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ARTICLE

Air Pollution Risk Assessment Using GIS and Remotely Sensed Data in Kirkuk City, Iraq

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ABSTRACT

According to World Health Organization (WHO) estimates and based on a world population review, Iraq ranks tenth among the most air-polluted countries in the world. In this study, the authors tried to evaluate the outdoor air of Kirkuk City north of Iraq. The authors relied on two types of data: field measurements and remotely sensed data. Fifteen air quality points were determined in the study region representing the monthly average measurements implemented for the one-year dataset. Geographic information systems (GIS) based geo-statistic and geo-processing techniques have been applied to collected data. Spatial distribution data related to Air Quality Index (AQI), and Particulate Matter (PM10 and PM2.5) were obtained by mapping collected records. Remotely sensed data of PM2.5 were analyzed and compared with the collected data. Health impacts were assessed per each air pollutant determined in the study. Spatial distribution maps revealed the hazardous air type in the study area. Overall AQI ranged between 300 and 472 μg/m^3 referring to unhealthy, very unhealthy, and hazardous classes of pollution. Also, PM10 ranged between 300 and 570 μg/m^3 indicating the same class of air pollution from unhealthy to hazardous. While PM2.5 ranged between 40 and 60 μg/m^3 which represents unhealthy air for sensitive persons and unhealthy air. The remotely sensed data revealed different air types for the study period ranging from 14.5 to 52.5 μg/m^3 represented in moderate and unhealthy air for sensitive persons. Significant correlations were obtained where the mean local R^2 (coefficient of determination) was obtained as 0.83. The assessed data were within high air pollution that requires immediate intervention for controlling causes and eliminating their effects.

Keywords: Air pollution risk; AQI; GIS; Particulate matter; Remote sensing

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1. Introduction

Iraq is known as an oil exporting country and this industry is considered the main source of pollution in Iraq [1,2]. Besides, the country has suffered from many wars that led to many effects including high rates of air pollution [3]. Also, it today suffers from increased daily dust storms [4]. Dust storms cross the borders of countries and increase their intensity and frequency by increasing desertification and reducing vegetation cover. They have adverse effects that carry particles suspended in the air for a long time and cause health effects [5]. The entire world is going through major climate change, including the Middle East region in which Iraq is located [2]. Besides the rapid urbanization and industrialization development combined with the increased number of cars in the streets, have led to serious air contamination in terms of haze. This increased the particulate matter in the air more than standard levels [6]. All these conditions have caused many problems in the country involving high levels of air contamination dramatically [2,3]. Various forms of air pollution are available, but most of them include particulate matter PM2.5 and PM10. PM2.5 particularly, has been detected to be harmful to people according to many epidemiological studies. So, researchers emphasized PM2.5 in air quality evaluation and monitoring [7]. The outcomes of many research show the exceeding levels of these pollutants in various regions in Iraq which passes standard criteria [3,8], where according to an exploratory analysis using a GIS-based spatial method applied in Kirkuk City, defined the high concentrations of PM2.5 as unhealthy air [9].

The U.S. Environmental Protection Agency introduced the AQI which is a useful reporting index of daily air criteria. It reports the air quality data per its health effects [10].

Numerous studies have highlighted the adverse effects of air pollution on public health and the environment [11-13]. However, conducting a comprehensive air pollution risk assessment that incorporates spatial analysis and remote sensing techniques can provide a more detailed understanding of pollution sources, dispersion patterns, and potential exposure hotspots. GIS enables the integration of diverse data layers, including meteorological, topographical, and land-use data, to create accurate pollution models and visualizations [14]. Meanwhile, remotely sensed data acquired from satellites and aerial platforms offer valuable information on pollutant concentrations, atmospheric conditions, and land cover characteristics [15]. By combining these technologies, a holistic approach to air pollution assessment can be achieved [16].

Environmental modeling has a significant history and many applications in environmental-related problems [17]. These problems relate to the study of large areas where the geographic information system (GIS) is a beneficial tool for assessing and evaluating [18].

