International Journal of Future Engineering Innovations

Evaluating the Air Quality Index Using Sentinel-5P and GIS-Based IDW Interpolation with Fuzzy AHP Over Kirkuk Governorate in June 2025

Hiba M Sami
Department of Environment and Pollution Engineering Techniques, Technical Engineering College of Kirkuk, Northern Technical University, Kirkuk, Iraq

* Corresponding Author: **Hiba M Sami**

Article Info

ISSN (online): 3049-1215
Impact Factor (RSIF): 8.25
Volume: 03
Issue: 03
May-June 2026
Received: 07-03-2026
Accepted: 04-04-2026
Published: 06-05-2026
Page No: 45-52

Abstract
One of the key issues related to the environment in terms of human health and sustainable development in urban and industrial areas is air pollution. The purpose of this research is to approximate the Air Quality Index (AQI) in Kirkuk Governorate based on satellite remote sensing data on Sentinel-5P and Geographic Information Systems (GIS). Six atmospheric pollutants such as methane (CH_4), carbon monoxide (CO), formaldehyde (HCHO), nitrogen dioxide (NO_2), ozone (O_3) and sulfur dioxide (SO_2) were examined. The point features were created to take care of missing values and gaps between spatial features of the raster datasets retrieved by Sentinel-5P. Inverse Distance Weighting (IDW) interpolation was used to come up with continuous pollutant concentration surfaces. The relative weight of each pollutant in the estimation of AQI was identified using the Fuzzy Analytic Hierarchy Process (Fuzzy AHP). The end weighted AQI map gives a complete spatial coverage of air quality conditions in Kirkuk Governorate. The last Air Quality Index (AQI) map will categorize the study region to two major air quality classes. The analysis indicates that the area has only 33.25 km^2 (3.05%) of area with acceptable air quality, with most of the area, 1057.68 km^2 (96.95%), being poor or unhealthy. These results show that a large part of the territory of the study is under the influence of massive air pollution deterioration.

DOI: https://doi.org/10.54660/IJFEI.2026.3.3.45-52

Keywords: AQI, Pollution Risk, GIS, IDW Interpolation, Fuzzy AHP

1. Introduction

One of the primary causes of health issues in cities is air pollution (Ibrahim & Khidhir, 2023) [9]. Among the most serious environmental issues of the 21 st century, air pollution has far-reaching implications on human health, climate change, and sustainable ecosystems (Gul & Das, 2023) [8]. Millions of premature deaths per year are attributable to exposure to ambient air pollution, which is closely linked to respiratory and cardiovascular diseases, particularly in urban and industrial areas (Santos & Parés, 2025) [21]. Air pollutants including nitrogen dioxide (NO2), sulfur dioxide (SO2), ozone (O3), carbon monoxide (CO), formaldehyde (HCHO), and methane (CH4) are known to be the biggest contributors towards air quality deterioration and environmental stress (Garajeh *et al*., 2023) [7].

Traditional air quality monitoring schemes are predominantly ground-based stations that give precise measurements at particular points (Brauer *et al*., 2019) [2]. Yet, in most of the developing world, as is true in some areas of the Middle East, monitoring networks are either few and far between, or not well distributed to capture spatial variability in pollution levels (Bagkis *et al*., 2025) [1]. This has created gaps in the coverage of large areas making it hard to effectively manage the environment and formulate policies.

Satellite remote sensing has become an effective substitute of large-scale monitoring of the atmosphere (Mahmood Ajaj *et al*., 2023) [14]. The Sentinel-5 Precursor (Sentinel-5P) satellite, which carries the Tropospheric Monitoring Instrument (TROPOMI), offers high-resolution measurements of atmospheric trace gases, with almost daily global coverage (Lindqvist *et al*., 2024) [13]. The accuracy of Sentinel-5P products in assessing air quality of regions and cities, specifically NO2, SO2, and CO, has been validated by many studies (Santos & Parés, 2025) [21].

Geographic Information Systems (GIS) are crucial in processing, analyzing, and visualizing the environment data collected by satellites (Mohammad Aman Ullah Sunny, 2024) [16]. Spatial interpolation methods (IDW) of GIS have been extensively used to interpolate pollutant concentrations in unmeasured locations and to create continuous maps of surfaces (Elumalai *et al*., 2017) [6]. IDW is fairly very simple and computationally efficient but its performance is affected by density and spatial distribution of data (Sajid *et al*., 2013) [20].

Moreover, the multi-criteria decision analysis (MCDA) methods are beginning to find application in the environmental assessment field to incorporate various variables as composite indicators (El *et al*., 2018) [5]. One of the most popular methods of MCDA has been the Analytic Hierarchy Process (AHP) and has been successful in giving relative weights to air pollutants in terms of their health and environmental effects (Nozad & Shareef, 2024) [18].

