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A Regional Investigation of Inverse Distance Weighting Particulate Matter Prediction within Kirkuk City, Iraq

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Abstract: It is well known that air polluted with particulate matter (PM) has a negative impact on human health. It is important to monitor and evaluate air quality by revealing the nature of the air and identifying the areas affected by particles. The methods and tools used for this purpose vary. This study aims to predict air quality based on PM data collected using an air pollution measuring device to measure the values of particulate matter (PM) in different sizes. The Inverse Distance Weighted (IDW) approach was used within the Geographic Information Systems (GIS) analysis tools. The tool was applied to measurements collected in Kirkuk city's study area for 2022. Besides, testing PM2.5 data has been collected in 2025 for the validation process. The results showed that there are higher rates of PM than the acceptable standards, which therefore cause health effects. The accuracy value of the prediction data was also calculated for each of the PM1, PM2.5, PM5, and PM10 concentrations. Model validation accuracy results were 80%, 89%, 84%, and 72%, respectively. While cross validation resulted in 82%. The results indicated a good fit for the prediction determined by the analysis. Moreover, the health risks have also been detected from the spatial distribution of each pollutant. Based on our analysis and results, good, moderate, and unhealthy air was detected in the study area.

Keywords: Particulate Matter, IDW, GIS, air quality, health impact.

Introduction

Public health faces an urgent environmental challenge from air pollution because PM concentrations in the atmosphere continue to grow (Ajaj et al., 2025; Amiri and Shahne, 2025; Jumaah and Kamran, 2024; Jumaah et al., 2023). The suspension of solid and liquid particles in the air, called particulate matter, functions as a primary agent in creating damaged air quality environments while simultaneously being a direct cause of heart and respiratory diseases (Ameen et al., 2025; Nawaz et al., 2025). Size-classification of PM types includes PM1 as well as PM2.5 and PM5 and PM10, which correspond to airborne particles with dimensions below 1 micrometer, 2.5 micrometers, 5 micrometers, and 10 micrometers, respectively (Ngangmo and Adiang, 2025). Particles that originate from vehicle emissions and industrial production, and construction activities, as well as dust storms, naturally create these polluting air molecules (Ibrahim and Khidhir, 2023; Salih and Hassan, 2023; Singh et al., 2025). Because fine particles are small enough to reach deep areas through the lungs and bloodstream, they produce health problems when present at moderate levels (Nyayapathi et al., 2025; Mahmood et al., 2024; Zhang et al., 2024). Urban planning, together with public health management, depends strongly on continuous PM concentration monitoring and accurate prediction systems (Jumaah et al., 2024; Sharma et al., 2024; Ali et al., 2022).

The Inverse Distance Weighted (IDW) method used in GIS serves as one of the major interpolation techniques for estimating values in areas without data points based on observed data (Vadurin et al., 2025; Jumaah et al., 2019; Ajaj et al., 2018). IDW functions by calculating that points nearer to sampling sites possess more values in common than distant points, allowing it to predict realistic spatial pollution patterns within defined regions (Gu et al., 2021). In comparison with other methods, the results from Kriging are better than those from IDW in regions where values vary (Ikechukwu et al., 2017). Contrarily, spline interpolation gives the surface a sleeker appearance but can reduce the number of visible changes in contaminants (Qiao et al., 2019).

You might observe that as data follows spatial patterns, Kriging can deal with the uncertainties involved, even though IDW remains a good option for straight forward and fast calculations in many situations (Aalianvari et al., 2025).

The research objectives are to assess and analyze airborne particulate matter (PM1, PM2.5, PM5, PM10) levels across Kirkuk City and to implement the IDW interpolation technique in GIS, which determines the spatial distribution patterns of air pollution. The PM concentration predictions need assessment for accuracy through testing the performance quality of the developed model. The significant problems with the health risks related to excessive urban particulate matter levels are emphasized through this study. This work is notable for employing GIS-based interpolation to create maps of PM concentrations across Kirkuk city from multi-size particulate data. It brings together maps of pollution with assessments of health risks, showing a complete picture of air quality. This type of process gives urban planners and public health teams tips useful for local communities. This study supports policy authorities by helping them create focused interventions for reducing air pollution in order to safeguard public wellness.

Materials and Methods

Study Area and PM Sampling

The research sites were located within Kirkuk City (Fig 1), situated in northern Iraq. It has semi-arid weather conditions while facing growing population density that affects air quality conditions.