Whereas, GIS is able to integrate different information sources that allow the interpretation of data via different modeling and visualization techniques [19]. Therefore, GIS is considered a decision support system for the experts concerned with conducting evaluations and management [20-22]. Where using the modeling and GIS-based spatial analysis is risen to date [23]. modern techniques for analyzing, assessing, and modeling have been developed [24]. For instance, air quality assessment is useful in controlling air pollution problems [25]. Geographic information systems (GIS) and remotely sensed data have emerged as invaluable resources for analyzing and visualizing complex environmental phenomena, including air and water pollution [26,27].

In recent years, geographical information systems (GIS) and remotely sensed (RS) data have emerged as valuable tools for analyzing air pollution patterns and assessing associated risks. This study focuses on utilizing GIS and remotely sensed data to conduct an air pollution risk assessment in Kirkuk City, Iraq, a region facing increasing pollution challenges due to rapid urbanization and industrialization.

In the past decade, high levels of air pollution in the city of Kirkuk have become a problem, and have contributed to an increase in the rate of diseases associated with the respiratory system. Most asthma and other respiratory diseases are due to inhaling unclean air, which is polluted and loaded with "toxic gases and smoke emissions" from the oil industry and factories operating in Kirkuk. The city has become the third most polluted city in Iraq. Many causes lie behind the city's air pollution, including the oil industry, vehicle emissions, and waste. It is necessary to assess the risks and aggravation of air pollution in the city. The increasing number of cars in the streets of the city, the large number of private electrical generators, in addition to the industrial development, and the establishment of factories inside or near the city are all factors that have contributed significantly to the high levels of pollution in the air. Nowadays most of Iraq's cities suffering from severe air contamination causing serious health impacts.

This study aimed to investigate the contamination levels in Kirkuk City based on field measurements and remote sensing imagery. Moreover, GIS-based assessment was applied using geo-statistical analysis so health impacts can be determined and hazards of exposure detected. This work can be used for reference to air pollution management.

2. Materials and methods

2.1 Study area

Kirkuk city belongs to Kirkuk province and it's located in the northern part of Iraq. It lies between longitudes (44°14' and 44°28') E and latitudes (35°18' and 35°32') N. **Figure 1** represents the Kirkuk study area of air quality.

The study area climate is described as dry, very hot, and hot semi-arid in the summer season while, is cold in winter with rain periods from October to April, with an average annual precipitation of 342.7 mm. The evapotranspiration ranges about 1662.9 mm with average annual temperatures of 3 °C to 43 °C [28].

2.2 Datasets and measurements

Fifteen air quality points were selected in the study area, each point representing an area in the study site, the city of Kirkuk. The study period extended from April 2022 to January 2023, which was applied in the city of Kirkuk and included all areas within the city limits.

Data were collected in three ways: manually applied field measurements, remote sensing-based data downloaded as satellite imagery, and station data downloaded from global atmospheric sites. Field data have been collected regularly by five daily measurements at each point then we used the average value of all applied monthly measurements.

