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Air Quality Evaluation Using Gaussian Plume Model and GIS at Gas Flaring Region in Kirkuk City, Iraq

Deeman Salahaldeen Noori[1]✉ | Nada Subhi Abdulmajeed[2]

1. Department of Surveying Engineering Techniques, Technical Engineering College of Kirkuk, Northern Technical University, Kirkuk, Iraq.
2. Department of Architecture and Construction Engineering Techniques, Technical Engineering College of Kirkuk, Northern Technical University, Kirkuk, Iraq.

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ABSTRACT

Gas flaring continues as an environmental issue across oil-producing regions since it generates air pollution and climate change conditions. The purpose of the research is to examine, and compare the spatial distribution of deterioration of air quality, the environmental and health risks within the poor air quality area close to the gas flaring location and assess the density of gases and pollutants produced using the Gaussian-Plume model (GPM). Geographic Information Systems GIS technology has been combined with GPM in dispersion modeling. The gases produced by gas flaring to be emitted include sulfur dioxide (SO2), Nitrogen dioxide (NO2), and particulate matter (PM). Such pollutants worsen the quality of air and, therefore, are harmful to the health of the surrounding communities. Findings demonstrate that pollution intensities increase the most in locations proximate to flaring sites since atmospheric factors govern the way pollutants disperse. The GPM indicates that pollution concentrations decrease as distance increases from the sources. While some areas near the flare still contain unsafe levels, even in inhabited sections. Strict regulations with improved monitoring, together with cleaner technologies, must be adopted. This is for reducing the environmental and health effects of gas flaring in Kirkuk. This paper adds to the environmental sustainability investigation by proving the power of GIS-based spatial analysis and dispersion modeling for monitoring air pollution variations at different locations. The research produces a combination of strategies that use GIS-based approaches in decision-making as well as dispersion modeling to inform better policymaking on environmental matters related to gas flaring.

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INTRODUCTION

The environmental issue in oil regions stems from gas flaring activities, which cause air contamination while generating changes in climate (Ogele, 2016; Whittle & Ong, 2024). During unregulated gas burning operations in oil extraction sites, several dangerous pollutants such as SO_2, NO_2, and PM (Hesketh, 2023; Shabbir, 2024) escape into the air, leading to severe air quality deterioration that threatens nearby residents' health (Hamed et al., 2021; Jumaah et al., 2023; Jumaah et al., 2024; Ajaj et al., 2025). A substantial amount of gas flaring in Kirkuk City of Iraq, has brought forth significant doubts about environmental sustainability and public health risks (Mills, 2018).

The investigation uses GPM in conjunction with GIS to study how air pollutants spread from gas flaring facilities in Kirkuk City (Ajaj et al., 2023). As an atmospheric dispersion tool, the

*Corresponding Author Email: *deman.salahdeen24gs@ntu.edu.iq*

Gaussian Plume Model acts as a widespread model to track pollutant spread across spatial areas during time periods (Stockie, 2011; Khan & Hassan, 2020; Ajaj et al., 2023; Snoun et al., 2023). The analysis of severe air pollution sites combines GIS tools with spatial techniques to determine environmental degradation levels resulting from different operational elements (Yerramilli et al., 2011; Ajaj et al., 2022; Ajaj et al., 2023; Jumaah & Kamran, 2024). The benefits of GIS collaborations in the field of technological capabilities for environmental assessment monitoring are an enhanced attainment of mapping qualities, as well as an improvement in the visualization of pollution patterns(Mahmood & Jumaah, 2023; Jamal Jumaah et al., 2024; Mahmood et al., 2024; Mahmood et al., 2025) and pollution dispersion patterns (Ameen et al., 2021; Ajaj et al., 2022; Ajaj et al., 2023). GIS successfully performs Gaussian Plume Modeling through its capacity to model atmospheric transport and evaluate pollutant dispersion in space (Ajaj et al., 2022). GIS facilitates pollution trend analysis by merging environmental data sources, allowing researchers to identify exposure areas and develop efficient response plans (Nuckols et al., 2004; Nasehi & Nohegar, 2025; Patel et al., 2025). GIS operates as a highly effective tool for Gaussian Plume Modeling because it enables spatial evaluation of pollutant dispersion while modeling atmospheric transport (Liu et al., 2025). Effective pollutant dispersion modeling in atmospheric environments serves both to locate dangerous areas and develop proper prevention strategies (Tikle et al., 2024; Kumar et al., 2025; Valle et al., 2025). Atmospheric conditions make some occupied areas vulnerable to unsafe pollutant exposure despite these exposure risks (Jumaah et al., 2018; Jumaah et al., 2019; Arshad et al., 2024; Mohammadi et al., 2025).

The gas flaring sites across the world pollute the air by emitting a considerable amount of greenhouse gases and toxic pollutants (Anejionu et al., 2015), which increase climate change and health problems, posing risks to human life (Obi et al., 2021). These emissions are more so in oil-producing areas such as Nigeria, Russia, and Iran, where there is still poor flaring practice (Agbonifo et al., 2024). On the same note, gas flaring in Kirkuk City, Iraq, around oil facilities is another area of air quality reduction, as the concentrations of particulate matter and gaseous pollutants have been observed to surge in places (Saleh, 2024). Although campaigns such as Zero Routine Flaring, led by the World Bank, plan to minimize emissions, Kirkuk still does not face strict regulation and surveillance (Altraiki et al., 2024). In the last Conference of the Parties COP meeting, it was agreed to impose restrictions on oil-burning facilities (Oyewunmi, 2021). The ruling aims at flaring and combustion activities that contribute largely to climate change. It sought countries to incorporate cleaner technology and improve monitoring so as to achieve the reduction in emissions targets.