The study team selected twenty-seven separate locations across Kirkuk City that spanned residential, industrial, commercial, and traffic-rich zones to obtain sampling data. The used device for data collection was the Dust Detector (Figure 2). Moreover, Table 1 represents the study area sampling regions.

Average data of each pollutant have been considered after measurements, which applied in the years 2022 and 2025. Monthly data of PM10, PM5, PM2.5, and PM1 have been collected since 2022. The average data have been considered in the analyses. In order to test and evaluate the proposed model, cross validation applied on the 2025 PM2.5 dataset of ten testing points selected within the study area.

An analysis of different city regions took place through the selection of sites that provided full spatial coverage and allowed researchers to assess particulate matter distributions throughout the entire urban area. The air pollution measuring device conducted data collection activities by measuring PM1, PM2.5, PM5, and PM10 amounts simultaneously. The collected data from these particular areas formed the base for spatial interpolation models and geographic information systems-based IDW analysis. The zonal classification established a precise framework for pinpointing contamination origins and evaluating their health-related consequences at the city's subregions.

A research study evaluates the air quality standards of Kirkuk City in Iraq through the analysis of PM monitoring data with 2022. The city's different PM pollution sites were surveyed with an air pollution measuring device, which recorded PM1, PM2.5 and PM5, and PM10 particle counts. A spatial distribution analysis through GIS employing the IDW method processed the obtained data to produce mapping results for each PM category. The generated maps showed pollution zones that spanned from locations with good and moderate levels to those with unhealthy air quality. The study uses spatial analysis to both create pollution visualization elements and determine vital hotspots that need to be addressed through intervention strategies.

GIS-based IDW

IDW creates a surface map that shows pollution levels in the study area through a continuous presentation of calculated values while using distance-based weight assignments that enable hotspot detection.

Results and Discussion

The study explains how different PM concentrations match up with various health risks. The research successfully shows how GIS combined with IDW interpolation technology produces effective results for urban particulate matter spatial forecasting and assessment. The research performs a quantitative assessment to determine accuracy levels for each PM type within the prediction model. The research findings present essential knowledge for officials who work to control air pollution effects on human well-being and environmental protection organizations. Figure 3 represents the IDW map of PM10, PM5, PM2.5, and PM1, respectively.

Based on the (PM10 map), the area shows the spatial PM10 concentration distribution of 27 regions in Kirkuk City (in µg/m³) through IDW interpolation in GIS. Three colors on the map indicate PM10 pollution levels. Areas with low PM10 levels (Green color: 24–54 µg/m³) exist mainly in the northern and central areas of Kirkuk in regions 1, 2, 4, 5, 8, 9, 12, and 13. These geographic locations appear less industrialized frequently and maintain better air

Table 1. Study area sampling regions.

Id	Region
1	Raheem Awa
2	Sarjenar
3	Barotkhanah
4	Azadi
5	Almas
6	Shorja
7	Imam Kasim
8	Hay Alulamaa
9	Hay Alwihda
10	Hay Alnasir
11	Aluroba
12	Alqadesiyah
13	Province Street
14	Baghdad Way
15	Tisin
16	Hay Alkhadraa
17	Hay Alaskary
18	Hay Asra
19	Hay Alazawraa
20	Domeez
21	Wahid Athar
22	Abulrahman Street
23	Technical College
24	Wahid Huzairan
25	Hay Alwasity
26	Gas Alshimal Appartment
27	Sahat Alehtifalat

