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A Comprehensive Research of Air Quality Modeling Methods: A Case Study Kirkuk, Iraq

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ABSTRACT

This review presents a clear comparison of the most popular air quality modeling techniques. The main aims of the review were to compare the generally applied air quality modelling methods regarding assumptions, data demand, and applicability, assess how they can be used in urban areas with limited data, and to support the choice of the Box Model BM to assess air quality in Kirkuk, Iraq. The reviewed modeling approaches were Gaussian Dispersion Models GDM and Lagrangian Models LM of point source emissions in meteorological inputs. Computational Fluid Dynamics CFD and Eulerian Grid Models EGM to perform the high-resolution spatial and temporal analysis. The BM simplified model incorporates homogeneous mixing of pollutants in a given volume. The BM was used in this research to estimate the pollutant levels in Kirkuk, which allows referring to its limitations in combination with the Air Quality Index AQI analysis. The findings on the relevance of the BM in Kirkuk indicate that it can be utilized in initial analyses and rapid scenario testing in cities with limited data. Although the spatial detail is lower, it gives quite satisfactory pollutant estimates in combination with the analysis of AQI. Comparison indicates that BM is a relevant policy and cost-effective tool with minimal data access used to support air quality management in Kirkuk.



1. Introduction

Air pollution is also being seen as one of the most important environmental and human health issues of our era [1]. This issue has many different origins, such as rapid urbanization, industrialization, energy utilization, and the use of fossil fuels that are not going to end [2]. The scale of the problem has always been warned by the World Health Organization WHO, which associates the millions of untimely deaths each year with low air quality [3]. Although the industrialized countries have come up with superior mechanisms to check and reduce emissions, most developing areas are faced with insufficient infrastructure, monitoring networks, and resources, and therefore, whole populations in these areas face high risks [4].

Iraq, and especially the petroleum centre of Kirkuk, is one of such areas where the issue of air pollution lacks thorough research despite its huge importance [5]. Kirkuk city is one of the most industrialized cities of Iraq, it has its own environmental issues due to the reliance on the petroleum industry [6]. In contrast to cities in Europe or North America, where the tight monitoring networks give real-time estimates of sulfur dioxide, nitrogen oxides, particulate matter, and ozone, there are very few ground-based observation stations in Kirkuk [7]. The lack of credible information complicates determining the trends of pollution, the exposure of the population, and the long-term implications on health and the sustainability of the cities [8]. This gap shows how air quality modeling is an invaluable asset to such cities as Kirkuk [9]. Even in cases where the pollutants cannot be directly monitored, modeling can supply an analytical structure and predict the consequences of the mitigation strategies [10].

GIS has a significant potential in the storage, analysis [11], and visualization of spatial data [12], which allows the researcher to map the areas of pollution [13], estimate exposure risks [14], and understand the connection between emissions and land use [15]. Spatially continuous, high-frequency data on atmospheric pollutants, land cover, and meteorological conditions are availed through remote sensing, in the form of satellites, which include Sentinel-5P and Landsat images [16]. Such technologies are used to substitute the absence of ground monitoring networks and provide large-scale, near-real-time monitoring [17].

The literature gives a myriad of experiences of how GIS and remote sensing have revolutionized air quality research [18]. Indian research has employed aerosol optical depth AOD to estimate the level of particulate matter in localities where ground measurements were insufficient, and has been able to predict the distribution of pollution using GIS

[19]. The application of Sentinel-5P data in China to monitor nitrogen dioxide and sulfur dioxide concentrations in industrial belts has shown the spatial heterogeneity that is easily missed by the traditional models [20]. Other related efforts have been made in the Middle East, where scholars in Baghdad and Basra have combined Landsat data with scarce monitoring data to make maps of urban air pollution [21].

The tradeoff between the availability of data and the aims of analysis comes into focus when it comes to comparing the relative value of various approaches to modelling [22]. More complex EGM or CFD models can be more accurate and higher-resolution, but need detailed emissions inventories and meteorological data, which are unfeasible in pre-determined areas [23]. GDM, as well as Lagrangian models, although valuable in the instance of industrial point sources, can fail to resolve city-wide trends unless there is a dense network of observation [24]. Conversely, the combination of the BM and GIS, and remote sensing provides a combination tool that takes advantage of the capabilities of both [24]. The BM offers a simple model to connect emissions and concentrations, whereas GIS and remote sensing offer spatially continuous data and visualization functions [25]. They form a system that is economical and can be used to inform policymakers on how to devise ways to reduce pollution [26].

The research questions addressed in this work include whether a box model, which involves the use of GIS, Python-based modeling, and AQI analysis, can be a good predictor and mapper of air quality in urban areas in data-scarcity settings like Kirkuk City, Iraq. It tests the efficiency of simplified modelling methods in the representation of the spatial distribution of important air pollutants. The study also compares the box model performance with the possible ground observations. It further examines the value-added of geospatial and remote sensing data to enhance the prediction of AQI. The hypothesis that was used to support the study is that a box model with GIS integration could be used to give correct, cost-efficient, and policy-relevant air quality evaluations even when only minimal monitoring facilities are available.

The objective of this review is to give a comparative analysis of popular methods of air quality modeling techniques, especially when it comes to assessing the applicability of the box model to urban air pollution in Kirkuk, Iraq.

This paper is valuable in that it places the box model in a systematic position in the context of the overall system of Gaussian, Lagrangian, Eulerian, CFD, and GIS-based systems, and their strengths and weaknesses, and where they need data. Besides, it highlights the increasing importance of GIS and

remote sensing technologies in addressing the lack of data and improving the spatial knowledge of air pollution patterns. The review shows that the combination of the BM and satellite measurements and geospatial analysis could be an effective, cost-effective, and policy-relevant method of air quality evaluation in data-constrained and pollution-strained cities like Kirkuk.