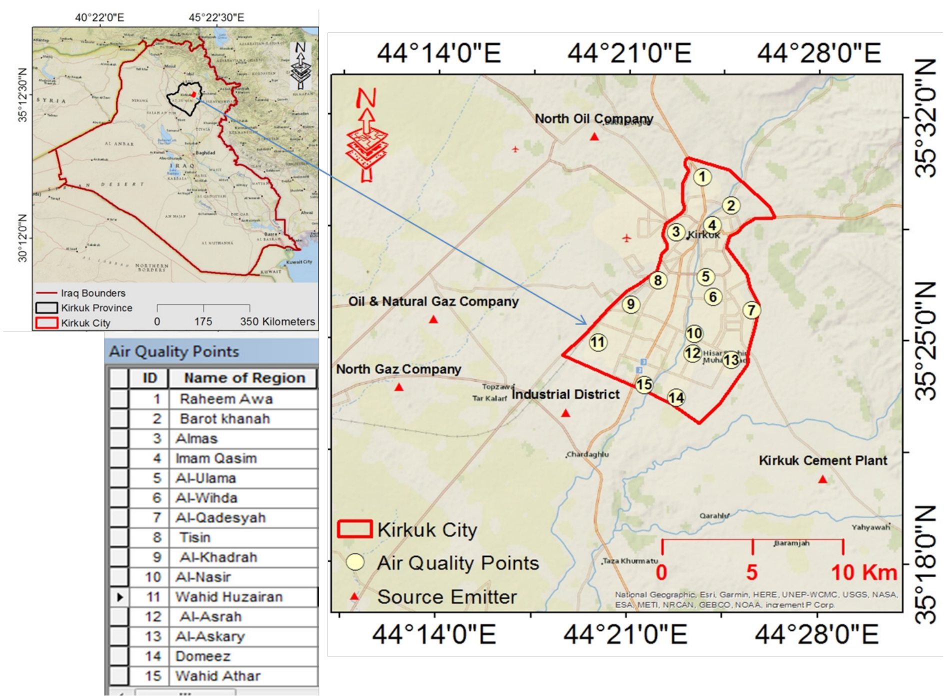


Figure 1. Kirkuk study area of air quality.

While AQI data were gathered from the historical data of the Kirkuk ground station for each month. The average value was used for mapping. Remotely sensed PM2.5 extracted from specific images for each month.

We relied on manual measurements using an Air Quality Monitor for trained data and Air Quality Multimeter for tested data. Air Quality Monitor (ZH01-B) a portable dust concentration device measures suspended dust particles data of PM10, PM5, PM2.5, and PM1 with a range of 0-1000 μg/m^3, ± 20% accuracy and 1 μg/m^3 resolution. In terms of health effects according to the criteria, we divided the type of data into two parts PM10 and less, and PM2.5 and less. Air Quality Multimeter device was used to collect tested PM2.5 data which was used later for validations. The device measures dust PM2.5 with a range of 0-500 μg/m^3 and ± 10% accuracy.

Remotely sensed PM2.5 data were downloaded from an open-source application via [29]. These data comprise PM2.5 dust mass levels extracted from the M2TMNXAER dataset which is data collection in (MERRA-2) Modern-Era Retrospective analysis for Research and Applications version 2. This group data comprise integrated aerosol diagnostics, for example (dust PM2.5, sulfate, black and organic carbon, aerosol, and Aerosol Optical Thickness (AOT) at 550 nm). In addition, it contains a variance of definite factors. MERRA-2 is the modern ver. of universal atmospheric re-analysis for the satellite era created by NASA Global Modeling and Assimilation Office (GMAO) via the Goddard Earth Observing System Model (GEOS) version 5.12.4.

Moreover, AQI data were obtained from the Air Matter Global Service downloaded from [30]. Air Matter displays air AQI for Kirkuk city station in the study area. We collected the ten months' data and then used the average in our investigation.

2.3 Methods

In this study, two GIS techniques were applied to draw distributed air pollution maps and to predict new locations based on the coordinates of each region and city boundaries of Kirkuk.

GIS-based geo-processing was used for the raster conversion of the downloaded images of each date (April 2022, June 2022, August 2022, October 2022, December 2022, and January 2023). The geo-processing outcomes have resulted in polygon data which was used later for mapping and point data estimation.

Besides, GIS-based geo-statistics has been applied for mapping air pollution distributed maps of the field data. Which was used to interpolate the points by Inverse Distance Weighted (IDW) to predict the new points data based on used 15 air quality points. This was applied to field group PM data.

The applied methods in the study are shown in **Figure 2**. Furthermore, **Table 1** represents the air quality criterion.

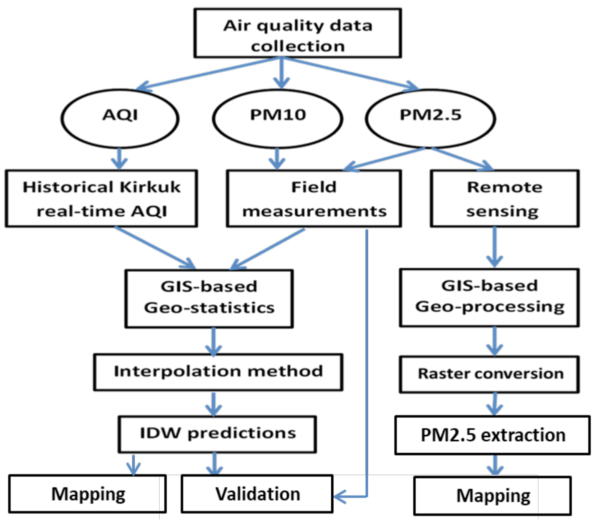


Figure 2. The applied methods in the study.

Table 1. Air quality criterion [3].