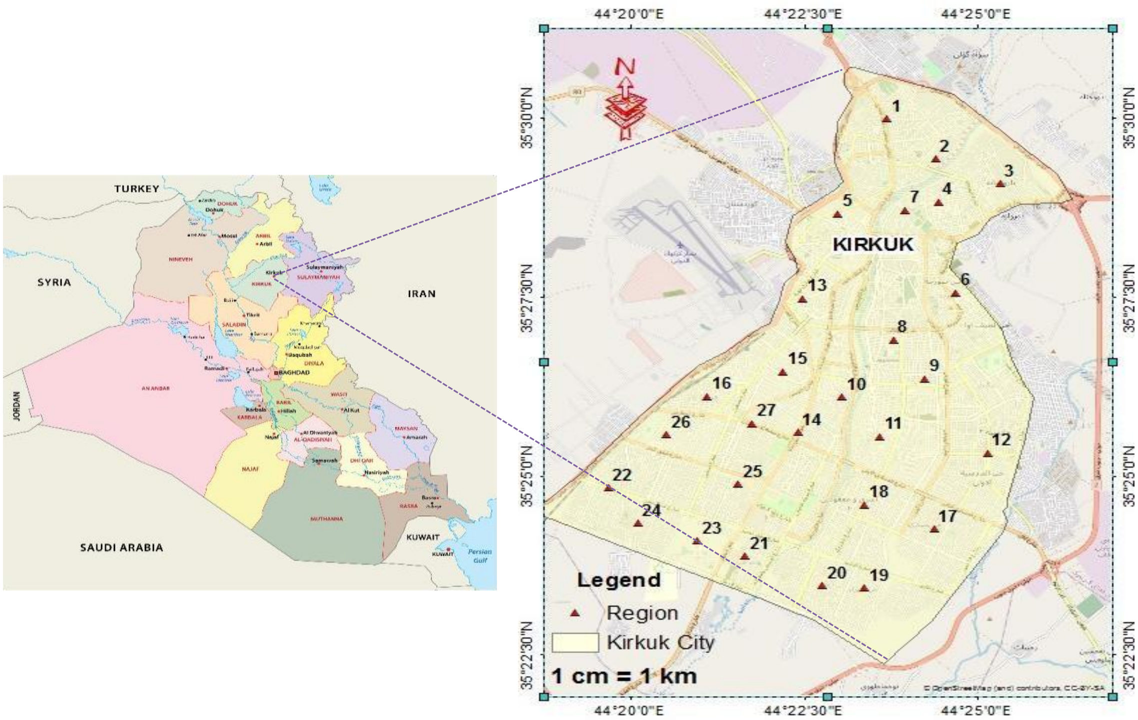

Fig 1. PM samples in Kirkuk City.

Fig 2. Dust Detector.

circulation while having light traffic levels PM10 levels shown in (Yellow color: 55–154 µg/m³) throughout the central and eastern parts of Kirkuk, involve the number 3, 6, 7, 10, 11, 14, 17, and 18 regions. This area represents moderate air pollution. The locations with mixed pollution sources contain both light-traffic areas and construction sites in their vicinity.

Unhealthy PM10 levels in (Orange color: 155–208 µg/m³) are shown in the southern and southwestern regions of Kirkuk, such as 16, 19, 20, 21, 22, 23, 24, 25, and 26. Multiple factors, such as industrial emissions, dirt roads and heavy road traffic, and wind-blown dust from arid terrain seem to explain why pollution levels remain high in this particular area.

Based on (PM5 map), the PM5 concentration distribution across Kirkuk City shows distinct geographical patterns since lower concentrations (15–54 µg/m³) exist mainly in central and northward areas, yet higher levels (55–110 µg/m³) predominate in the southern and southeastern parts of the city. PM5 levels remain high in areas from 17 to 25 because of elevated vehicle exhaust emissions, together with industrial activities, coupled with dust spreading from open land areas. The northern regions 1, 5, and 13 present clean air conditions. High concentration spots located in regions 2 and indicate that pollution sources exist throughout all areas, requiring targeted environmental improvement strategies.

Based on the (PM2.5 map), the PM2.5 concentration map of Kirkuk City shows high pollution levels exceeding safe limits in the southern regions 19 and 20, reaching levels from 55.5 to 115 µg/m³ as marked in red. According to PM2.5 standards provided by Jumaah et al. (2023), more than 55 µg/m³ falls within unhealthy levels. These extreme levels present substantial health dangers to the population. External areas 18 and 21 display moderate pollution quantities (35.5–55.4 µg/m³) while PM2.5 levels create a pollution range from south to north. The PM2.5 levels in the majority of central and northeastern parts amount to 12.1–35.4 µg/m³, which the environmental association classifies as noteworthy but less severe. The PM2.5 levels in region 16 characterize localized clean conditions because they remain at 11–12 µg/m³.

Based on the (PM1 map), the PM1 concentration rates in Kirkuk City show similarities with this and other particulate matter distributions by increasing pollution among southern regions. The areas from Regions 9 to 16 present air quality in the green zone between 6–12 µg/m³, which leads to no health risks. Locations situated across the central section of Kirkuk City would probably improve from enhanced airborne circulation patterns, together with reduced vehicle traffic and fewer contamination points. Most parts of the region, including northern and eastern areas, show light to moderate pollution levels that affect sensitive individuals according to the yellow zone ratings of 12.1–35.4 µg/m³.