The above-mentioned features of Kirkuk Governorate include intensive industrial operations, oil production plants, growing towns and cities, and large traffic systems, which are the causes of high air pollution rates. Although it is of great environmental significance, extensive spatial analyses of air quality in the area are still lacking. Thus, the paper will combine the Sentinel-5P satellite information, GIS-driven IDW and AHP weighting to approximate the Air Quality Index (AQI) in Kirkuk Governorate. The suggested method offers an effective and affordable system of monitoring air quality and environmental decision making in the region.

2. Study Area

Kirkuk Governorate is in northern Iraq, to be found in the transitional zone between the mountainous land of the Kurdistan Region and the central Iraqi planes (Rasoul, 2017) [19]. The governorate is situated some 240 km north of Baghdad and is surrounded by Erbil Governorate to the north, Sulaymaniyah Governorate to the east and Salah ad-Din Governorate to the south and west. The region, which is located in the area of approximately 9,600-10,000 km2 has predominantly flat plains fragmented with low hills and seasonal valleys. It has a semi-arid climate with hot and dry summers and mild to moderately cold winters with seasonal rainfall which sustains agricultural activities.

Kirkuk Governorate is administratively divided into four main districts: Kirkuk District, Daquq District, Hawija District and Dibbis District. Kirkuk District is home to the provincial capital of Kirkuk city that forms the political, economic, and administrative center of the governorate. The Daquq District is located south of the capital, and it is semi-urban and mixed agricultural in nature. Hawija District dominantly rural, is found in the southwestern region of the governorate with most of the people relying on farming activities. Dibbis District is located to the northwest of Kirkuk city and it houses significant infrastructure such as oil-based facilities and irrigation systems. All these districts together form the administrative government and developmental planning of the governorate.

Kirkuk is an important economic, political and cultural city in Iraq. It is also among the most significant oil producing regions in the country; it is also home to some of the largest oil fields which have over the years generated substantial national income. Kirkuk has become a strategic location nationally and regionally due to the fact that the country is endowed with giant petroleum reserves. Besides oil, agriculture is also a significant contributor in the local economy especially in the production of wheat and barley. In terms of culture, Kirkuk is a culturally diverse environment where Kurds, Arabs, Turkmens, and other groups live in the area. Politically, the governorate is a strategic territory, since it is a disputable territory and an element of general federal-regional relationships in Iraq.

Kirkuk suffers severe environmental problems especially the pollution despite its economic benefits. One of the main issues is air pollution, which is to a great extent caused by oil mining, gas flaring, industrial emissions, and vehicle exhaust. The emissions these sources emit into the air are sulfur dioxide, nitrogen oxides, carbon monoxide, and particulate matter that have harmful impacts on the quality and health of the air and people. The problem of soil and water pollution is also acute because the oil spill, industrial waste, and inefficient waste management activities endanger agricultural fields and underground water sources. Also, the high rate of urbanization and lack of environmental infrastructure have exerted strain on natural resources. The solution to these environmental issues should be a key to realizing sustainable development in Kirkuk Governorate.