2. Importance of Air Quality Modelling

Air quality modeling offers a quantitative model in the simulation of the dispersion, transformation, and the level of exposure to pollutants [27]. Environmental impact assessments, health risk studies, and urban planning are impossible without these models [28]. Using a combination of emission inventories, meteorological data, and the behavior of pollutants, models aid policymakers in developing mitigation strategies as well as predicting air quality conditions under varied regulatory or climatic conditions [29].

The methodology in air quality modeling has taken different trajectories, all of which have their merits and demerits [30]. The oldest and most commonly used is the GDM, which is used to model point-source emissions like smokestacks [31]. LM, which follow the paths of the pollutant particles, offer greater dynamism to their way of simulating the transport and dispersion, particularly in long-range pollution events [32]. CFD models, at the micro scale, can be highly detailed in their ability to capture street-level dispersion as well as the effect of buildings, but the expense of these types of simulations makes them only applicable to studies that are highly localized but not global in their coverage of a city [33].

As compared to these more sophisticated models, the BM provides a much simpler conceptualization of the process in the atmosphere. It is based on the assumption that the pollutants that are released into a specified volume of atmosphere are mixed evenly, with the result of an average concentration throughout a box [34]. Although such an assumption ignores local variations, chemical transformations, and fine-scale meteorology, the simplicity of the BM renders it an attractive choice for those situations in which less detailed data and computational resources are available [35]. In cities such as Kirkuk, where industrial emissions are the major pollutants and where monitoring data is ineffective [36]. The box model may be utilized as a practical and flexible model of the dynamics of pollution.

The drawbacks of the BM, however, cannot be ignored [37]. It only captures the heterogeneity of pollutant distribution over an urban area, simplistically by assuming uniform mixing, and fails

to consider the complex chemistry of the atmosphere [38]. It is in this case that the incorporation of developed technologies like GIS and remote sensing will be important [39].

Generally, air quality modeling plays a critical role in comprehending the behavior of pollutants, regulatory decision-making, as well as protecting the health of the population, particularly in urban areas with a high rate of development. Simplified models are mainly suitable in situations of limited data, where practical and explanatory consequences are essential. This is the reason why the box model is highlighted in this research because it presents a realistic trade-off among ease, effectiveness, and trustworthiness. It is also complemented with GIS and remote sensing, making it even more useful in the management of air quality in cities like Kirkuk.

3. Study Region

Kirkuk City is a hot semi-arid climatic region with extremely high temperatures during summer and mildly cool to cool temperatures during winter. In a typical condition of the atmosphere in the year 2025, the weather was mostly dry, and numerous dust events occurred, especially during the warm seasons. The wind direction is generally northwesterly to western and connected with the local Shamal winds, which contribute to a great part of the pollutants dispersion and dust transportation. These weather and wind patterns have a great impact on the concentration and transportation of air pollutants in the city. The city is largely governed by the existing northwesterly winds that govern the dispersal of pollutants and dust transportation. Fig. 1 and Fig. 2 show the air quality of Iraq and Kirkuk in 2025, respectively. Fig. 3 represents the 24-hour air quality forecast of Kirkuk in 2025 [40].

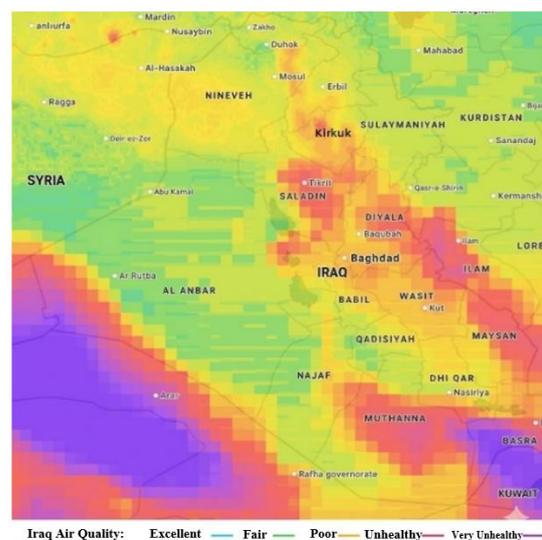


Fig. 1. Air quality of Iraq in 2025.