The purpose of this research is to assess the effects of gas flaring sites on air quality and the sustainable environment in Kirkuk City by adopting GIS tools and the Gaussian Plume Model for spatial-temporal analysis. Recognizing gas flaring locations in Kirkuk City through GIS tools to establish their effect and closeness to human settlements. Moreover, to evaluate the density of pollutant gases and particulates resulting from gas flaring exercises with the help of the Gaussian Plume Model. So, we can assess the process implications of gas flaring to the sustainable development of Kirkuk City and Public health.

MATERIALS AND METHODS

Study area

The research area extends across the northeastern portion of Kirkuk city, where it lies between (44˚ 21́ – 40˚ 27́) E and (35˚ 24́ – 35˚ 30́) N, as shown in Figure 1.

The industrial process of gas flaring has become a critical environmental and public health problem in Kirkuk city because this standard practice continues in oil-exporting countries. Owing to its significant petroleum resources, Kirkuk city has permanently served as an industrial hub for petroleum exploration along with refining activities. The industrial operation,

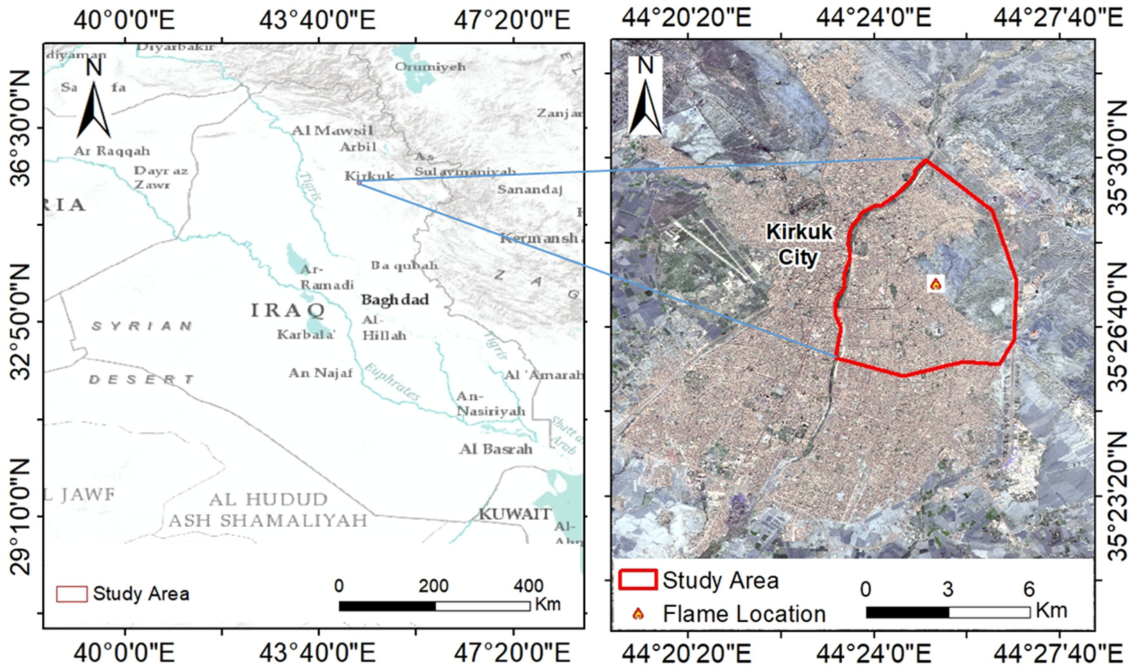


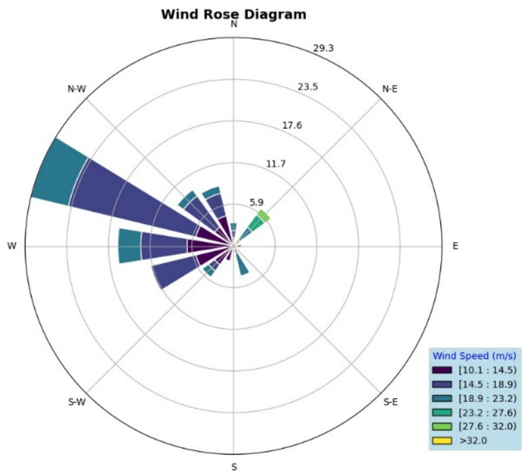
Fig. 1. Gas flaring location in the Kirkuk study region.

combined with natural gas flaring from crude oil extraction, results in substantial damage to the environment and public health in the city while opposing sustainable development initiatives.

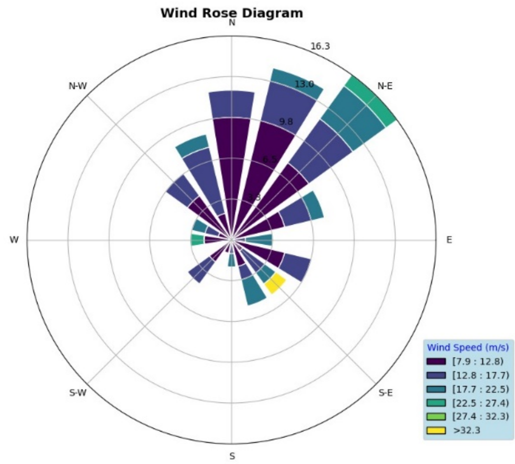
Data and analysis

The research collects different data points of air pollution measurements together with meteorological data to evaluate gas flaring effects on Kirkuk City's air quality. Figure 2 represents research data, including Wind Rose diagrams and data collection during the study period. The data collected in the year 2024 was divided into two periods; summer and winter.