AQI	PM2.5 (μg/m^3)	PM10 (μg/m^3)	Air quality
0-50	0-12.0	0-54	Good
51-100	12.1-35.4	55-154	Moderate
101-150	35.5-55.4	155-254	Unhealthy for sensitive groups
151-200	55.5-150.4	255-354	Unhealthy
201-300	150.5-250.4	355-424	Very unhealthy
301-500	250.5-500.4	425-604	Hazardous

Table 1 involves the air quality criteria for AQI, PM2.5, and PM10. Based on these criteria we can describe whether air quality is healthy or not. Air

quality is classified as good, moderate, and unhealthy. Besides the table involve the very unhealthy with hazardous air type and the unhealthy for sensitive people who suffer from respiratory diseases such as allergies and asthma, in addition to the elderly, and people who suffer from chronic diseases or heart diseases.

3. Results

3.1 GIS-based geo-statistics results

Figure 3 represents the air quality spatial distributions in Kirkuk City from April 2022 to January 2023.

Based on **Figure 3(a)** The AQI was within a very unhealthy air class with an average of 386 AQI. Based on **Figure 3(b)** PM10 was within unhealthy air to hazardous with values of 300 to 570 μg/m^3.

Regions 1, 2, 6, 7, 10, and 14 have shown hazardous values of PM10. Regions 3, 4, 5, 8, 9, and 15 have shown unhealthy air of PM10 concentrations. The remaining areas had very unhealthy air in terms of PM10.

Furthermore, PM2.5 values were between 40 and 60 μg/m^3 as shown in **Figure 3(c)** which represents unhealthy air and values out of standards that result in health effects.

Regions 5, 6, 10, 11, and 15 have shown unhealthy air of PM2.5 concentrations. While the rest areas were within 40-55.4 μg/m^3 unhealthy for sensitive groups of people and they should limit outdoor exertion.

The levels of PM2.5 in **Figure 3** showed unhealthy air for sensitive people in all regions except regions 5, 6, 10, 11, and 15 where depicted unhealthy air is situated in the southwestern part of the city and some regions in the center.

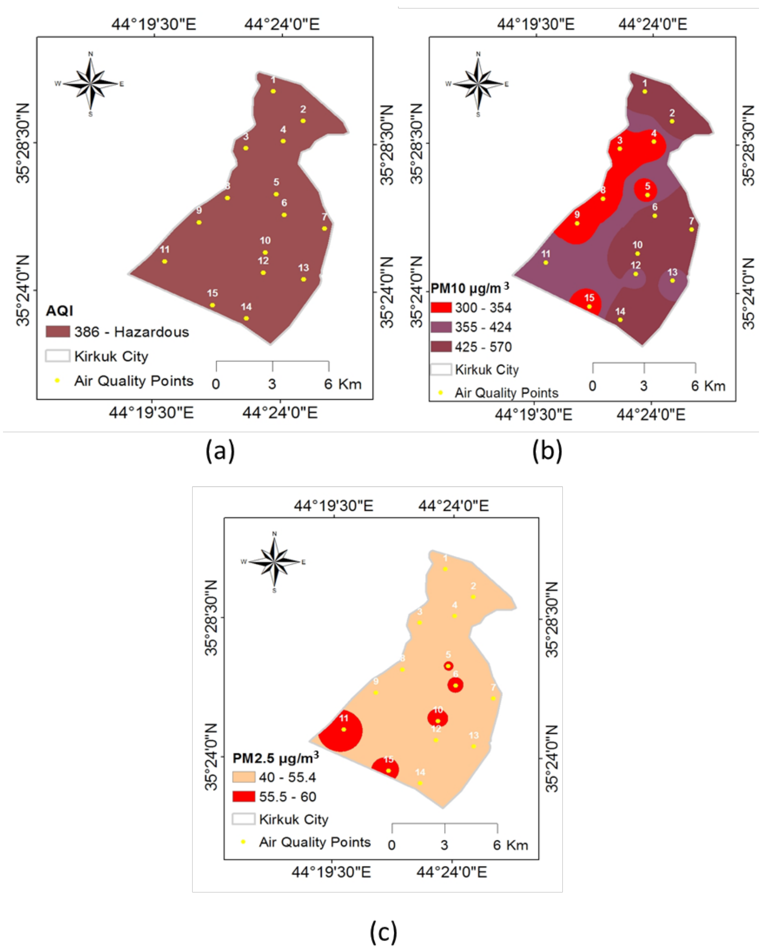


Figure 3. Air quality spatial distributions in Kirkuk city from April 2022 to January 2023: (a) AQI, (b) PM10, (c) PM2.5.