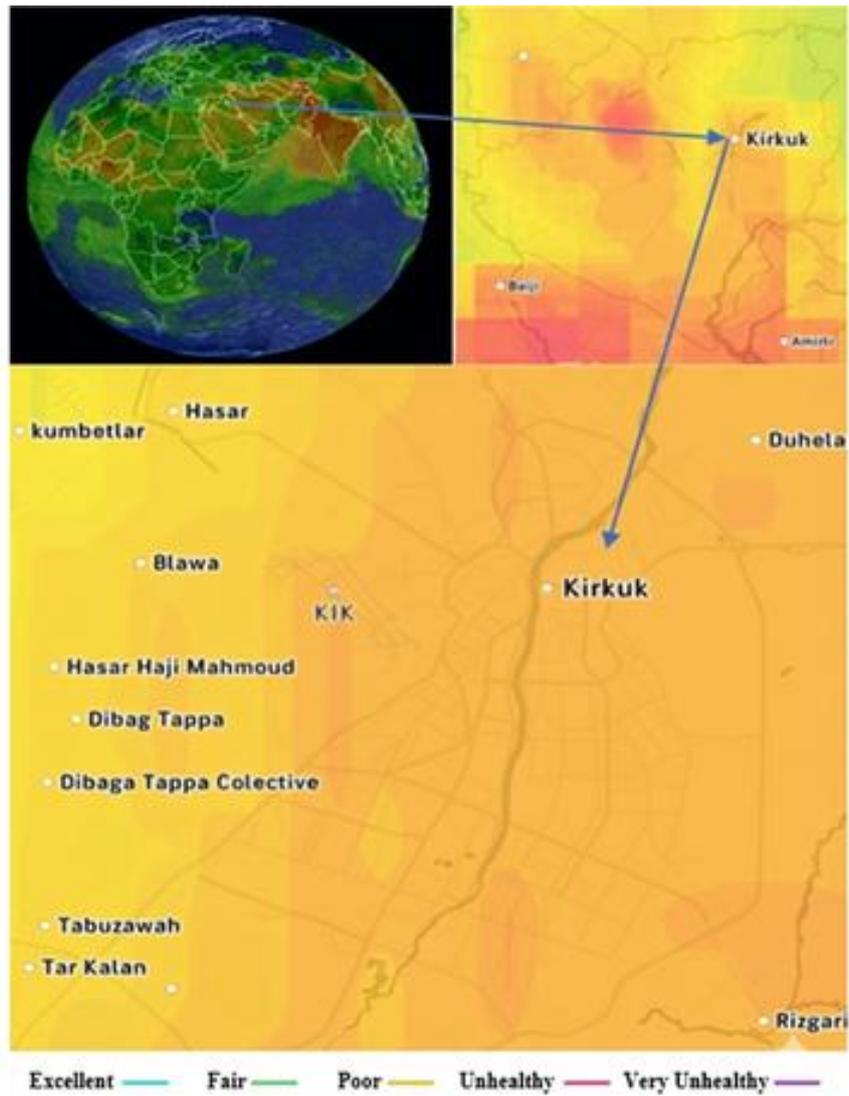


Fig. 2. Kirkuk study region air quality in 2025.

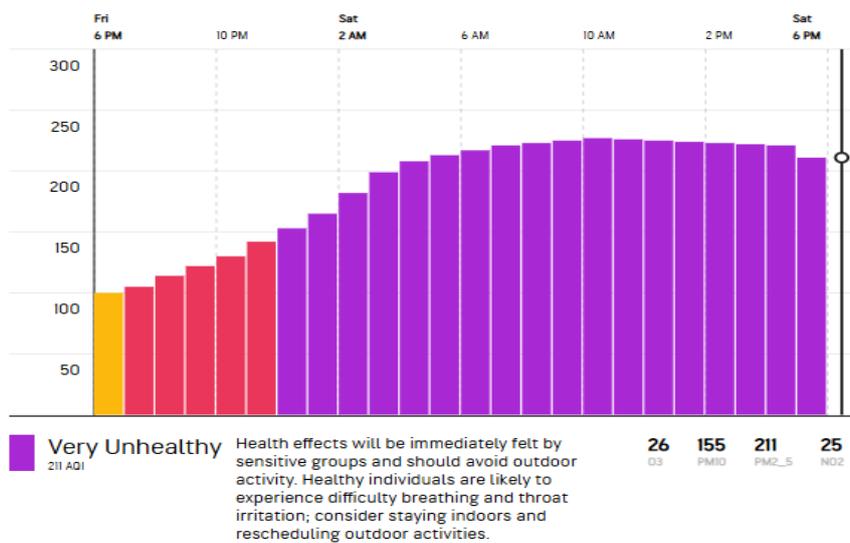


Fig. 3. The 24-hour air quality forecast of Kirkuk in 2025.

Kirkuk is a case that depicts such synergy. The process of petroleum mining and refining emits large amounts of sulfur dioxide and nitrogen oxides, and traffic jams contribute to the carbon monoxide and particle emissions. The extent of these problems can hardly be measured without adequate ground stations [41].

4. Literature Review

The models of air quality have greatly developed to underpin the environmental assessment and mitigation strategies against pollution, and different techniques vary in complexity, accuracy, and data requirements [42]. Table 1 shows a comparison of literature studies of air quality modeling.

The state of air quality modeling in Iraq is poor due to a lack of monitoring networks, poor emission inventories, and the lack of access to long-term meteorological data.

The majority of the current literature only depends on single case studies; little is done on incorporating modeling frameworks and geospatial methods. Sophisticated models like CFD and EGM were used very infrequently because of excessive data and computing requirements. It is, as well, deficient in validated models at the city scale, and applicable to the rapid evaluation and support of decisions. Therefore, there is an evident void in flexible and cost-effective modeling methods that can be adopted to incorporate GIS, remote sensing, and simplified models of the Iraqi cities.

Table 1. Comparison of literature studies of air quality modeling.

Author / Year	Study Region	Study Interest	Modeling Type	Required Data	Area Coverage	Computing Mandate	Findings / Notes	Refs.
<i>Jumaah et al., 2026</i>	Kirkuk, Iraq	Air Quality Mapping with Python & GIS	BM integrated with GIS	Low–Moderate/PM2.5, PM10, GIS layers	Medium/ City blocks, aggregated cells	Low	GIS-based BM tool. Validated by ground truths with 80–90% accuracy.	[34]
<i>Salih, 2025</i>	Kirkuk Refinery, Iraq	Air Pollution Dispersion Modeling from Point Sources	GDM	Moderate–High / Site emissions, Weather data	Medium/ City to neighborhood	Medium	Dispersion model for refinery emissions.	[43]
<i>Saleh & Hassoon, 2024</i>	Baba Industrial Area, Iraq	Industrial gas flare monitoring	BM	Moderate/temporal emission, Climate data	Low-Medium/ Temporal city-scale	Low–Medium	Estimates exposure over time	[44]
<i>Jumaah & Kamran, 2024</i>	Kirkuk, Iraq	AQI-based Box Modeling	AQI-based BM	Low/Limited points	Low/ City scale	Low	AQI from BM by combining remote-sensing and ground data.	[25]
<i>Ajaj et al., 2023</i>	Kirkuk cement plant, Iraq	Air Pollution Modelling and its Impact	GDM	High/ Meteorology, Land-cover layers, GIS layer	Medium–High/ Industrial zone	Medium–High	Python, GDM using QGIS, permitted accurate mapping of dispersion.	[45]
<i>Pantusheva et al., 2022</i>	Global	Air Dispersion Modeling	CFD	High/ Urban topography, emission sources, meteorology	High/ Local Scale	High	Provided detailed air dispersion modeling	[46]
<i>Ngo & Lim, 2020</i>	Global	Multiscale Eulerian CFD	CFD	High/ Meteorology, Emission	Medium–High/Local Scale	High	CFD provides detailed chemical process resolution	[47]
<i>Rakesh et al., 2020</i>	India	Gaussian & Lagrangian modeling	GDM LM	High Emissions, Climate data	Moderate/ Industrial region	Medium	GDM accuracy is reduced by low wind; LM performs better.	[48]