The pollution hotspots that form the major concern exist in regions 19, 20, and 21, which have been designated as orange zone areas (35.5–50 µg/m³). These areas face significant air pollution, mostly due to vehicle emissions and industrial activities combined with wind-blown dust. High-pollution areas of the southern districts need particularly concentrated environmental controls to protect air quality, but existing limits in clean areas should remain intact.

Furthermore, Figure 4 shows an IDW map of cross validation PM2.5 points in Kirkuk City. The map data is distributed between (30-32) µg/m^3.

The assessment of IDW predictions achieved satisfactory accuracy ratings of 80% for PM1 and 89% for PM2.5 and 84% for PM5, as well as 72% for PM10. The predictions show good accuracy levels, particularly for smaller particle sizes, due to their natural tendency to disperse easily. Figure 5 shows the validation process of PM in Kirkuk City. While Figure 6 represents cross validation of PM2.5 in Kirkuk City.

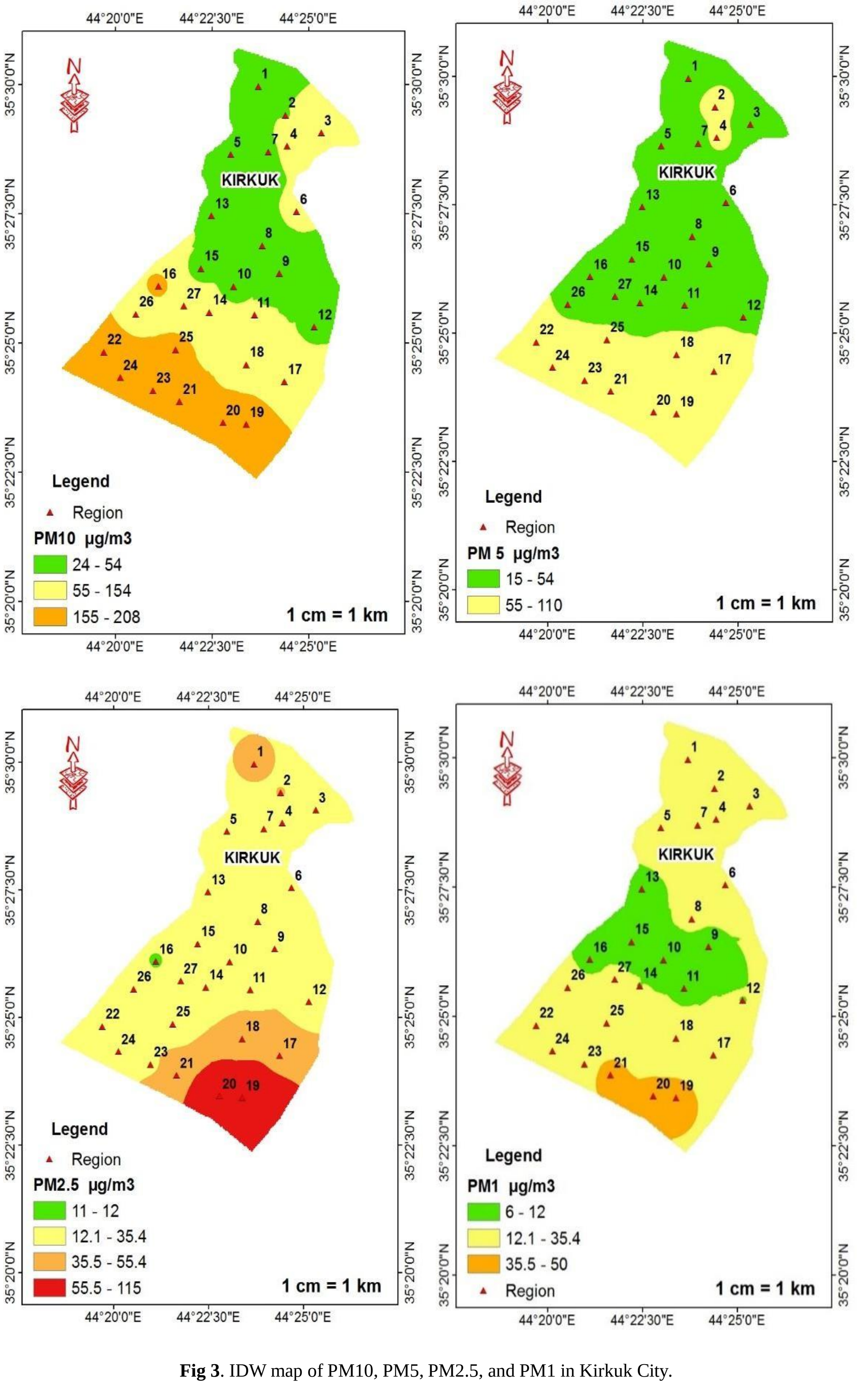

Fig 3. IDW map of PM10, PM5, PM2.5, and PM1 in Kirkuk City.