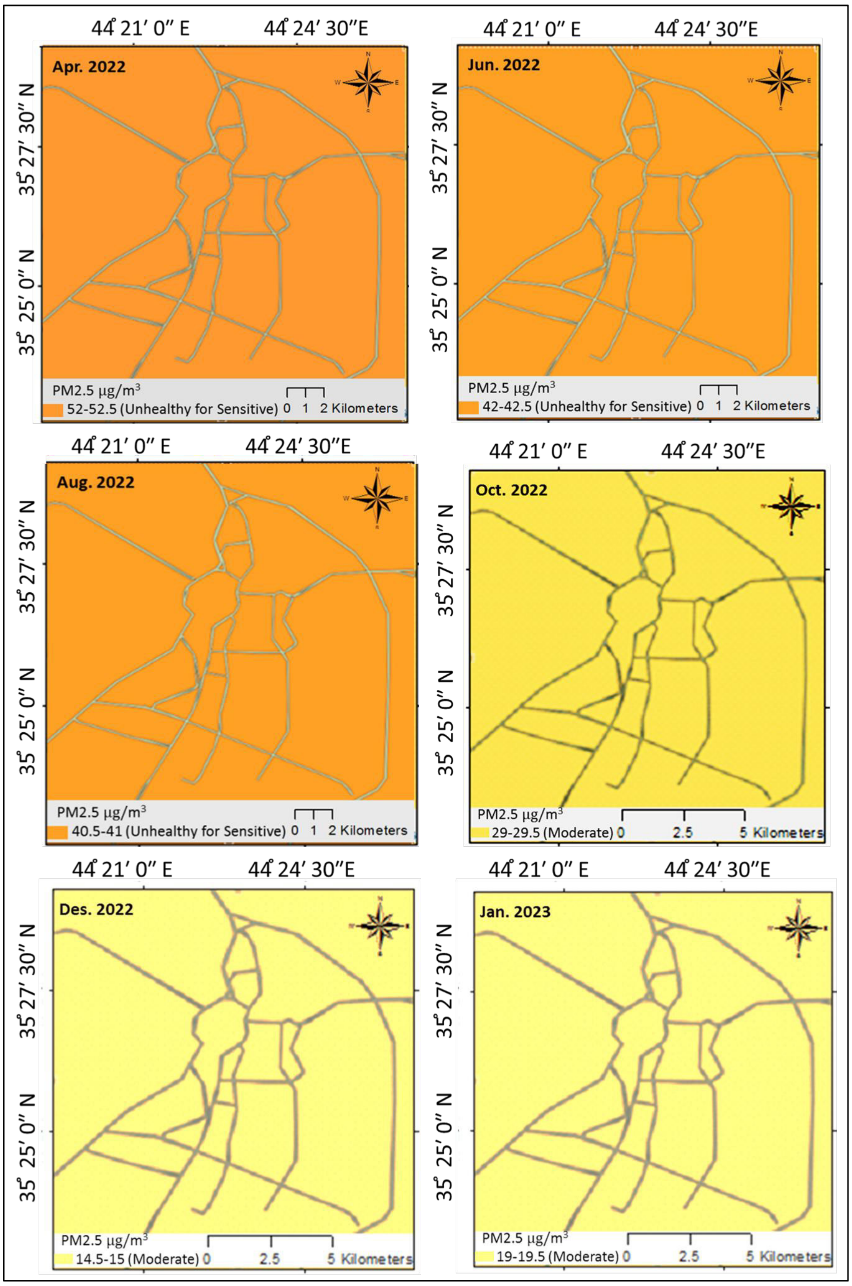


Figure 4. Remotely sensed PM2.5 air quality spatial distributions in Kirkuk city from April 2022 to January 2023.