The air quality in Kirkuk, according to previous research, indicates that there was a distinct difference in methodology between simplified and advanced models. BM-based studies of [25], [34], and [44] concentrate on the low data demand and calculation efficiency, which use a limited monitoring infrastructure that facilitates city-scale judgment and air quality mapping. Conversely, the use of GDM in the areas near industry, like the Kirkuk refinery and cement plant in [43], and [45] offers a more in-depth dispersion pattern but demands a large amount of meteorological and emission data. Kirkuk Global studies of advanced CFD and EM, as presented in [46] and [47], provide a high-spatial, high-process-level resolution, but are computationally expensive, limiting their application to local areas. Based on [48], LM is effective in practice when the wind is complicated, but it is also data-intensive. In general, the Kirkuk-based study represents a trade-off between the complexity of the model and the practicality of the study, where the box model is a reasonable compromise in the case of data-limited urban settings.

GDMs are still the most popular to use when dealing with point-source emissions since they are easy to use and are based on the behavior of plumes, but they demand specific meteorological inputs [49]. EGM has great spatial resolution and the capability of chemical transformation, but requires a lot of computational power and fine input datasets. One way to offer a flexible transport simulation but still sensitive to the effect of meteorological variability is LM, which is used to track pollutant parcels through time [50]. Comparative analysis reveals that although advanced models are more precise than BM, the latter is still useful to develop regions with limited monitoring networks and limited computational facilities [51-53].

On the whole, the studies reviewed indicate a vivid trade-off between the variants of air quality modeling in regard to the data requirements, coverage of space, and computation requirements. Gaussian and Lagrangian models are better applied to point sources and industries, in that they can provide more detail of dispersion, but demand a lot of meteorological and emission data. The methods of CFD and Eulerian give the best resolution of space and process level, but cannot be used due to the high computational costs. Box model-based approaches, on the contrary, are more flexible and efficient and should be useful at the city scale assessment in environments with a limited amount of data, like Kirkuk.

5. Methodology

Air quality modeling has also become an inseparable element in the study, forecasting, and reduction of the effects of air pollution, especially in fast-moving industrial and resource-scarce areas. Fig. 4 shows the workflow of literature selection.

Fig. 5 shows the workflow of the proposed AQI model based on BM.

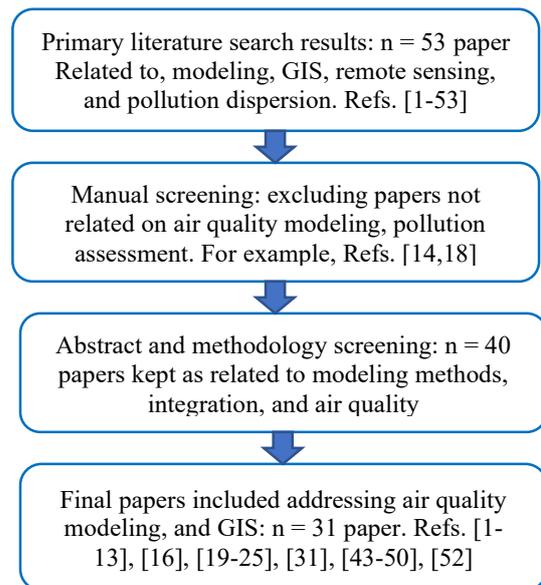


Fig. 4. Workflow of literature selection.

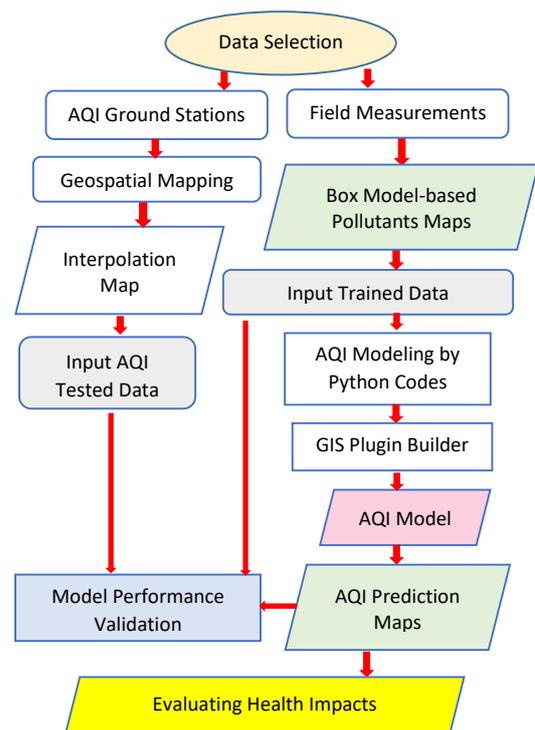


Fig. 5. Workflow of proposed AQI model-based BM.

From a preliminary search in databases, we used 53 peer-reviewed articles that concern air quality modelling, dispersion analysis, GIS, and remote sensing applications. After the screening of titles and scopes manually, the studies that were not relevant to the air quality assessment or systems were filtered.