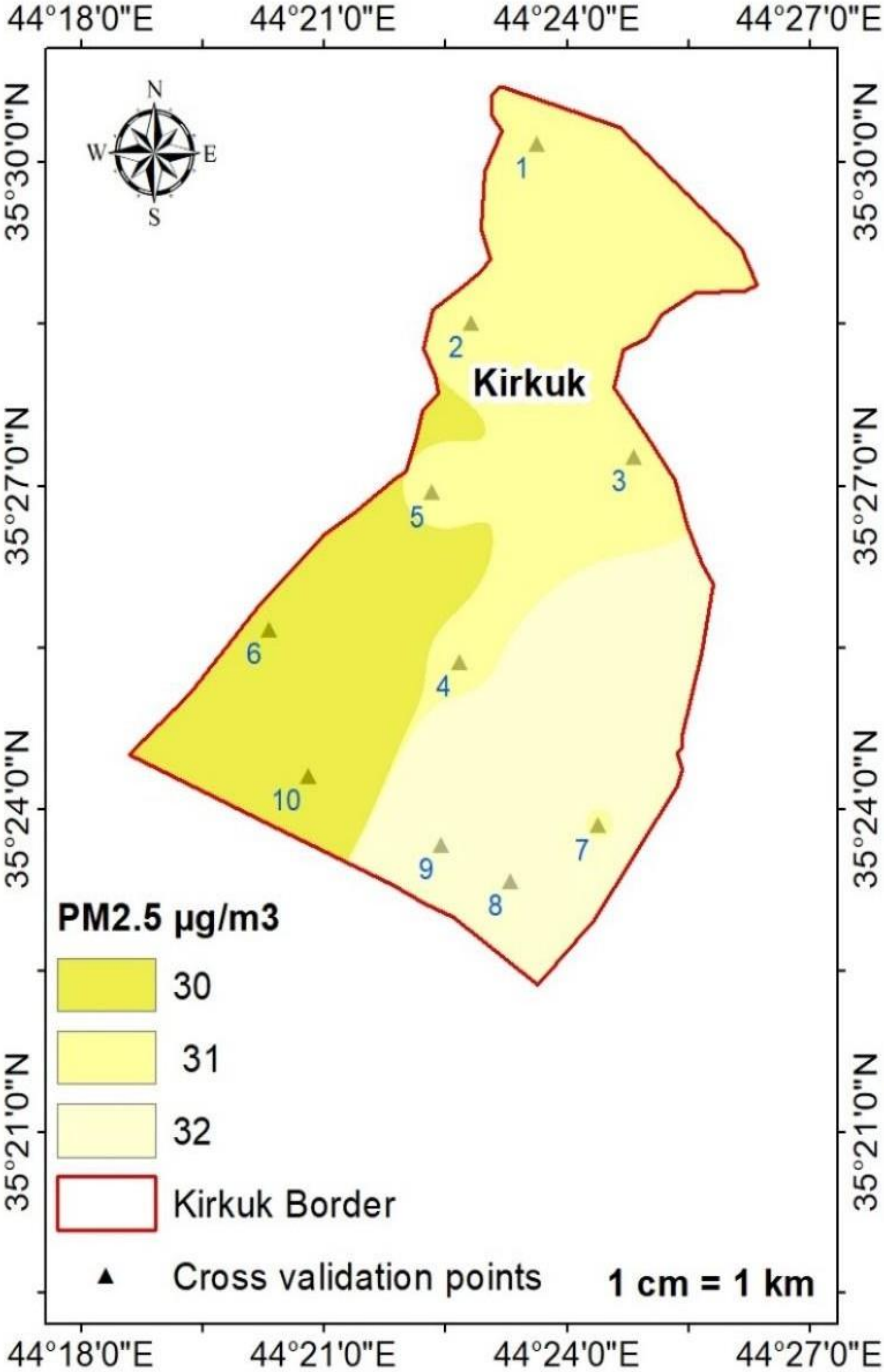

Fig 4. IDW map of cross validation PM2.5 points in Kirkuk City.