3.2.GIS-based geoprocessing results

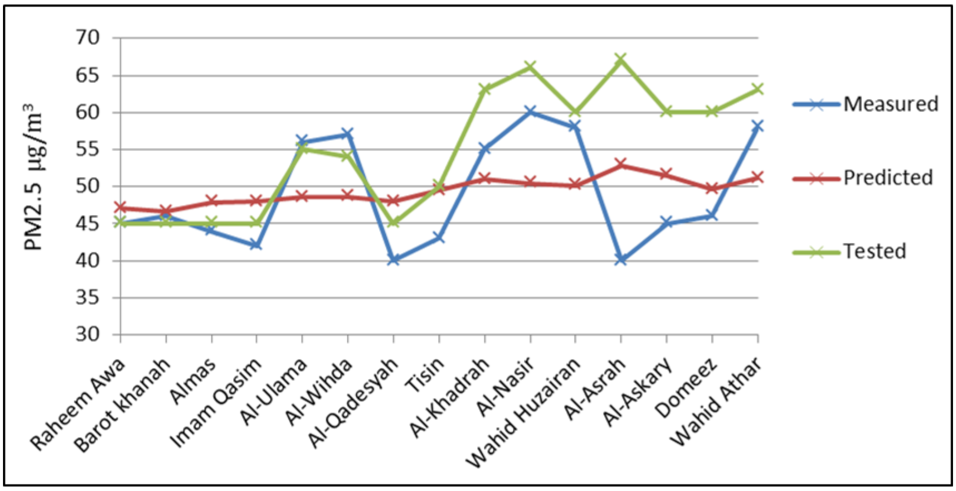
Figure 4 represents the remotely sensed PM2.5 air quality spatial distributions in Kirkuk City from April 2022 to January 2023. PM2.5 values were between 40.5 and 52.5 μg/m^3 for the period of April to August 2022. The air quality was classified as out of criteria that cause some problems for people with respiratory diseases and who have allergies. The highest value was in April 2022 which ranged between 52 and 52.5 μg/m^3. While in June 2022 it ranged between 42 and 42.5 μg/m^3. The lowest value was between 40.5 and 41 μg/m^3 in August 2022.

From October 2022 to January 2023, the air quality was moderate type with no serious effects of PM2.5. The highest values were within 29-29.5 μg/m^3 in October 2022, 14.5 and 15 μg/m^3 in December 2022, and 19-19.5 μg/m^3 in January 2023.

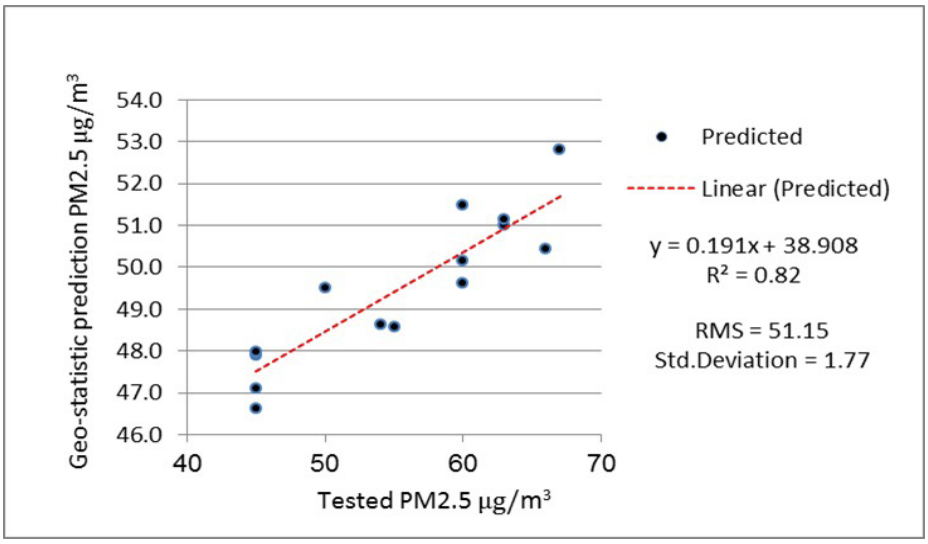
Remotely sensed PM2.5 was at moderate concentrations in the entire Kirkuk in the period of October 2022 to January 2023 as shown in **Figure 4**. While the previous period from April 2022 to August 2022 was unhealthy for sensitive people.