Accumulated air pollution information contains measurements of sulfur dioxide (SO_2, NO_2, $PM_{2.5}$, and PM_{10} through both monitoring stations at ground level from online sources such as (https://air-quality.com/) and special devices used for data collection. The used device is shown in Figure 2(c), A portable multi-gas detector. Multiple datasets serve as vital information for validating the Gaussian Plume Dispersion Model, along with identifying the polluted areas. The data were collected each 100m intervals from the flare site for 2km in the study area. A successful model of pollutant dispersion depends heavily on meteorological data expressing wind speed and direction measurements. The data processing is based on $ArcGIS_{10.8}$ software and statistical analysis. The research uses GIS to combine datasets, which generates a complete pollution risk analysis to detect vulnerable zones while creating sustainable air quality management plans for Kirkuk City. In order to examine the model based on the measurements applied a sensitivity analysis was applied. A model of dispersion of gas flaring pollution functions on the conviction of Gaussian Plume principles using the Pasquil-Gifford stability divisions along with dispersion components. While scientists ought to find the key gas flaring points, scientists are to measure the rate of emission by pollutants, SO_2 and NO_2, and PM. The method adopted by the simulation is picking up meteorological data by incorporating wind speed and atmospheric stability, and temperature data to represent the dispersion of pollutants. Having resolved the position of the flaring site, the rate of emission, stack height, wind velocity, direction, category of atmospheric stability, mixing height over the study period of time, and other parameters, it is possible to



(a)



(b)

(c)

Fig. 2. Research data: (a) Wind in Summer, (b) Wind in Winter, and (c) Data collection.

obtain the expected downwind dispersion of pollutants using the model equation. The mapping of the results of dispersion with GIS to determine the affected areas and verify the hazards to nature and human health is done.

The process of estimation involves the application of Pasquil-Gifford stability classes, wind speed data, and atmospheric parameters to generate concentration values at specified measurements. Wind observation, solar radiation during the day, and cloud cover at night are applied to determine Pasquill-Gifford stability classes. Stability classes, when properly selected, prove useful in the determination of a proper calculation of the way gas settles after flaring in Kirkuk. As an example, during the summer, under sunny and windy conditions, pollutants can easily rise high due to Class A-C (unstable) conditions, but in the winter, pollutants can already

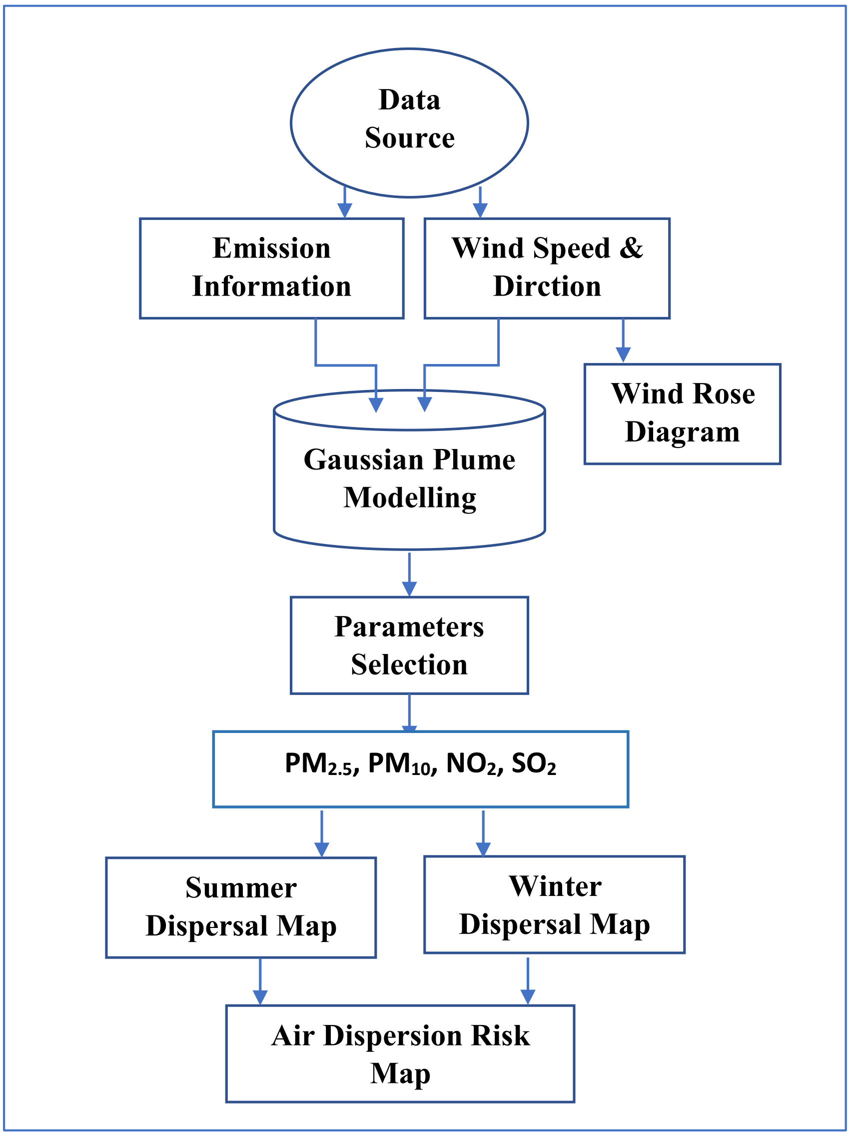


Fig. 3. The methodology applied in the research.

be at a lower level compared to low wind or cloud cover, i.e., Class D-F conditions become more stable. The dispersion is thus depicted realistically in different seasons as a result.