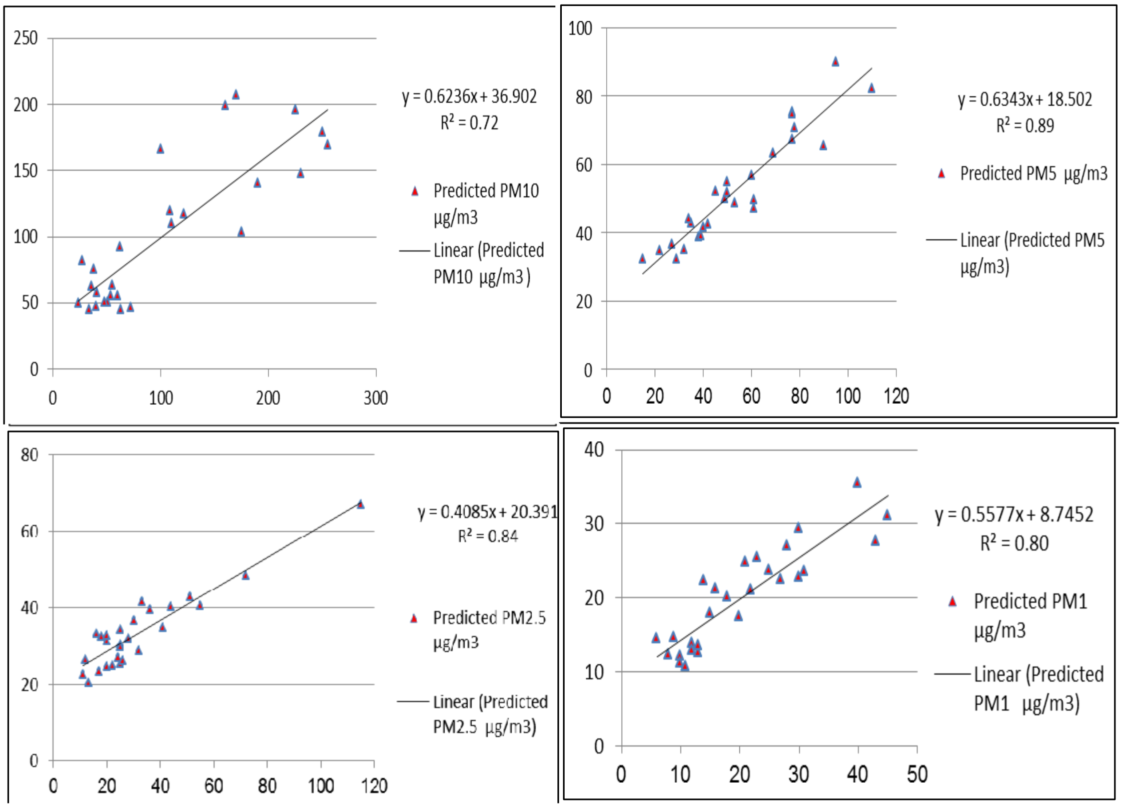

Fig 5. Validation process of PM in Kirkuk City.