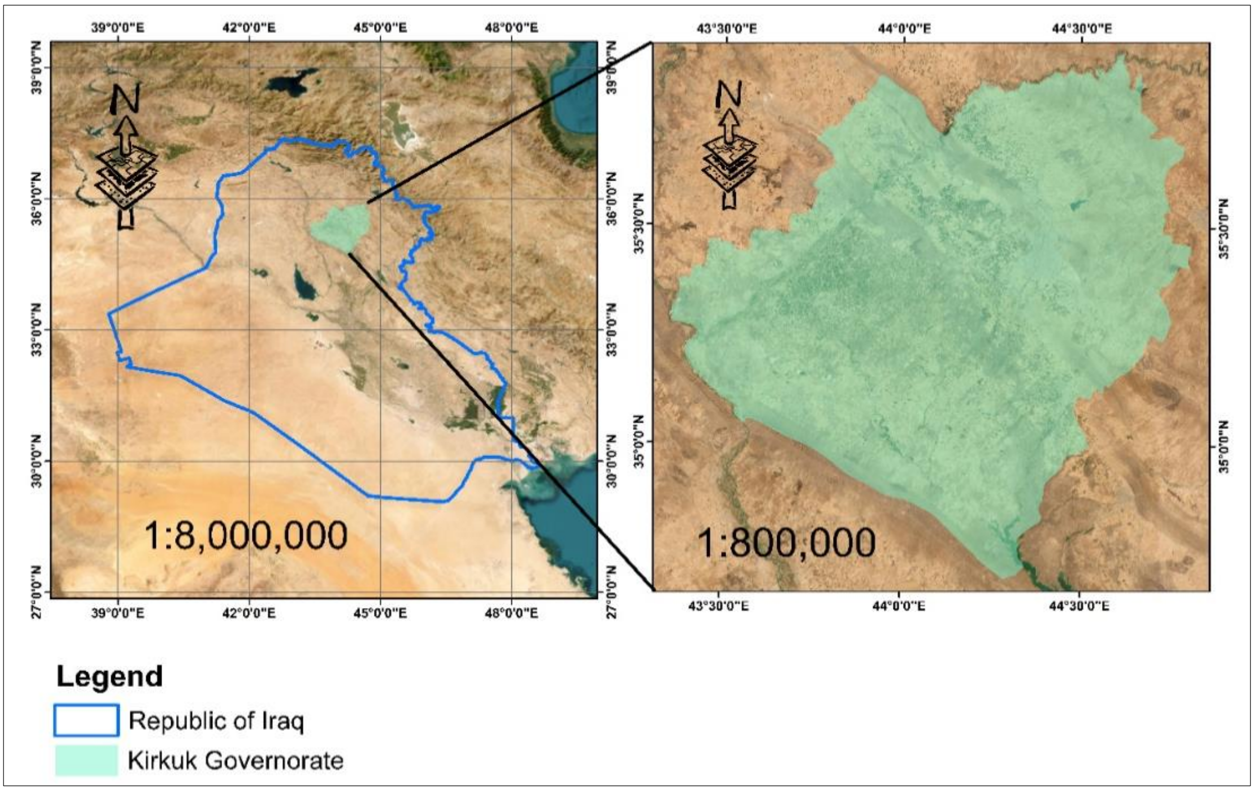


Fig 1: The study region (Kirkuk Governate)

3. Data Sources

3.1. Sentinel-5P Satellite Data

Sentinel-5P, operated by the European Space Agency (ESA), is dedicated to monitoring atmospheric composition (Martin, C., Amigo, J. M., & Castro, 2023) [15]. The Tropospheric Monitoring Instrument (TROPOMI) onboard Sentinel-5P provides daily global coverage of key air pollutants (Morozova *et al*., 2022) [17].

In this study, raster datasets for the following pollutants were obtained:

- Methane (CH_4)
- Carbon Monoxide (CO)
- Formaldehyde (HCHO)
- Nitrogen Dioxide (NO_2)
- Ozone (O_3)
- Sulfur Dioxide (SO_2)

All the datasets were downloaded in the raster format and analyzed using the GIS software. Administrative boundary data of Kirkuk Governorate was used to clip and mask the satellite datasets. The unification of the coordinate reference systems was done to provide spatial consistency.

4. Methodology

The research is performed in a framework of remote sensing, spatial analysis and multi-criteria decision-making. The current research methodology includes AQI calculation, mapping of pollutants, spatial interpolation, assigning weights using AHP, and data processing. Figure 2 shows the methodology of this research.

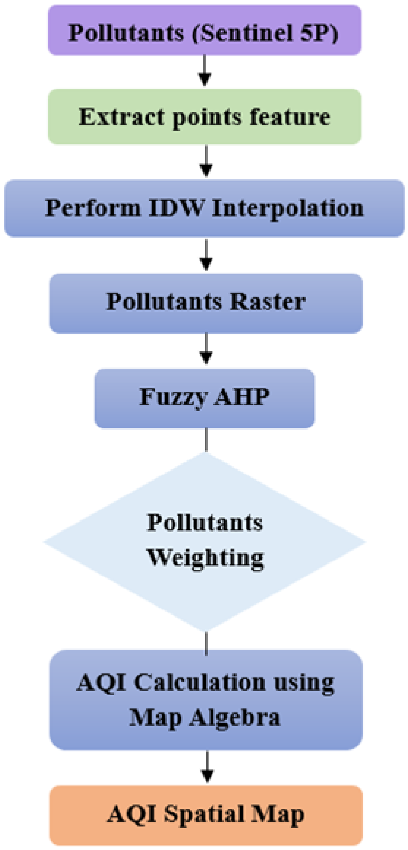


Fig 2: Flowchart of generating AQI spatial map

4.1. Data Preprocessing

In order to restrict the analysis to the research area, Sentinel-5P raster data initially extracted to the Kirkuk Governorate's administrative boundary. The quality control criteria which arrived with the satellite products were used to filter out invalid pixels, noise, and cloud-contaminated data (Singh & Pal, 2025) [22].

subsequently that, each pollutant raster was converted into spatial point features, each of which indicates a pixel center and the concentration value that corresponds with it. This raster-to-point conversion helps with missing or irregular data patterns and makes spatial interpolation easier.