Flowchart

The methodology of the study is divided into three primary stages, starting with area data investigations, followed by Gaussian Plume Dispersion Model application, and ending with GIS-based pollution mapping. Figure 3 represents the flowchart of this research.

The flowchart starts with an initial process shown in its topmost section. Starts by identifying and creating the core issues that will direct the complete workflow in this initial step. The declared objective represents the central theme, allowing all following processes to remain focused on reaching this defined outcome.

The methodology contains two principal components that contribute to obtaining data through input collection.

The two components operate simultaneously to demonstrate the use of multiple data collection resources or methods. The data inputs include observations from source data, such as wind speed and wind direction, in addition to air pollution-related information at the flaring site. Adhesive data collection pathways merge into the modeling process section, which performs the GPM based on collected information. This information involves the emission rates of each pollutant will be modeled, besides wind speed and further GPM inputs such as sigma y and sigma z.

In modelling, the processed information will become stored and structured data in the form of prediction maps. The main function of this process enables proper organization and indexing of information to create access for upstream processing needs. The structured data goes through normalization, together with cleaning and transformation techniques, to optimize its usability for upcoming analytical procedures. As well, the inclusion of auxiliary data also takes place at this phase to expand the dataset for more extensive analysis capabilities.

Gaussian plume modeling represents this chart with its method for atmospheric pollutant dispersion prediction. The process initiation starts at level one with defining the objective by identifying pollutant dispersal characteristics along with emission sources and environmental consequences. The analysis phase purposefully arranges studies based on particular atmospheric conditions and emission patterns.

wind speed and direction alongside atmospheric stability measurements, together with information about emission sources that entails emission type and height, together with emission rate. The data processing step removes errors as well as inconsistencies to guarantee precise dispersion modeling results. The structured database receives the prepared data to provide convenient database access for processing operations. The development process includes transformation procedures that convert units while normalizing values and include combined environmental variables to improve simulation quality.

The following data collection phase gathers information from several sources, including the GPM allows us to evaluate how SO_2, NO_2, CO_2, and PM pollutants disperse from gas flaring sources. The concentration results at specific distances utilize Pasquill-Gifford stability classes and wind speed information, and atmospheric elements during the estimation procedure. The model determines gas flaring site emission levels through a comparison between its prediction model results and data from current airborne pollutant measurements. The analytical method shows precise distribution patterns of pollutants across every part of the urban area.

The system employs GIS technology to develop thorough air pollution risk zone mapping for visualization purposes. Environmental hazards appear as visual data through spatial studies via GIS operations during the last stage of the process. Model outputs and land use data, and population density information combine to create a single assessment through environmental impact assessment.

Dispersion model equation

The Gaussian plume equation serves as the main tool during the core analysis to create mathematical models for pollutant concentration based on source-to-point distances. The dispersion model determines vertical and horizontal distributions through diffusion coefficients and wind patterns, together with atmospheric stability group criteria.

The model software produces three types of results, which serve various impact assessment purposes, including air quality reporting and health risk evaluation, and compliance monitoring. The validated outputs use real-world monitoring data or historical observations for assessment. Implementable conclusions resulting from these activities become available to policymakers as well as environmental agencies and industries for effective pollution control and air quality management decisions.

The gas flaring pollution dispersion model functions using Gaussian Plume mechanics, which integrates Pasquill-Gifford stability sectors with dispersion variables. Researchers need to determine gas flaring sites and measure emission levels of pollutants such as SO_2, NO_2, along with PM. The simulation implements meteorological data integration through wind speed data and atmospheric stability, and temperature additions for modeling pollutant dispersion.

The Gaussian dispersion equation enables workers to predict pollutant concentrations, which they can use to determine concentrations at different distances from the release point. This model follows the following mathematical statement, according to Ajaj et al. (2023).

$$C(x,y,z) = \frac{Q}{2\pi u \sigma_y \sigma_z} \exp\left(-\frac{y^2}{2\sigma_y^2}\right) [\exp\left(-\frac{(z-H)^2}{2\sigma_z^2}\right) + \exp\left(-\frac{(z+H)^2}{2\sigma_z^2}\right) \quad (1)$$

Where, $C(x,y,z)$; The input parameters concentrations at a specific distance from the flare point. (Q): Is the emission rate of each input (pollutant). (u): Is wind speed. ($\sigma_y \sigma_z$) Are the pollutant dispersion coefficients in the lateral direction (y) with vertical direction (z), and (H) is the effective height.

RESULTS AND DISCUSSIONS

Pollutant monitoring results demonstrate concentration changes throughout time at different distances from the emission point, where changes result from meteorological wind characteristics. The described concentration values serve to identify exposure hotspots that enable specialists to evaluate health dangers for residents surrounding emission sources.