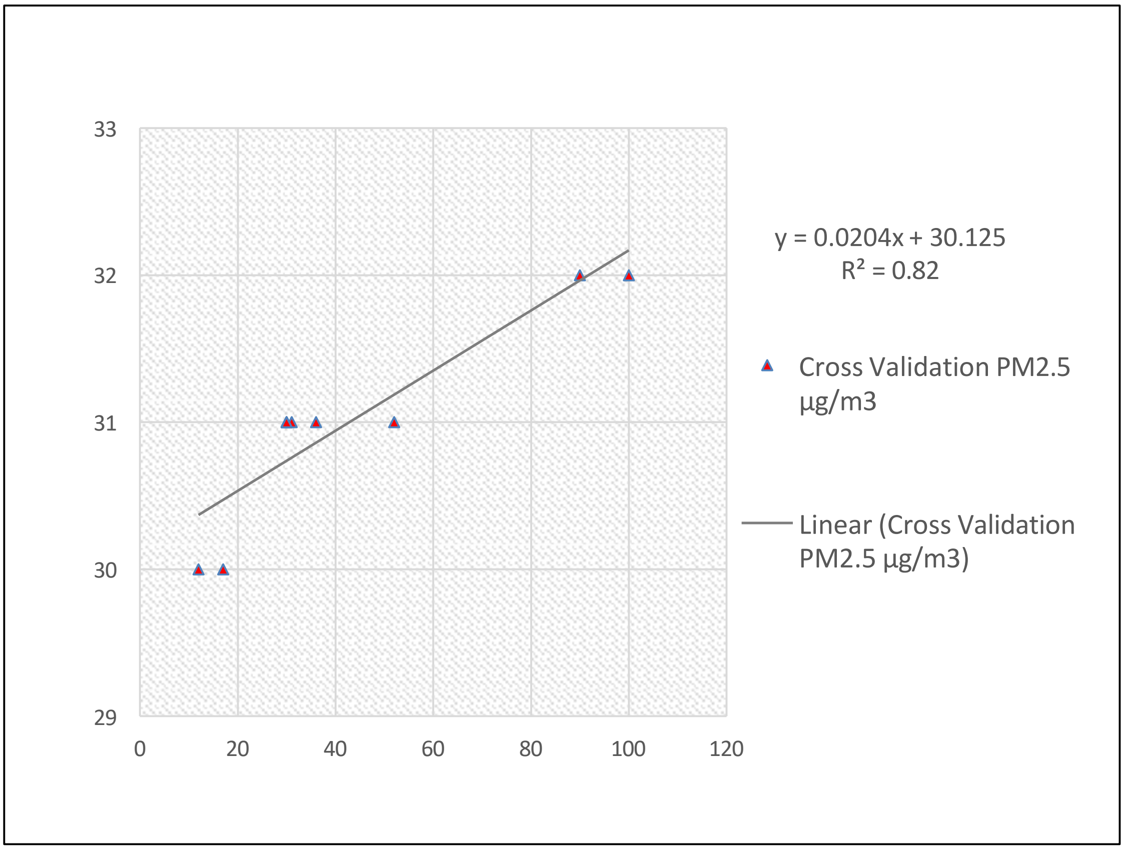

Fig. 6. Cross Validation of PM2.5 in Kirkuk City.

Part of the PM pollution in the city comes from heavy traffic vehicles, especially from diesel-fuelled automobiles used for public transport. The operations involved in processing oil add significantly to the amount of air pollution. In the region, construction workplaces and unpaved roads, plus regular dust storms, cause more coarse PM to appear in the air.

This study gives useful information on the quality of air in Kirkuk, but it also has some data and error constraints. A concern is how properly the air pollution measuring instruments are working to collect PM data. Slight errors in setting up or using the sensors can lead to wrong readings for nearly invisible PM1 and PM2.5. Assuming that togetherness in the data directly guides prediction, the IDW method may neglect the influence of winds, the landscape, and urban areas on pollutant dispersal. Furthermore, PM10 predictions are less accurate than others, as the validation found an accuracy of 72% for those PMs. The results imply that there is still a chance to improve the predictive approach, as the model works differently for various pollutant sizes. In addition to weather, patterns of road use, industrial activities, and short-term building work might have made PM concentrations vary in a way unaccounted for in our model during the study. When applying these findings, the limitations should not be ignored.

Conclusion

Different zones throughout the city displayed varying degrees of air pollution according to internationally accepted air quality thresholds, but failed to meet these thresholds in several areas. The spatial maps effectively depicted different zones, which corresponded to air quality categories from good to moderate to unhealthy, while suggesting irregular pollutant distribution that originates from nearby emission areas. The prediction model achieved remarkable accuracy when measuring PM2.5 at 89% and PM1 at 80%, thus confirming the reliable performance of IDW for air pollution spatial estimation with cross validation of 82%. Research evidence confirms that elevated particles in urban areas create severe dangers to the environment and human health.

The proposed recommendations will work to solve both the PM level increase sources and the resulting problems. Green spaces should increase throughout urban areas. Trees and green belts serve as effective natural instruments that block the transit of dust, together with pollutants. The government should prioritize building access to cost-efficient public transportation options to minimize vehicular usage because of their high reliability rates. Reducing vehicular emissions, which constitute significant PM sources, will be possible through this initiative. The public needs to understand air pollution dangers through education efforts that promote pollution reduction measures by staying indoors during dangerous pollution times. Urban planners should make GIS tools and spatial analysis fundamental for environmental research to detect polluted areas and determine the proper locations for infrastructure development that protect the environment.

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