The number of articles that were retained to be evaluated in terms of abstract and methodology was 41. Following screening in full text, 34 studies were

included in the study as they directly covered air quality modeling methods such as BM, GDM, LM, and EGM, CFD models, and geospatial models as applied to Kirkuk, Iraq, and similar data-constrained urban settings.

Although the conceptual framework of the box model is quite simple, it yields useful results concerning the relationships between emissions and concentrations, and can be used as a useful tool to make preliminary conclusions about the quality of the air. The approach has a systematic procedure of incorporating ground observations, field measurements, and geospatial analysis in AQI modeling and evaluation. Firstly, there are data on air quality gathered at AQI ground stations and measurements in the field, and they constitute the foundations of the data selection. Alongside, based on BM, there is the formation of BM-based maps of certain pollutants, where they are used as trained inputs to perform Python-written AQI model codes, which are incorporated into an ArcGIS plugin environment. For the validation process, there is a need for testing data, which is executed from geospatial distributions of AQI values based on interpolation techniques. The performance assessment of the generated AQI models is done by employing performance evaluation using trained and tested AQI data. Lastly, verified AQI prediction maps are used to determine the feasible health effects in the place of the study, Kirkuk City.

BM is less appropriate to capture fine-scale variations because of its assumptions of uniform mixing, although in low data settings, it allows researchers and policymakers to do scenario testing, approximate average concentrations, and calculate air quality indices without making big inputs. Combined with GIS, the outputs of the box models can be plotted spatially, and policymakers can be able to see the areas of pollution hotspots and focus on interventions. Remote sensing would also enhance this integration process by providing near-real-time and spatially continuous information of the major pollutants like nitrogen dioxide, sulfur dioxide, and particulate matter.

6. Review Results and Discussion

Table 2 represents a summary of GIS tools and models used in the literature. Moreover, Fig. 6 represents the air pollution exposure assessment indicators used in the literature.

The table shows the key position of GIS and geospatially integrated tools in measuring air pollution, especially in data-sparse areas like Iraq. The most common platforms are ArcGIS and QGIS, which promote pollutant mapping, dispersion modeling, and analysis of AQI.

Table 2. Summary of GIS tools and models.

Used Tool	Factors	Application/ Model	Key Refs.
ArcGIS/ ArcGISPro	PM _{2.5} , PM ₁₀ , NO ₂ , CO, AQI	Mapping, GIS-based interpolation, GIS-based BM, and geostatistics	[1], [5], [9], [25], [34]
Remote Sensing Images	PM _{2.5} , NO ₂ , SO ₂ , O ₃ , AOD	Satellite image-based prediction of pollution and limited data assessment.	[3], [10], [16], [17], [20]
Python (GIS-integrated)	PM _{2.5} , PM ₁₀ , AQI	BM, AQI estimation, and GIS-based spatial analysis	[25], [31], [34]
PostGIS/ Spatial Databases	PM _{2.5} , PM ₁₀	Spatial query of air quality and emissions, and data storage and management.	[29], [34]
CFD Platform	NO _x , PM _{2.5} , PM ₁₀	Street-canyon analysis of pollution and dispersion on a high-resolution scale.	[33], [38], [46], [47]
QGIS	PM _{2.5} , PM ₁₀ , NO _x	GDM, emission from industries, spatial mapping, and land use/land cover.	[43], [45], [52]

These platforms have powerful spatial analysis and can be used with Python-based automation. Road map, the combination of remote sensing data, particularly from Sentinel and MODIS sensors, is especially useful in increasing the spatial coverage of pollutants like PM, NO_x, and SO₂ in regions under dense ground monitoring. Tools, including PostGIS, allow working with large datasets of spatial data in an effective, pre-processing, and management way, which enhances the effectiveness of models and their reproducibility. Detailed dispersion and street-level analysis is available with advanced CFD platforms, which, however, demand large amounts of computational resources, which restricts their wide use in Iraqi cities.

In general, the table has shown that there is a methodological inclination in favor of flexible, low-cost GIS-based tools that provide a viable compromise between accuracy, scalability, and operational viability in modeling air quality.

When comparing the RMSE and R² of the different studies in the table, it is evident that there is a significant variation in the degree of model validation as well as in the level of reporting. Moderate to very high R² and low RMSE are clearly specified in GIS-based box modeling in Kirkuk e.g., [25], and [34] validates the suitability of the model on city scales.

Based on [43] and [45] and under distinctive atmospheric conditions, the GDM in the industrial areas has shown a higher R^2 , nonetheless, in low wind or complex conditions, RMSE increases due to sensitivity to the input data quality. BMs, as shown in [44], are used in studies that concern temporal exposure and put more focus on consistency of trends as opposed to finer RMSE-R-square metrics. Conversely, reviews based on global CFD and Eulerian methods [46, 47] use the concept of validation, with very high potential accuracy, but usually without location-specific RMSE or R^2 because of model complexity.

Comprehensively, Kirkuk-studies value pragmatic validation at reasonable RMSE and R^2 , which consolidate the box model credibility in data-stifled settings.

The application of the results within the local setting of Kirkuk demonstrates that the air quality modeling results are strongly affected by the environmental setting, infrastructural setting, and socio-economic situation of the city. The major characteristics of Kirkuk include high traffic flow, oil and industrial production, high frequency of dust occurrences, and a small number of air quality monitoring stations, which influence the patterns of pollutant distributions. Such a good fit between the modeled and observed concentrations (as indicated by reasonable RMSE and R^2 values in studies of BMs using GIS) would indicate that simplified models can succeed in capturing the prevailing pollution indications at the city level. GDMs are effective close to particular sources like the refinery and cement plant, but are vulnerable to the local wind variability and emission uncertainty. More complex CFD methods are more theoretical but not practical due to the level of data and computational complexity.

