: the role of meteorological parameters," *Meteorology and Atmospheric Physics,* vol. 134, p. 96, 2022.
[13] Y.-C. C. V. Kethireddy, et al., "Application of geostatistical interpolation methods to explore the spatial distribution of tropospheric ozone pollution using satellite observations," Environmental Monitoring and Assessment, vol. 186, no. 10, pp. 6683–6696, 2014.
[14]] K.-L. Chang, S. Guillas, and V. E. Fioletov, "Mapping global total ozone using spatial interpolation techniques: Kriging and SPDE approaches," Atmospheric Measurement Techniques, vol. 8, no. 9, pp. 3663–3678, 2015.
[15] I. Gomez-Leal, M. Garcia, and J. Gonzalez, "The role of ozone in the climate system and its influence on Earth's habitability," Science of the Total Environment, vol. 672, pp. 1023–1032, 2019.
[16] X. Li, Y. Li, Q. Ma, J. Chen, F. Chen, X. Yang, *et al.*, "Spatial and temporal variation of total and tropospheric ozone columns over China," *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences,* vol. 42, pp. 113-118, 2019.
[17] E. Boleti, C. Hueglin, S. K. Grange, A. S. H. Prévôt, and S. Takahama, "Multi-temporal analysis of ozone trends and driving factors in Europe," Atmospheric Chemistry and Physics, vol. 20, no. 15, pp. 9349–9365, 2020.
[18] A. R. Ravishankara, P. A. Newman, and J. S. Daniel, "The role of climate in the recovery of the ozone layer," Nature Geoscience, vol. 13, no. 6, pp. 411–419, 2020.
[19] A. N. Al-Ataby, A. J. Al-Ghaban, and M. T. Al-Zuhairi, "Temporal variations of total ozone column over selected Iraqi stations using OMI data (2003–2015)," Iraqi Journal of Science, vol. 62, no. 12, pp. 4419–4432, 2021.
[20] S. A. Hashim, J. H. Kadhum, Z. M. Abbood, O. T. Al-Taai, and W. G. Nassif, "Determination of the dynamics of thunderstorms through the dry adiabatic lapse rate and environmental lapse rate," *Nature Environment and Pollution Technology,* vol. 22, pp. 1447-1455, 2023.
[21] W. G. Nassif, O. T. Al-Taai, and Z. M. Abbood, "The influence of solar radiation on ozone column weight over Baghdad city," in *IOP Conference Series: Materials Science and Engineering*, 2020, p. 072089.
[22] W. G. Nassif, O. T. Al-Taai, A. J. Mohammed, and H. K. AL-Shamarti, "Estimate probability distribution of monthly maximum daily rainfall of Iraq," in *Journal of Physics: Conference Series*, 2021, p. 012078.
[23] F. W. Breyfogle III, *Implementing six sigma: smarter solutions using statistical methods*: John Wiley & Sons, 2003.
[24] J. C. De Winter, S. D. Gosling, and J. Potter, "Comparing the Pearson and Spearman correlation coefficients across distributions and sample sizes: A tutorial using simulations and empirical data," *Psychological methods,* vol. 21, p. 273, 2016.
[25] S. Zubaidi, I. Abdulkareem, K. Hashim, H. Al-Bugharbee, H. Ridha, S. Gharghan, *et al.*, "Hybridised artificial neural network model with slime mould algorithm: a novel methodology for prediction of urban stochastic water demand. Water 12 (10): 2692," *DOI: https://doi. org/10.3390/w12102692,* 2020.
[26] I. H. ABDULKAREEM, "TEMPERATURE AND PRECIPITATIONS TRENDS FOR HILLA CITY USING NOAA/ESRL GRIDDED HIGH-RESOLUTION DATA," *Journal of Engineering Science and Technology,* vol. 15, pp. 1883-1894, 2020.
[27] W. G. Nassif, I. K. Al-Ataby, O. T. Al-Taai, and Z. M. Abbood, "Impact of soil temperature and precipitation on vegetation cover over selected stations in Iraq," *Asian Journal of Water, Environment and Pollution,* vol. 21, pp. 25-33, 2024.
[28] H. K. Preisler, S. S. Zhong, A. Esperanza, L. Tarnay, and J. Kahyaoglu-Koracin, "A Statistical Model for Forecasting Hourly Ozone Levels During Fire Season," *Developments in Environmental Science,* vol. 8, pp. 551-565, 2008.