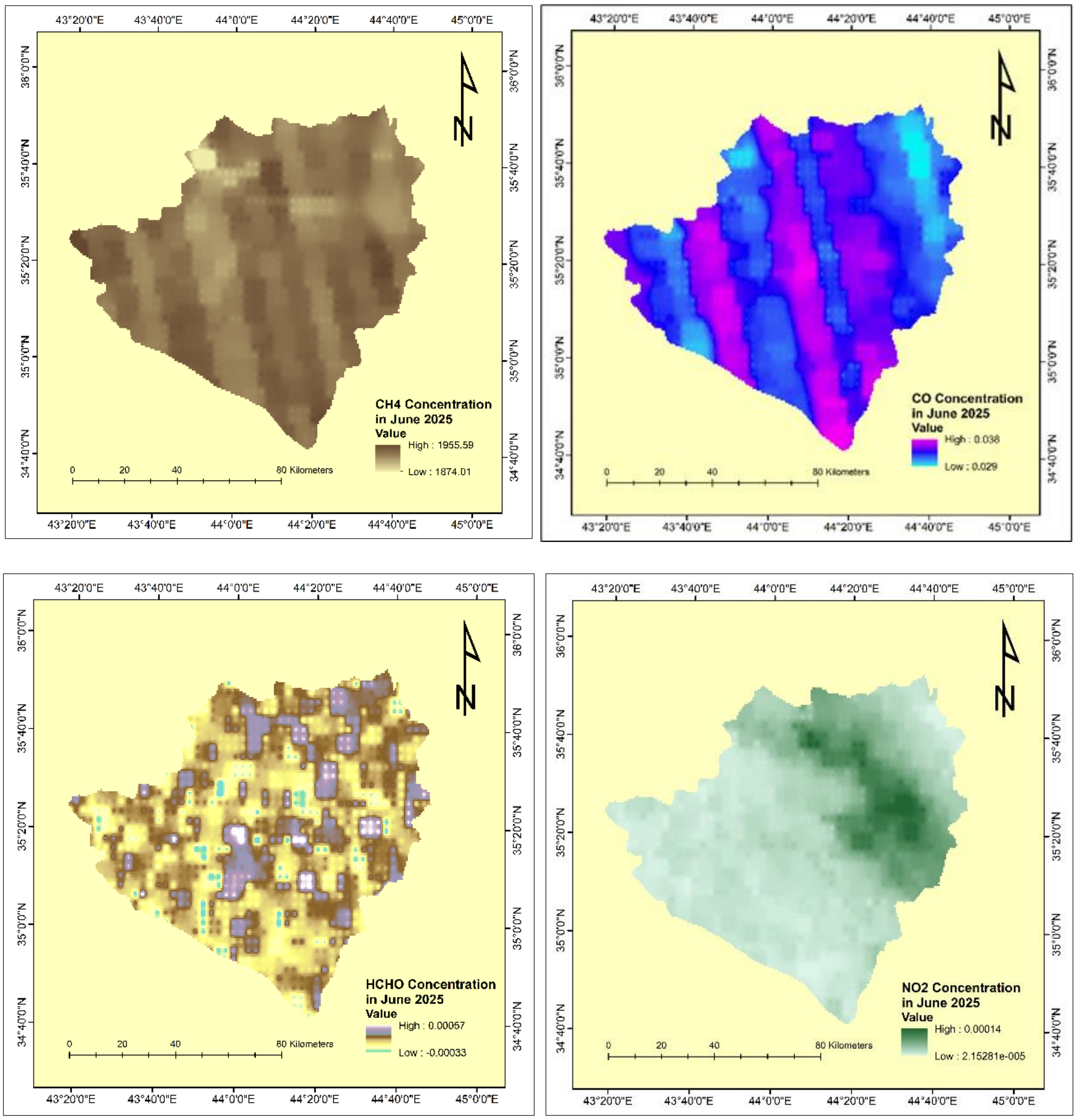
4.2. IDW Interpolation

Pollutant concentration estimations at unsampled locations were created using Inverse Distance Weighting (IDW) (Choi & Chong, 2022) [3]. The method is predicated on the idea that nearby points have a greater influence than those who are further away (Ikechukwu *et al*., 2017) [10]. IDW is a widely used tool in air quality research due to its ease of use and efficiency (Jumaah *et al*., 2019) [11].

Each pollutant was interpolated separately, and in order to increase accuracy, ideal parameters like power value and search radius were chosen through experimental testing.

4.3. Pollutant Map Generation

The IDW results yielded six continuous surface maps of the spatial distribution of CH_4, CO, HCHO, NO_2, O_3 and SO_2. The visual examination and statistical evaluation of these maps were done to demonstrate spatial consistency. All the layers of pollutants were then given a standard scale of between 0 and 1 so as to be integrated into the AQI model. The spatial distribution of six pollutants is presented in a form of concentration in Figure 3.