In general, the findings demonstrate that the combination of box models with GIS and remote sensing offers a practical, realistic approach towards providing air quality evaluation and policymaking in Kirkuk.

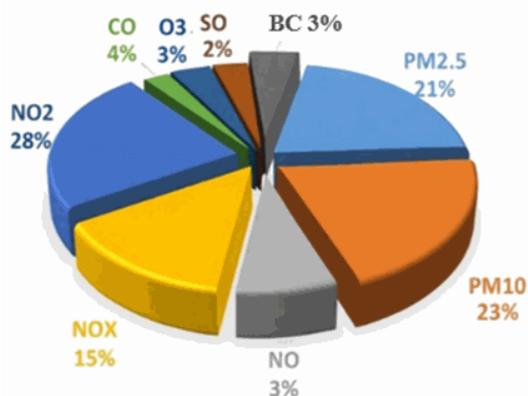


Fig. 6. Air pollution exposure assessment indicators.

As shown in the figure, the indicators of PM ($PM_{2.5}$ and PM_{10}) and nitrogen-based pollutants (NO_2 and NO_x) are primarily used in the air pollution exposure evaluation of the examined literature. This is an indication of the heavy impact of traffic emissions, industrial muscle, and frequent dust occurrences in Kirkuk.

The comparatively large weighting of NO_2 depicts the significance of this gaseous element as an urban combustion indicator. On the contrary, fewer gaseous pollutants, including CO, O_3 , SO, and Black Carbon BC, are often evaluated, simply because of the lack of monitoring.

The research had a number of limitations, the main one being the scarcity and unequal spatial coverage of the ground-based air quality monitoring data in Kirkuk. There was also uncertainty in inventories of emissions and variation of conditions with time due to the variability of meteorological conditions that influenced model accuracy. Furthermore, not all the pollutants were long-term continuously observed hence limited the validation.

7. Conclusion

The analysis of the modeling techniques shows that some of these advanced methods, including the EGM, LM, and CFD, are highly accurate and detailed, but are not practical in an environment with sparse data and computing facilities. On the contrary, more basic models like the BM continue to be of eternal importance, particularly when integrated with the development of GIS as well as remote sensing technologies.

This hybrid approach is important, as seen in the example of Kirkuk, Iraq. Kirkuk is a city that has been greatly influenced by petroleum production, refining, and gas flaring activities, as well as traffic pollution, which has significantly contributed to the presence of high atmospheric pollution rates in the city, which consequently has a direct impact on the health and sustainability of the city. Nonetheless, this is not as broadly applicable as the data-intensive models due to the lack of well-organized networks of ground-based monitoring and the absence of systematic accounts of the emissions. In this case, the BM that is reinforced by GIS and satellite observations can be viewed as a feasible and affordable solution.

This method will give a basis for air quality management in the urban area, as coarse but meaningful assessments are made possible.

The simplified air quality models, including the BM, based on the results, should become a tool of the standard preliminary assessment and regular monitoring in data-limited cities such as Kirkuk. Model outputs should be used by local authorities to act as aides to AQI reporting, urban planning, and mitigation measures in regard to pollution.

It is advised that policy-makers integrate modeling output and health impact analysis in order to make judgments. Future research must concentrate on hybrid modeling where box models are coupled with Gaussian models or Lagrange models to enhance precision in and around major sources of emission. The validation of the models will be improved by the expansion of ground monitoring networks and the creation of local inventories of emissions. Temporal studies are required over a long period to determine seasonal and climate variability in air pollution. Lastly, the connection of air quality models to the epidemiological data will enhance the health risk assessment in the cities of Iraq.

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Author Contributions

Huda J. Jumaah conceptualized and wrote the manuscript. Wafaa A. Hasan collected data. Khalil Valizadeh Kamran supervised.

Competing Interests

The authors declare there are no competing interests.

References:

- [1] H. H. Hamed, H. J. Jumaah, B. Kalantar, N. Ueda, V. Saeidi, S. Mansor, & Z.A. Khalaf, "Predicting PM2.5 levels over the north of Iraq using regression analysis and GIS techniques," *Geomatics, Natural Hazards and Risk*, vol. 12, no. 1, pp. 1778–1796, 2021.
- [2] H. Jamal Jumaah, W. Abbas Hasan, Z. Ali Khalaf, "Applications of remote sensing and GIS in assessing climate change and forecasting air quality," *Journal of Engineering and Technology Development*, vol. 1, no. 1, pp. 1-7, 2023.
- [3] H. J. Jumaah, M. H. Ameen, S. Mahmood, & S. J. Jumaah, "Study of air contamination in Iraq using remotely sensed data and GIS," *Geocarto International*, vol. 38, no. 1, p. 2178518, 2023.
- [4] H. J. Jumaah, M. H. Ameen, B. Kalantar, H. M. Rizzei, & S. J. Jumaah, "Air quality index prediction using IDW geostatistical technique and OLS-based GIS technique in Kuala Lumpur, Malaysia," *Geomatics, Natural Hazards and Risk*, vol. 10, no. 1, pp. 2185–2199, 2019.
- [5] H. J. Jumaah, A. Jasim, A. Rashid & Q. Ajaj, "Air pollution risk assessment using GIS and remotely sensed data in Kirkuk City, Iraq," *Journal of Atmospheric Science Research*, vol. 6, pp. 1–10, 2023.
- [6] Y. H. Mahmood, M. A. Najemalden, & R. T. Ahmed, "Air quality in Kirkuk regarding PM10 concentrations," *Review of International Geographical Education Online*, vol. 11, no. 5, 2021.
- [7] World Health Organization, *Air Quality Guidelines: Global Update 2005*. WHO, 2006.
- [8] M. J. Nieuwenhuijsen, "Urban and transport planning, environmental exposures and health—new concepts, methods and tools," *Environmental Health*, vol. 15, suppl. 1, S38, 2016.
- [9] H. J. Jumaah, W. A. Hasan, & S. J. Jumaah, "A regional investigation of inverse distance weighting particulate matter prediction within Kirkuk City, Iraq," *Int. J. Econ. Environ. Geol.*, vol. 16, no. 1, pp. 5–13, 2025.
- [10] H. J. Jumaah, M. A. Dawood, & S. Mahmood, "Estimating chemical concentrations of dust PM2.5 in Iraq: A climatic perspective using polynomial model and remote sensing technology," *Journal of Atmospheric Science Research*, vol. 7, no. 3, 2024.
- [11] H. J. Jumaah A. A. Rashid, S. A. Saleh, & S. J. Jumaah, "Deep neural remote sensing and Sentinel-2 satellite image processing of Kirkuk City, Iraq for sustainable prospective," *Journal of Optics and Photonics Research*, vol. 2, no. 3, pp. 172–180, 2025.
- [12] H. J. Jumaah, A. Ghanbari, A. T. Jasim, & Z. A. Khalaf, "Using RS and AI GIS in land management and urban planning in Mosul, Iraq for sustainable development," *Geodesy and Cartography*, vol. 51, no. 3, pp. 165–177, 2025.
- [13] Q. M. Ajaj, N. A. Awad, H. J. Jumaah, & H. M. Rizzei, "Air quality regression analysis over Iraq during severe dust periods using GIS and remotely sensed PM2.5," *DYSONA–Applied Science*, vol. 6, no. 2, pp. 300–308, 2025.
- [14] M. H. Ameen, M. Azmi, & H. J. Jumaah, "Evaluating exposure to road traffic air and noise pollution: A comprehensive review," *Tikrit Journal of Engineering Sciences*, vol. 32, no. 2, pp. 1–19, 2025.
- [15] S. Mahmood, A. Ali, & H. J. Jumaah, "Geo-visualizing hotspots of smog-induced health effects in Gujranwala, Pakistan," *Environmental Monitoring and Assessment*, vol. 196, no. 5, 457, 2024.
- [16] H. J. Jumaah, M. A. Dawood, T. A. Abd Alreza, & M. A. Meteab, "Air pollution landscape in Iraq: A Sentinel-5P based assessment of key atmospheric pollutants," *DYSONA–Applied Science*, vol. 7, no. 1, pp. 82–87, 2026.
- [17] A. O. Najim, M. A. Meteab, A. T. Jasim, Q. M. Ajaj, H. J. Jumaah, & M. H. A. Sulyman, "Spatial analysis of particulate matter using MODIS AOT and GIS over East Malaysia," *Egyptian Journal of Remote Sensing and Space Science*, vol. 26, no. 2, pp. 265–271, 2023.
- [18] M. H. Ameen, H. J. Jumaah, B. Kalantar, N. Ueda, A. A. Halin, A. S. Tais, & S. J. Jumaah, "Evaluation of PM2.5 particulate matter and noise pollution in Tikrit University based on GIS and statistical modeling," *Sustainability*, vol. 13, no. 17, 9571, 2021.
- [19] A. K. Ranjan, A. K. Patra, & A. K. Gorai, "A review on estimation of particulate matter from AOD," *Asia-Pacific Journal of Atmospheric Sciences*, vol. 57, no. 3, pp. 679–699, 2021.
- [20] Z. Zheng, Z. Yang, Z. Wu, & F. Marinello, "Spatial variation of NO2 and its impact factors in China using Sentinel-5P," *Remote Sensing*, vol. 11, no. 16, 1939, 2019.
- [21] A. S. Hadeel, M. T. Jabbar, & X. Chen, "Environmental change monitoring in arid regions: Al-Basrah Province," *Environmental Monitoring and Assessment*, vol. 167, no. 1, pp. 371–385, 2010.
- [22] M. El-Harbawi, "Air quality modelling, simulation, and computational methods: A review," *Environmental Reviews*, vol. 21, no. 3, pp. 149–179, 2013.