The necessary data enables environmental agencies, together with policymakers, to develop preventive measures for emission control and zoning management while creating emergency preparedness plans for hazardous material releases. The model demonstrates useful capabilities to understand the effects different atmospheric conditions have on dispersion, thus enabling experts to forecast future risk scenarios and improve weather prediction systems.

Model refinement must be done if observations differ from predictions because this indicates that deviations require improved input data or expanded dispersion strategy inclusion. Following verification of model results, they become applicable for regulatory compliance assessments and industrial planning purposes, and environmental impact studies. Table 1 represents the atmospheric stability results.

The table provided calculations of the GPM dispersion coefficient in the lateral and vertical directions of certain pollutants in both summer and winter as a function of distance from a flare site. We evaluated the impact within 2km of the source. As observed, the impact of dispersion has spread 1 km from the source. The distance from the source point seems to relate to increased variability within measurement results. The parameter values during the summer months exceed winter measurements for both metrics according to seasonal data. The system exhibits changes due to external elements like temperature, humidity, and wind patterns, along with industrial activity, since these factors show seasonal variations.

According to the equations, the parameters exhibit a nonlinear pattern of increase because minimal distance changes result in significant parameter fluctuations.

The physical property dynamics that happen in different seasons at a distance from a source can be explained by studying this table. These defined power-law mathematical relationships provide useful predictive modeling tools for environmental science or engineering disciplines because they explain measurement processes at depth. Additional research should examine the natural factors as well as the characteristics of source emissions, which function differently between seasons.

Moreover, Figure 4 and Figure 5 represent the GPM in Summer and Winter, respectively.

Figure 4 and Figure 5 show results establishing spatial relationships that explain the

Table 1. Atmospheric stability results.

Proposed remoteness of flame (m)	Summer Season		Winter Season	
	σ_y 0.22* $y^{0.91}$	σ_z 0.2* $y^{0.86}$	σ_y 0.16* $y^{0.90}$	σ_z 0.12* $y^{0.85}$
100	14.53526	10.49615	10.09532	6.014247
200	27.31241	19.05091	18.83853	10.84069
300	39.50054	26.99941	27.13496	15.30151
400	51.32126	34.57814	35.15394	19.54035
500	62.87607	41.89326	42.97273	23.62141
600	74.22331	49.00496	50.63562	27.58099
700	85.40079	55.95183	58.17123	31.44232
800	96.43497	62.76064	65.59957	35.22149
900	107.3454	69.45101	72.93538	38.93027
1000	118.147	76.03788	80.18996	42.57761
1100	128.8517	82.53301	87.37223	46.17055
1200	139.469	88.94589	94.4894	49.71476
1300	150.0069	95.28428	101.5474	53.21488
1400	160.472	101.5547	108.5513	56.67481
1500	170.87	107.7627	115.5054	60.09783
1600	181.2057	113.913	122.4131	63.48677
1700	191.4834	120.0096	129.2778	66.84406
1800	201.7069	126.0562	136.1022	70.17184
1900	211.8793	132.056	142.8888	73.47199
2000	222.0036	138.0117	149.6398	76.74618

distribution patterns. This map shows four maps that display simulated pollutant dispersal from a "Gas Flame" source located in Kirkuk city, where the emission originates from industrial or combustion activities. The circular dispersion pattern depicts "Gas Flame" sources through concentric circles spreading from their central points on each of the displayed maps. The visual indications of pollutant levels demonstrate increased concentration through warmer tones and decreased concentration through cool tones.

Based on Figure 4, four air pollutant dispersion maps ($PM_{2.5}$, PM_{10}, NO_2, and SO_2) in summer from a gas flame source cover an urban area in Kirkuk city. The dispersion patterns in the maps follow a concentric arc design, which demonstrates increasing concentrations from the source outward. A green-yellow-red color scheme displays $PM_{2.5}$ dispersion, which expands widely throughout the displayed area. PM_{10} presents a dispersion pattern that resembles that of $PM_{2.5}$ while displaying a slightly more compact spreading area. Blue-colored NO_2 is the most widespread due to its extensive area of dispersion compared to other airborne pollutants. SO_2 can be observed through its red-beige gradient pattern and demonstrates steady distribution, yet it dissipates faster than NO_2. Visual assessments indicate gas pollutants such as NO_2 spread greater distances than both particle matter classifications, and $PM_{2.5}$ travels higher distances than PM_{10}.

Based on Figure 5, the $PM_{2.5}$ μg/m³ dispersion pattern demonstrates a tight distribution since the densest concentrations remain near the source point, which reduces quickly moving away from the source. According to the legend, the study area shows $PM_{2.5}$ concentrations ranging from the very low value of 1.93E-11 μg/m³ to the very high concentration of 5194.2394 μg/m³. The air pollutant $PM_{2.5}$ poses serious health risks to humans because it manages to pass