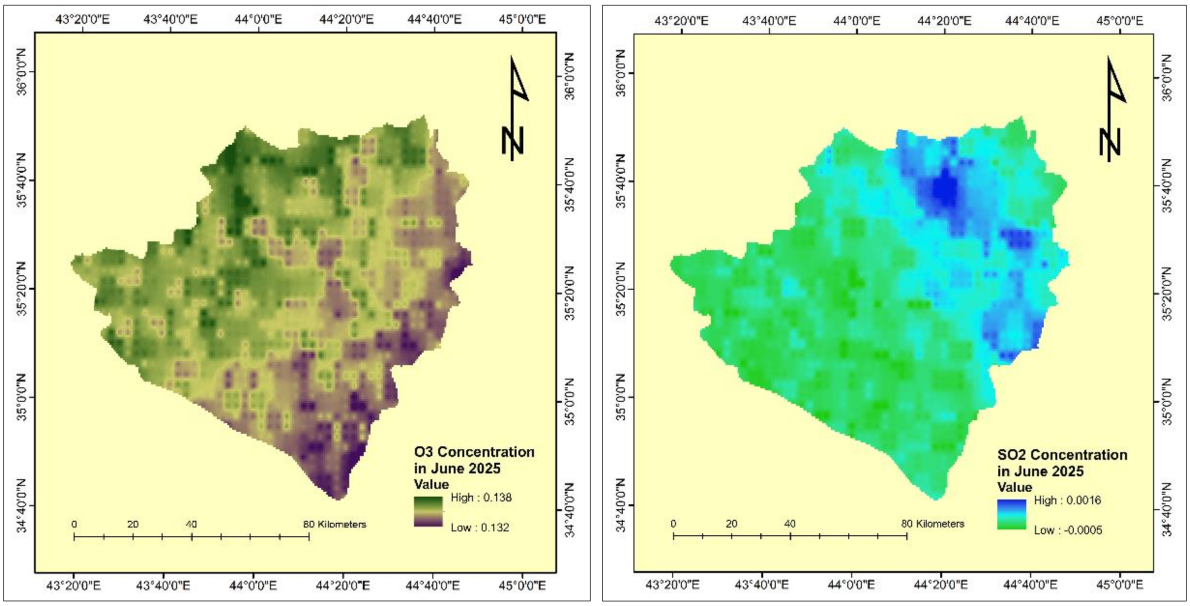


Fig 3: Pollutants concentration in June 2025, (a) CH_4, (b) CO, (c) HCHO, (d) NO_2, (e) O_3, (f) SO_2

4.4. Fuzzy AHP weights

Analytic hierarchy Process (AHP) was used to provide relative weights to the various pollutants in terms of their effects on human health and the environment (Chompook *et al*., 2023) [4]. Expert judgment and literature evidence were used to make a pairwise comparison matrix (Kou *et al*., 2016) [12].

Eigenvector analysis was performed to derive priority weights, and the Consistency Ratio (CR) was calculated to validate the reliability of comparisons. Only matrices with CR values below 0.10 were accepted. The following are the calculation steps with required equations (1-11) of assigned weights by Fuzzy AHP.

(1) Triangular Fuzzy Number (TFN)

$$ã\_ij = (l_{ij}, m_{ij}, u_{ij}),\ l_{ij} \leq m_{ij} \leq u_{ij} \quad (1)$$

(2) Fuzzy Pairwise Comparison Matrix

$$\bar{A} = \begin{bmatrix} \bar{a}_{11} & \cdots & \bar{a}_{1n} \\ \vdots & \ddots & \vdots \\ \bar{a}_{n1} & \cdots & \bar{a}_{nm} \end{bmatrix} \quad (2)$$

$$ã_{ji} = (1/u_{ij}, 1/m_{ij}, 1/l_{ij}) \quad (3)$$

(3) Fuzzy Geometric Mean

$$ĝ_i = (\prod_{j=1}^{n} l_{ij})^{(\frac{1}{n})}, (\prod_{j=1}^{n} m_{ij})^{(\frac{1}{n})}, (\prod_{j=1}^{n} u_{ij})^{(\frac{1}{n})} \quad (4)$$

(4) Fuzzy weight vector

$$\hat{w}_i = ĝ_i \times (\sum_{k=1}^{n} ĝ_k)^{-1} \quad (5)$$

(5) Inverse of a Triangular Fuzzy Number

$$\bar{x} = (l, m, u)^{-1} \quad (6)$$

$$\bar{x}^{-1} = (\frac{1}{u}, \frac{1}{m}, \frac{1}{l}) \quad (7)$$

(6) Defuzzification (Centroid Method)

$$w_i = \frac{l_i + m_i + u}{3} \quad (8)$$

(7) Normalization of Crisp Weights

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \quad (9)$$

(8) Consistency Ratio

$$CI = \frac{(\lambda_{max} - 1)}{(n-1)}, \quad (10)$$

$$CR = \frac{CI}{RI} \quad (11)$$

Where;
i,j indices representing criteria (pollutants),
n is the total number of criteria