- [23] D. Barbero, Eulerian and Lagrangian Air Quality Modelling at Regional, Local and Microscale, 2024. <https://www.politesi.polimi.it/handle/10589/23> 2012.
- [24] P. T. Rakesh, R. Venkatesan, C. V. Srinivas, R. Baskaran, & B. Venkatraman, "Performance evaluation of modified Gaussian and Lagrangian models," *Annals of Nuclear Energy*, vol. 133, pp. 562–567, 2019.
- [25] H. J. Jumaah, & K. V. Kamran, "AQI-based box model using GIS and remote sensing over Kirkuk City, Iraq," *Advanced Engineering Days*, vol. 9, pp. 144–146, 2024.
- [26] A. Khalil Ibrahim & A. M. Khidhir, "Ozone and nitrogen dioxide pollutants detection system based on IoT," *NTU Journal of Engineering and Technology*, vol. 2, no. 1, 2023.
- [27] H. J. Jumaah, S. Mansor, B. Pradhan, & S. N. Adam, "UAV-based PM2.5 monitoring for small-scale urban areas," *International Journal of Geoinformatics*, vol. 14, no. 4, 2018.
- [28] D. J. Briggs, "A framework for integrated environmental health impact assessment," *Environmental Health*, vol. 7, no. 1, 61, 2008.
- [29] S. J. Smith, E. E. McDuffie, & M. Charles, "Coordinated development of emission inventories for climate forcers and air pollutants," *Atmospheric Chemistry and Physics Discussions*, 2022.
- [30] R. S. Sokhi, N. Moussiopoulos, A. Baklanov, J. Bartzis, I. Coll, S. Finardi, & J. Kukkonen, "Advances in air quality research," *Atmospheric Chemistry and Physics Discussions*, 2021.
- [31] Q. M. Ajaj, H. Z. Mohd Shafri, M. F. Ramli, & A. Wayayok, "Prediction of air pollutants concentration emitted from Kirkuk Cement Plant using deep learning," *Pollution*, vol. 9, no. 2, pp. 810–820, 2023.
- [32] A. Amicarelli, G. Leuzzi, & P. Monti, "Lagrangian micromixing models for concentration fluctuations," *American Journal of Environmental Sciences*, vol. 8, no. 6, pp. 577–590, 2012.
- [33] P. Neofytou, & T. Stathopoulos, "CFD modelling of pollution dispersion in a street canyon: Comparison between LES and RANS," *Journal of Wind Engineering and Industrial Aerodynamics*, vol. 99, no. 4, pp. 439–448, 2011.
- [34] H. J. Jumaah, K. V. Kamran, A. Ghanbari, & M. Jeihouni, "Development of GIS-based box model tool for air quality mapping using Python and ArcGIS Pro," *International Journal of Engineering and Geosciences*, vol. 11, no. 1, pp. 212–225, 2026.
- [35] Y. Zhang, M. Bocquet, V. Mallet, C. Seigneur, & A. Baklanov, "Real-time air quality forecasting: State of the science," *Atmospheric Environment*, vol. 60, pp. 656–676, 2012.
- [36] Y. H. Mahmood, M. A. Najemalden, & R. T. Ahmed, "Air quality in Kirkuk regarding PM10," *Review of International Geographical Education Online*, vol. 11, no. 5, 2021.
- [37] M. Johnson, N. Lam, S. Brant, C. Gray, & D. Pennise, "Modeling indoor air pollution from cookstoves using a Monte-Carlo box model," *Atmospheric Environment*, vol. 45, no. 19, pp. 3237–3243, 2011.
- [38] J. Zhong, X. M. Cai, & W. J. Bloss, "Modelling photochemical pollutants in a deep urban street canyon," *Atmospheric Environment*, vol. 143, pp. 86–107, 2016.
- [39] M. R. Mahmood, & H. J. Jumaah, "NBR index-based fire detection using Sentinel-2 images," *International Journal of Geoinformatics*, vol. 19, no. 3, pp. 67–74, 2023.
- [40] AccuWeather, "Kirkuk weather forecast," AccuWeather.com. Available: <https://www.accuweather.com/en/iq/kirkuk/207046/weather-forecast>. Accessed: Nov. 2025.
- [41] S. H. Saleh, & A. F. Hassoon, "Atmospheric stability classes and its effect on CO emission around Kirkuk refinery," in *Proc. Journal of Physics: Conf. Series*, vol. 1963, no. 1, p. 012034, 2021.
- [42] A. Miranda, C. Silveira, J. Ferreira, A. Monteiro, D. Lopes, H. Relvas, & P. Roebeling, "Current air quality plans in Europe," *Atmospheric Pollution Research*, vol. 6, no. 3, pp. 434–443, 2015.
- [43] A. S. Salih, N. D. Hassan, & N. S. Abdulmajeed, "Air pollution dispersion modeling using Gaussian plume model," *Tikrit Journal of Engineering Sciences*, vol. 32, no. 1, pp. 1–15, 2025.
- [44] S. H. Saleh, & A. F. Hassan, "Assessment of air pollutants for Baba Industrial Area at Kirkuk Oil Field," *The Iraqi Geological Journal*, pp. 125–137, 2024.
- [45] Q. M. Ajaj, H. Z. M. Shafri, A. Wayayok, & M. F. Ramli, "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.*, vol. 26, no. 1, pp. 1–16, 2023.H
- [46] M. Pantusheva, R. Mitkov, P. O. Hristov, & D. Petrova-Antonova, "Air pollution dispersion modelling in urban environment using CFD: A systematic review," *Atmosphere*, vol. 13, no. 10, 1640, 2022.
- [47] S. I. Ngo, & Y. I. Lim, "Multiscale Eulerian CFD of chemical processes: A review," *ChemEngineering*, vol. 4, no. 2, 23, 2020.
- [48] P. T. Rakesh, R. Venkatesan, P. Roubin, C. V. Srinivas, R. Baskaran, & B. Venkatraman, "Formulation of turbulence diffusion relationships under stable atmospheric conditions and its effect on pollution dispersion," *Meteorology and Atmospheric Physics*, vol. 132, no. 6, pp. 909–924, 2020.
- [49] H. Snoun, M. Krichen, & H. Chérif, "A comprehensive review of Gaussian atmospheric dispersion models," *Euro-Mediterranean Journal for Environmental Integration*, vol. 8, no. 1, 219–242, 2023.
- [50] M. Jia, X. Huang, K. Ding, Q. Liu, D. Zhou, & A. Ding, "Impact of data assimilation and aerosol radiation interaction on Lagrangian particle dispersion modelling," *Atmospheric Environment*, vol. 247, 118179, 2021.
- [51] A. Garcia, Y. Saez, I. Harris, X. Huang, & E. Collado, "Advancements in air quality monitoring: a systematic review of IoT-based air quality monitoring and AI technologies," *Artificial Intelligence Review*, vol. 58, no. 9, 275, 2025.
- [52] A. S. Salih, & N. D. Hassan, "The impact of urban trees on air pollution in Kirkuk City: A Gaussian Dispersion Model Approach," *NTU Journal of Engineering and Technology*, vol. 2, no. 4, 2023.
- [53] A. A. Nozad, & M. A. Shareef, "Using GIS spatial analysis for examination the utility of the suggested suitability energy farms over Kirkuk City," *NTU Journal of Engineering and Technology*, vol. 3, no. 3, 2024.