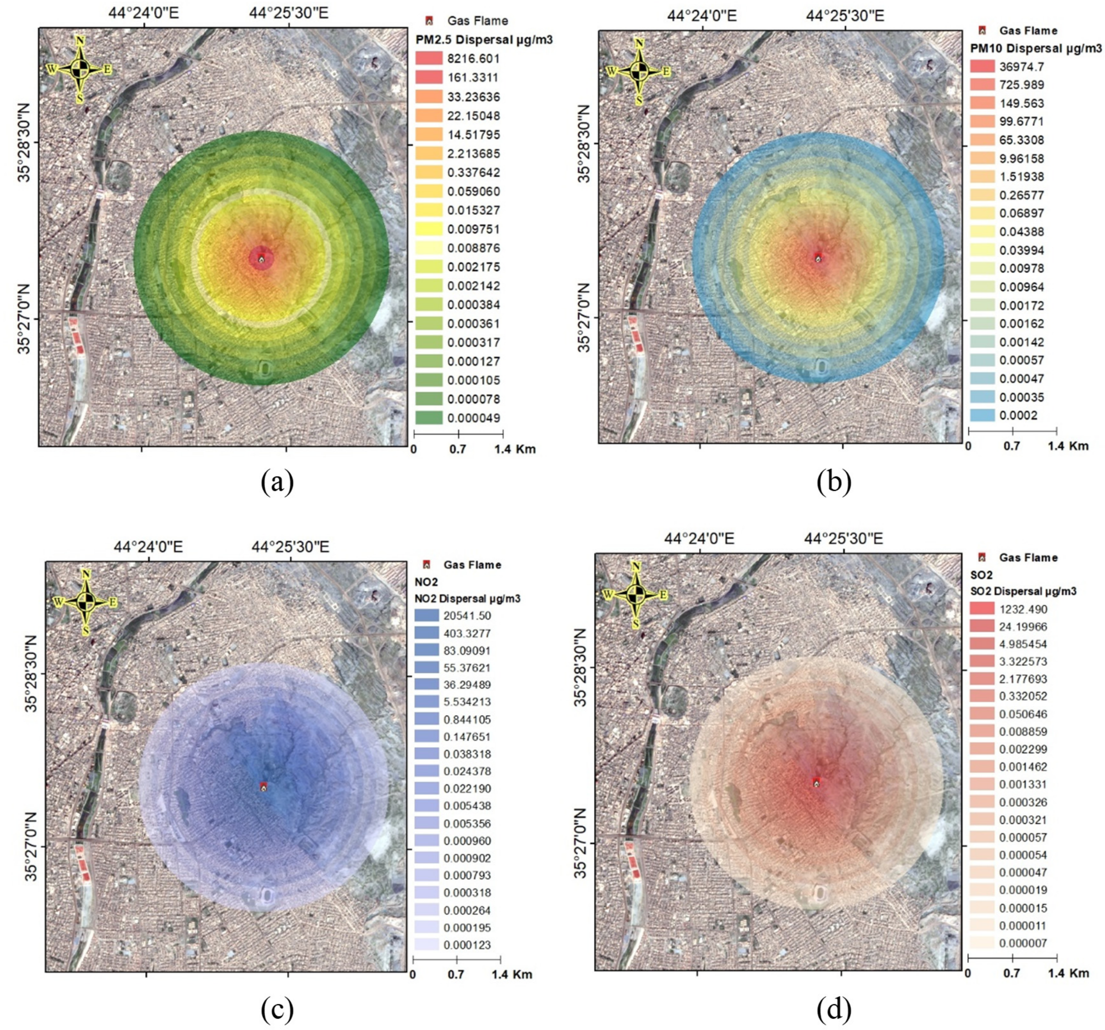


Fig. 4. Gaussian Dispersion Model in Summer: (a) $PM_{2.5}$, (b) PM_{10}, (c) NO_2, (d) SO_2.

through the respiratory system to the deepest parts of the lungs. The distribution pattern of PM_{10} Dispersion µg/m³ reveals that larger particles move away from their source point over greater distances when compared to $PM_{2.5}$. A legend measuring from 3.47438E-12 µg/m³ to 307.985516 µg/m³ displays within the dispersion pattern. Despite having a lower maximum concentration than $PM_{2.5}$, the overall values are considerable. The health hazards attributed to PM_{10} exist, yet are typically less serious than those related to $PM_{2.5}$.

The dispersion pattern of NO_2 extends more broadly throughout the area compared to particulate matter because air currents easily carry NO_2 particles. The legend spans across a measurement width from 3.47438E-up to 584.3519384 µg/m³. NO_2 is one of the primary constituents of smog, which causes respiratory issues in people.

SO_2 dispersion displays a density pattern that stands close to $PM_{2.5}$ densities, though it exhibits higher concentrations in specific localized areas. The legend area in this map extends across a range from 2.86643E-13 µg/m³ to 648.275553 µg/m³. SO_2 is a significant airborne substance that both causes acid rain formations and respiratory problems.

Furthermore, Figure 6 represents the air dispersion risk map.

The presented map shows that "Gas Flame" as an emission source releases substantial levels of $PM_{2.5}$ and PM_{10} particulate matter along with NO_2 and SO_2 pollutants into the atmosphere.