Table 1: Pollutant criterion pairwise computation

Criteria	NO_2	O3	SO2	CO	HCHO	CH4
NO_2	1.000	1.000	2.000	3.000	4.000	5.000
O3	1.000	1.000	2.000	2.000	3.000	4.000
SO2	0.500	0.500	1.000	1.000	2.000	3.000
CO	0.333	0.500	1.000	1.000	2.000	3.000
HCHO	0.250	0.333	0.500	0.500	1.000	2.000
CH4	0.200	0.250	0.333	0.333	0.500	1.000
Sum	3.283333333	3.583333333	6.833333333	7.833333333	12.5	18

Table 2: Pollutant criterion normalize computation

Criteria	NO_2	O3	SO2	CO	HCHO	CH4	AHP Weights	FAHP Weights
NO_2	0.305	0.279	0.293	0.383	0.320	0.278	0.310	0.310
O3	0.305	0.279	0.293	0.255	0.240	0.222	0.266	0.266
SO2	0.152	0.140	0.146	0.128	0.160	0.167	0.149	0.149
CO	0.102	0.140	0.146	0.128	0.160	0.167	0.140	0.140
HCHO	0.076	0.093	0.073	0.064	0.080	0.111	0.083	0.083
CH4	0.061	0.070	0.049	0.043	0.040	0.056	0.053	0.053
Sum	1	1	1	1	1	1	1	1

4.5. AQI Computation

The Fuzzy AHP weights were multiplied with the normalized pollutant maps. The raster overlay techniques in GIS were then used to add the weighted layers to create the final AQI map.

$$AQI = \sum(W_i \times P_i) \quad (12)$$

Where W_i represents the weight of pollutant i, and P_i represents its normalized concentration. The resultant AQI raster was categorized into standard air quality to ensure easy interpretation and decision making. The interpolated pollutant maps were each multiplied by the weight. This was followed by the summation of the weighted layers to give the final AQI raster using GIS based Map Algebra raster calculator.

5. Results and Discussion

5.1. AQI Spatial Pattern

The final AQI map classified the study area into two distinct air quality categories, as illustrated in the figure 4. According to quantitative analysis, there are some 33.25 km2 (3.05 percent) of acceptable air quality in the study area, and 1057.68 km2 (96.95 percent) of poor/unhealthy air quality. This distribution is a clear indication that there is a high percentage of the study area under poor air quality conditions. The spatial distribution of the AQI indicates that there is a severe disproportion between the two classes, with the acceptable air quality areas being an extremely small proportion to the vastly contaminated ones. The short range of the acceptable category indicates that clean air zones are restricted to a few areas which are comparatively far away to the key sources of pollution. On the contrary, the prevailing air quality category of poverty indicates a general environmental pressure in the study area.

The further analysis of the spatial distribution shows that the regions related to the intensive human activity, including high traffic density, urban growth, and localized emissions, are mainly concentrated in the poor/unhealthy air quality category. These regions have higher values of AQI because of the constant production and accumulation of pollutants. Regions that have lesser anthropogenic factors on the other hand such as peripheral and less developed regions fall under the acceptable air quality category which depicts relatively lesser pollution levels.

Additionally, the AQI map demonstrates a clear regional variance in the research area's air quality conditions. The substantial impact of urbanization and transportation systems on air pollution is shown in the likelihood that pollution rates will increase in the periphery areas and move to the center and more active locations. This gradient provides important insights into the spatial dynamics of pollution concentration and distribution.

By utilizing the spatial relationship between the measured locations, the IDW interpolation also made a significant contribution to the estimation of the AQI values in the unsampled sites. This method effectively captured the locally fluctuating air quality by providing a continuous surface image of the air quality. In addition, the AHP weighting made it feasible to methodically evaluate the relative importance of the many contributing aspects, strengthening the model stability and reducing its subjectivity.

The combination of these two methodologies (IDW and AHP) resulted in a more accurate and scientifically sound AQI map. By utilizing spatial interpolation and multi-criteria decision analysis, the study was able to achieve an equal balance between data and expert patterns. This will boost trust in the results and make them more applicable to environmental planning and management.