3.3 Validation

In order to validate our data we used Air Quality Multimeter for testing the obtained data based on GIS analysis. Our predictions represented Geo-statistical PM2.5 which was used as trained samples. In order to test and examine obtained predictions tested PM2.5 samples were used which were measured by Air Quality Multimeter in the same 15 regions. **Figure 5** represents the validation of Geo-statistic PM2.5. The obtained R^2 was 0.82 with Root Mean Square (RMS) equal to 51.15 and 1.77 standard deviation.



(a)



(b)

Figure 5. Validation: (a) PM2.5 dataset (b) Validation of geo-statistic predictions of PM2.5.

4. Discussion

Air contamination is a significant environmental concern that stances numerous risks to public health and ecosystems worldwide. In urban areas, the rapid pace of industrialization, population growth, and urbanization has led to a substantial increase in air pollution levels. Kirkuk City, located in northern Iraq, is no exception, facing similar challenges due to its expanding industrial and urban sectors. To effectively address and mitigate the risks associated with air pollution, it is essential to assess the spatial distribution and identify the contributing factors using advanced tools and techniques.

AQI values were bad in the entire Kirkuk City for the study period. In **Figure 3**, the concentrations of PM10 showed hazardous air in the northern and south-eastern parts. Besides unhealthy to very unhealthy air was depicted in the south-western part of the city and regions 12 and 13.

Based on **Figure 4** also bad air quality was depicted in some periods of the study.

High levels of air pollution and being unhealthy, especially for allergy sufferers, should reduce the time spent outside if symptoms such as difficulty breathing or throat irritation are felt.

Air pollution has exceeded the natural limits and has become outside the national limits, and the green areas are few, compared to the size of the city, and certain areas of industrial activities show an abnormal number of pollution.

Figure 5 the validation applied to the trained data to gain the typical accuracy and to investigate the equivalent range at the measured points using tested points of PM2.5 measured by further devices. The result showed that observations were in the confidence boundary by a high coefficient of determination R^2. This indicates that the predicted values were verified well.

Based on a study [20], GIS-based analysis in Kirkuk City reported an increase in blood disease. Their outcomes conformed to the high incidence of blood disease situated in southern parts of Kirkuk and the minimum spread of blood disease was confirmed in northern parts of Kirkuk and a few areas in the center.

Alongside the obtained results of unhealthy air quality during the study period, a study conducted [9] in Kirkuk province in 2021 resulted in unhealthy air quality, PM2.5 was unhealthy for sensitive people to unhealthy air based on field measurements and remotely sensed images. Developing effective strategies to mitigate and manage air pollution requires accurate assessment and monitoring of pollutant levels.

5. Conclusions

Kirkuk City has witnessed rapid urban growth and industrial activities in recent years. This urbanization process has raised concerns about increasing pollution levels and their potential impacts on the population and environment. However, limited research has been conducted to comprehensively assess air pollution risks in this region. Therefore, this study aims to fill this knowledge gap by utilizing GIS and remotely sensed data to evaluate air pollution risks in Kirkuk City.

In this study, we examined the air quality based on some major air pollutants for risk and evaluation. The concerned data involved the measurement and downloading of air quality parameters such as PM10, PM5, PM2.5, PM1, and AQI. Two GIS-based techniques have been applied for analysis and assessment. The health impacts also were determined for each parameter. Unhealthy to Hazardous air quality was detected in the study area of Kirkuk City. Validation processes resulted in significant value with an accuracy of 82%.

The study recommended monitoring, controlling, and reducing air pollutants values and exposures by methods of alternative strategies and mitigations. Should increase people's awareness of how to deal with the contamination impacts along with early warning and predictions. Besides, promoting clean and renewable energy, and increasing afforestation inside the city to lessen the pollution effect, the future would be more promising. The findings of this research can provide valuable insights for urban planners, policymakers, and environmental agencies to formulate effective strategies for pollution control and mitigation.

For improving public health, and to a further and wide understanding of the impacts of PM2.5 and PM10 with their toxicological compounds, additional research on sampling regions and results of air pollution should be applied in the study area for further periods.

Author Contributions

H. Jumaah and Q. Ajaj collected the data besides conceptualizing and implementing the analysis; A. Jasim wrote the introduction, A. Rashid discussed the analysis; H. Jumaah edited, updated, and completed writing the paper.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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