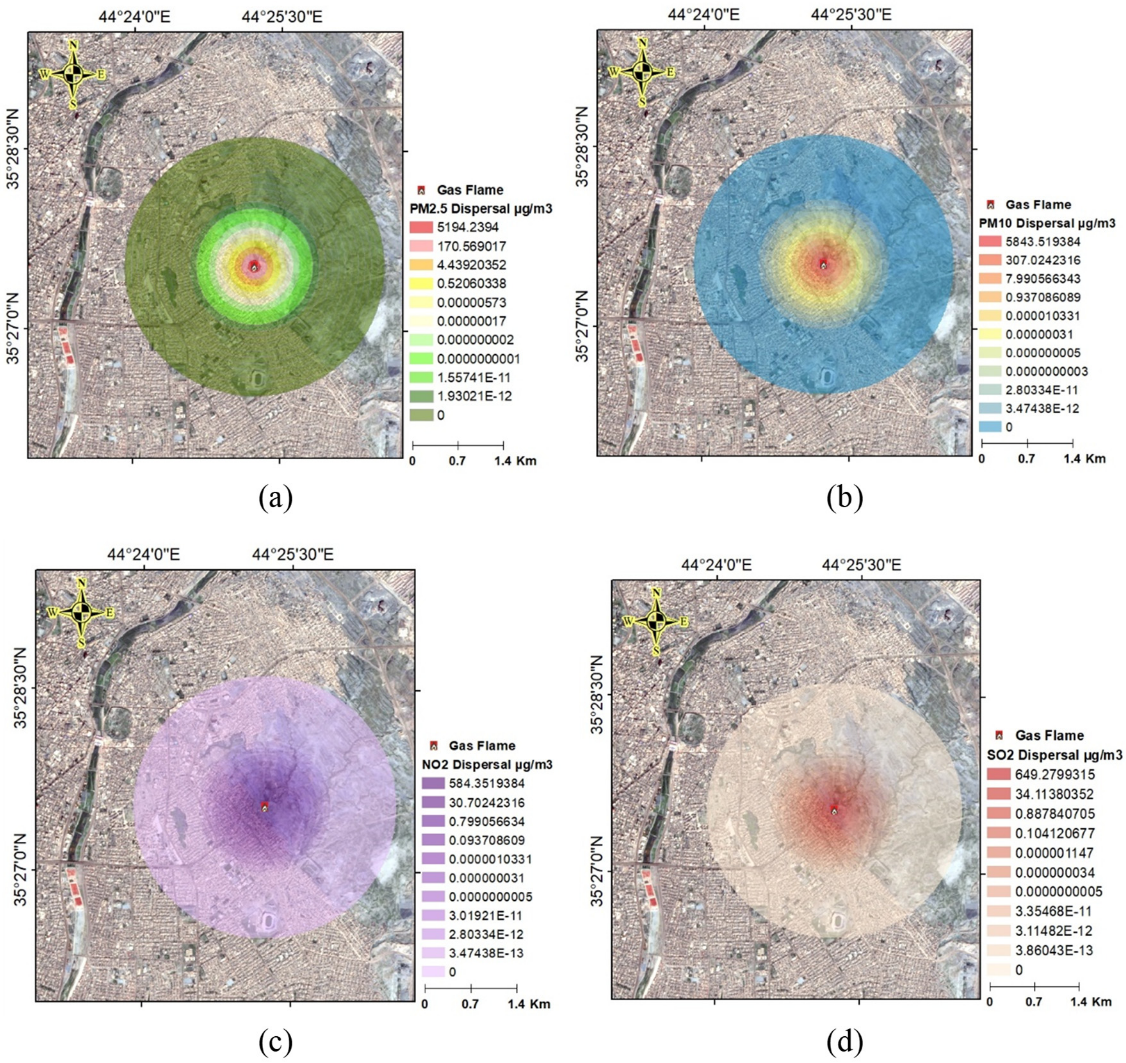


Fig. 5. Gaussian Dispersion Model in Winter: (a) $PM_{2.5}$, (b) PM_{10}, (c) NO_2, (d) SO_2.

The distribution of pollutants varies by substance since their chemical components exhibit diverse physical characteristics. This fundamental information enables the proper estimation of environmental and health repercussions from emission sources alongside the development of reduction techniques. The patterns of dispersion depend heavily on wind velocities and directions, as well as atmospheric stability. Meteorological factors affect the dispersion pattern.

Compared to World Health Organization (WHO) standards, the ratified average daily limit $PM_{2.5}$ reading of 15 μg/m³ and the annual average $PM_{2.5}$ limit of μg/m³ (Ameen et al., 2025). Based on Walters et al. (2015) are to be followed as opposed to the U.S. Environmental Protection Agency USEPA limit of 35 μg/m³ and 12 μg/m³ annually. According to Lindvall (1985) and Jumaah et al. (2025), the WHO promotes a maximum of μg/m³ of NO_2 during no more than an hour, and the USEPA establishes 188 μg/m³ (100 ppb).

The topography close to the source affects how pollutants spread in the environment. The terrain produces either funneling patterns or blocks the spread of pollutants.

Implementations of GPM for four essential pollutants in Kirkuk city show how pollutants spread into the environment from the gas flame source while illustrating health and environmental risks related to this emission.