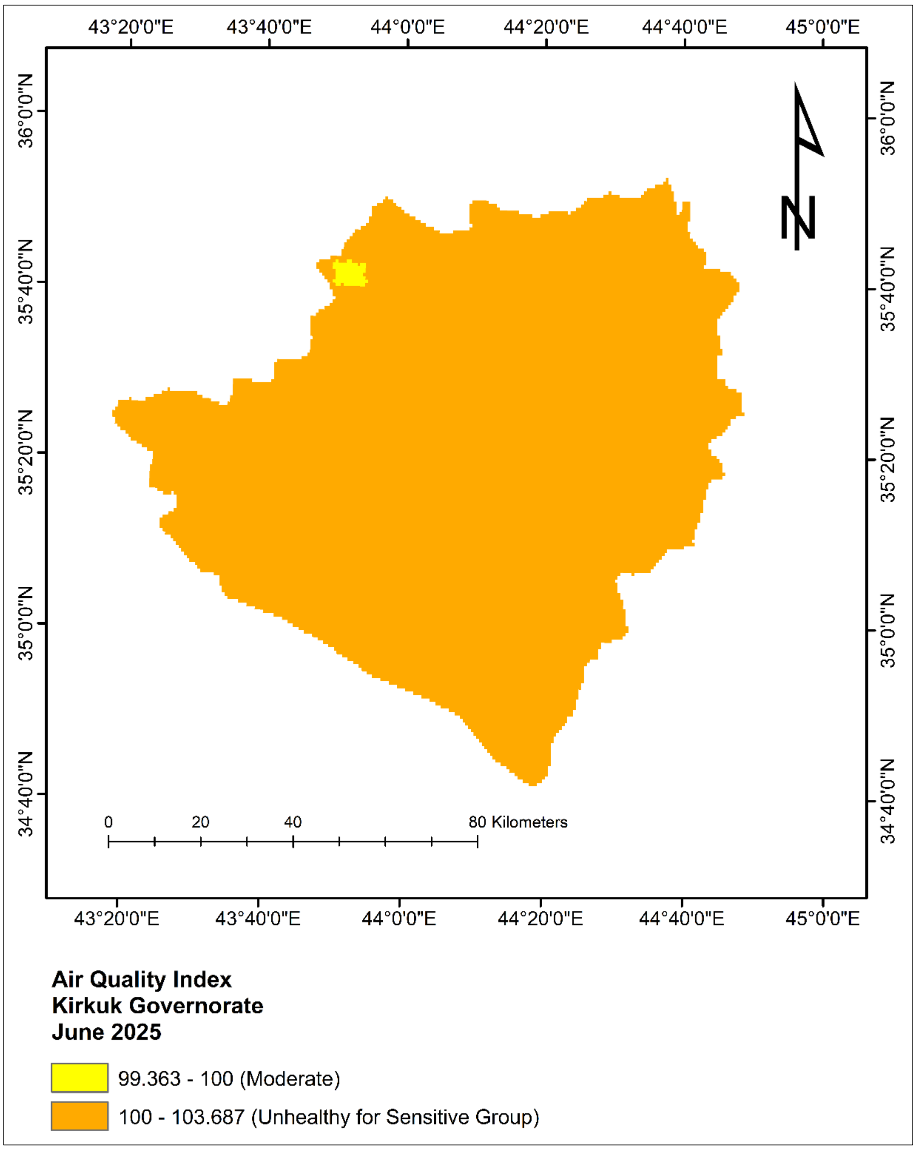


Fig 4: Air Quality Index over Kirkuk City

6. Conclusion

Sentinel-5P satellite data, along with GIS-based IDW interpolation and AHP multi-criteria analysis, proved to be an excellent way to estimate the Air Quality Index in Kirkuk Governorate. The division of the study region into two groups provides a simple yet effective structure for interpretation of air quality conditions. Although the classification is relatively rudimentary, the results clearly show that there is a substantial environmental issue, with the majority of the area classed as having poor air quality. The significance of the findings lies in the need for immediate mitigation actions and educated planning in order to improve air quality and protect public health.

The AQI mapping results show a critical environmental issue, as the majority of the studied area (96.95% or 1057.68 km^2) has poor to harmful air quality, while only a minor portion (3.05% or 33.25 km^2) is in tolerable circumstances. This distribution indicates the severity of the local air pollution and emphasizes the need for adequate mitigation and management strategies.

References

1. Bagkis E, Hassani A, Schneider P, Desouza P, Shetty S, Kassandros T, *et al*. Evolving trends in application of low-cost air quality sensor networks: challenges and future directions. Clim Atmos Sci. 2025;8(1):1–17.
2. Brauer M, Guttikunda SK, Nishad KA, Dey S, Tripathi SN, Weagle C, *et al*. Examination of monitoring approaches for ambient air pollution: a case study for India. Atmos Environ. 2019;216:116940. doi:10.1016/j.atmosenv.2019.116940.
3. Choi K, Chong K. Modified inverse distance weighting interpolation for particulate matter estimation and mapping. Atmosphere. 2022;13(5). doi:10.3390/atmos13050846.
4. Chompook P, Roemmontri J, Ketsakorn A. The application of analytic hierarchy process (AHP) for selecting community problems: multicriteria decision-making approach on environmental health aspects. J Sustain Sci Manag. 2023;18(10):138–149.
5. El S, Trinidad G, Francisco G. Building composite indicators using multicriteria methods: a review. J Bus Econ. 2019;89(1):1–24. doi:10.1007/s11573-018-0902-z.
6. Elumalai V, Brindha K, Sithole B, Lakshmanan E. Spatial interpolation methods and geostatistics for mapping groundwater contamination in a coastal area. Environ Sci Pollut Res. 2017;24(12):11601–11617.