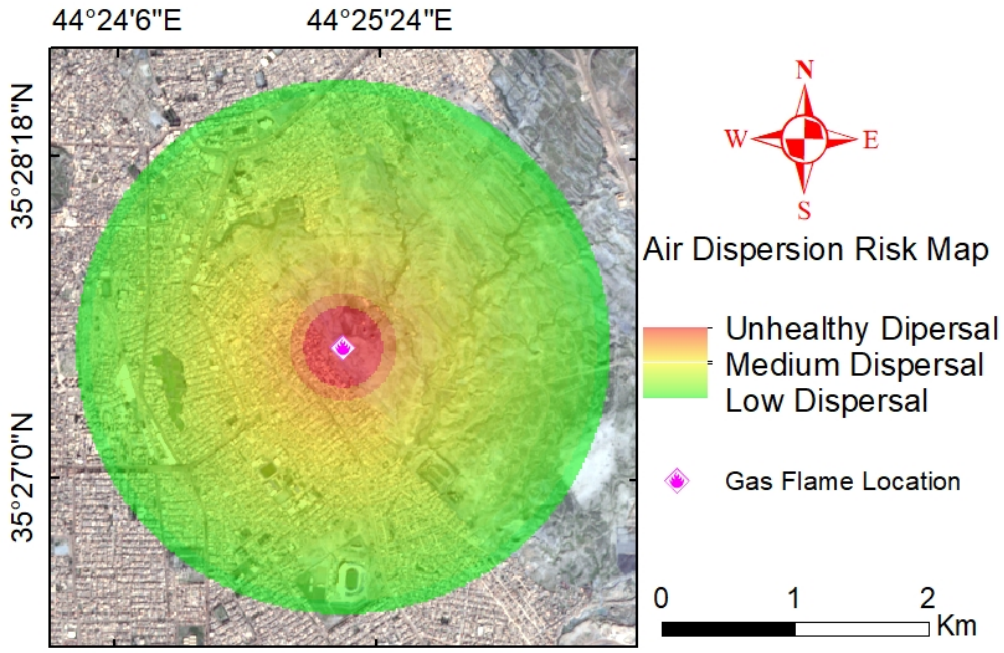


Fig. 6. Air dispersion risk map.

To examine the accuracy of measurements used in the research and to get a clear picture of the outputs of the models, a sensitivity analysis was used. Even in the ideal circumstances, the Gaussian Plume Model tends to have 30-50 percent errors relative to the actual data. Some difference in Q of +10 % and -10 % means that the concentration will vary by +10 % and -10 % in that same direction.

The effect of wind speed is opposite to that of dispersion; a change in the wind speed can vary the availability by 20-30 percent. In addition, when the stability varies, the ground-level concentrations may change dramatically. The main effects of even slight rises in height are high amounts of toxic gas near the ground. In the sensitivity analysis component, the basic parameter (wind speed) in the study is adjusted to determine its impact on the model results. we changed (wind speed) by +20%, the result was -16.6%. This implies an increment in the speed of wind, resulting in a 16.6 percent reduction in the level of pollution. The speed of the wind works opposite to pollution dispersion.

Most likely, the wind speed and direction will not be the same as assumed in the Gaussian Plume Model. This adaptation may falsely portray the alteration of the dispersion of pollutants in regions that have a high density of buildings. With such constraints, pollution may not be calculated accurately, especially where the weather conditions have been erratic.

The obtained research results help develop a deeper understanding of air pollution patterns, which strengthens decision-making capabilities regarding pollution regulation and health safety assessments, and sustainable city structure development.

The limitations of this study have to be mentioned. At first, the dispersion modeling relied much on the availability and quality of the input data, especially the meteorological parameters and the emission rate, which were, in some cases, limited or generalized. Second, there was a paucity in ground-based air quality measurements that restricted verification of the concentrations in the models. Furthermore, the experiment only has a limited period in consideration and might not reflect changes in pollutant dispersions across all seasons. The limitations used here would indicate that future research ought to incorporate more extensive and persistent information sources to make better model calibration and validation.

CONCLUSION

Environmental and atmospheric hazards that are highly sustained are based on gas flaring in oil-producing provinces such as Kirkuk City. This research demonstrates that the concentration of pollutants is the highest in the vicinity of flaring places, and it lowers with distance, yet certain places are still in danger. These results appear to be strong indications that appropriate policies are necessary to tightly curb and correct the effects of gas flaring, as this affects the quality and sustainability of the air. An environmental assessment based on GIS spatial analysis linked with dispersion modeling provides useful tools to policymakers as it offers a systematic approach for developing sustainable solutions, according to the research.

Sensitivity analysis was applied in this study to evaluate the accuracy of the Gaussian Plume Model, because, in addition to placing the analysis in an inference position, it was used as a method of understanding and quantifying uncertainty regarding the predictions. Uncertainties in input variables, which include emission rates, wind speed, mixing height, and stability class, are very sensitive to the model outputs, and hence, a slight deviation in the input variables may cause a huge variation in estimated pollutant concentrations. The sensitivity test showed that some of the parameters were so essential, especially the wind speed and the atmospheric stability, that they are influential on the output concentrations. This means that the ambiguity surrounding model outcomes is firmly connected to the accuracy and dependability of such main inputs. Thus, uncertainty is part of the model even where the model is well-calibrated with measured pollutant concentrations, particularly in the urban setting where the meteorology is complex.

Improving gas flaring response is vital because it enhances the quality of city air while defending human health and promoting sustainable Kirkuk City development.

The most important recommendations include elevating the flare pipe beyond 10 meters to minimize the concentration of the pollutants on the ground to secure residential facilities. Establishing a green buffer around a flare site to reduce the dispersion and enhance the local air quality. Encourage investment in flared gas into energy projects to cut down wastage and attain sustainable economy and environmental gains. The research creates a complete framework that combines decision-making methods from GIS with dispersion models for helping policymakers handle environmental problems caused by gas flaring. The research study demonstrates that sustaining environmental regulations together with proper planning remains crucial to reduce air pollution threats throughout Kirkuk City, as well as additional worldwide areas.

A future study should be directed to high-resolution temporal surveillance to detect short-lived exposure spikes. Researchers ought to also assess how well developed emission controls work, and simulate the health scores of the vulnerable groups in the long run. This could be enhanced by combining satellite with ground measurements to achieve more accuracy in identifying hotspots of pollution.

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CONFLICT OF INTEREST

The authors declare that there is not any conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

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