doi:10.1007/s11356-017-8681-6.
7. Garajeh MK, Salmani B, Naghadehi SZ, Goodarzi HV, Khasraei A. An integrated approach of remote sensing and geospatial analysis for modeling and predicting the impacts of climate change on food security. Sci Rep. 2023;13(1):1–24. doi:10.1038/s41598-023-28244-5.
8. Gul H, Das BK. The impacts of air pollution on human health and well-being: a comprehensive review. J Environ Impact Manag Policy. 2023;3(6):1–11.
9. Ibrahim AK, Khidhir AM. Ozone and nitrogen dioxide pollutants detection system based on IoT. NTU J Eng Technol. 2023;2:1–5.
10. Ikechukwu MN, Ebinne E, Idorenyin U, Raphael NI. Accuracy assessment and comparative analysis of IDW, spline and kriging in spatial interpolation of landform (topography): an experimental study. J Geogr Inf Syst. 2017;9(3):354–371. doi:10.4236/jgis.2017.93022.
11. Jumaah HJ, Ameen MH, Kalantar B, Rizeei HM, Jumaah SJ. Air quality index prediction using IDW geostatistical technique and OLS-based GIS technique in Kuala Lumpur, Malaysia. Geomat Nat Hazards Risk. 2019;10(1):2185–2199. doi:10.1080/19475705.2019.1683084.
12. Kou G, Ergu D, Lin C, Chen Y. Pairwise comparison matrix in multiple criteria decision making. Technol Econ Dev Econ. 2016;22(5):738–765. doi:10.3846/20294913.2016.1210694.
13. Lindqvist H, Kivimäki E, Häkkilä T, Tsuruta A, Schneising O, Buchwitz M, *et al*. Evaluation of Sentinel-5P TROPOMI methane observations at northern high latitudes. Remote Sens. 2024;16(4):1–40.
14. Mahmood Ajaj Q, Shafri HZM, Wayayok A, Firuz Ramli M. Assessing the impact of Kirkuk cement plant emissions on land cover by modelling Gaussian plume with Python and QGIS. Egypt J Remote Sens Space Sci. 2023;26(1):1–16. doi:10.1016/j.ejrs.2022.12.001.
15. Martin C, Amigo JM, Castro K. Environmental science through orbiters: COVID-19 pandemic impacted the air quality. Chemom Intell Lab Syst. 2023;240:104927.
16. Mohammad Aman Ullah Sunny. Unveiling spatial insights: navigating the parameters of dynamic geographic information systems (GIS) analysis. Int J Sci Res Arch. 2024;11(2):1976–1985. doi:10.30574/ijsra.2024.11.2.0690.
17. Morozova AE, Sizov OS, Elagin PO, Agzamov NA, Fedash AV, Lobzhanidze NE. Integral assessment of atmospheric air quality in the largest cities of Russia based on TROPOMI (Sentinel-5P) data for 2019–2020. Cos Res. 2022;60(4):S57–S68. doi:10.1134/S0010952522700071.
18. Nozad AA, Shareef MA. Using GIS spatial analysis for examination the utility of the suggested suitability energy farms over Kirkuk city. NTU J Eng Technol. 2024;3(3).
19. Rasoul RM. History of Kirkuk from the beginning of the nineteenth century until becoming part of the Iraqi monarchy in 1925.
20. Sajid AH, Rudra RP, Parkin G. Systematic evaluation of kriging and inverse distance weighting methods for spatial analysis of soil bulk density. Can Biosyst Eng. 2013;55:1–13.
21. Santos DG, Parés ME. Assessing nitrogen dioxide monitoring techniques: a comparative analysis of Sentinel-5 Precursor satellite and ground measurements in Catalonia. Atmos Meas Tech. 2025;18(20):5569–5590.
22. Singh R, Pal M. Cloud detection methods for optical satellite imagery: a comprehensive review. Geomatics. 2025;5(3):1–42.

How to Cite This Article
Hiba M Sami. Evaluating the Air Quality Index Using Sentinel-5P and GIS-Based IDW Interpolation with Fuzzy AHP Over Kirkuk Governorate in June 2025. International Journal of Future Engineering Innovations. 2026 May-Jun;3(3):45-52. doi:10.54660/IJFEI.2026.3.3.45-52.