Journal of Civil & Environmental Engineering

Hasan et al., J Civil Environ Eng 2014, 4:5
DOI: 10.4172/2165-784X.1000155

Research Article | Open Access

Sulfur Dioxide (SO_2) Monitoring Over Kirkuk City Using Remote Sensing Data

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Abstract

Air pollution mapping is now being an important issue to manage and enhance the environment of a city. The major problems of air pollution mapping is the data acquisition due to the high cost of instruments and the high spatial distribution requirements. This study aimed to monitor Sulfur Dioxide over Kirkuk city using Landsat-8 thermal bands to provide Department of Environment Kirkuk with low-cost Sulfur Dioxide concentration maps to better manage the city. The study used correlation analysis to find a relationship between Sulfur Dioxide ground-based measurements and satellite data. The ground-based measurements were collected from (17) stations distributed in Kirkuk city in January, 2014 using NOVA device to measure SO_2 concentrations. The research showed a good correlation between ground-based measurements and satellite data with (R^2=0.48 for band 11 and R^2= 0.52 for band 10). Therefore, the study resulted that with band 10 of Landsat-8 data, better SO_2 can be monitored than using band 11. It is recommended to other researchers to investigate the ability of free remote sensing data to monitor all elements that specify the air quality of a city.

Keywords: Sulfur dioxide; Air pollution; Remote sensing; GIS; Environment; Kirkuk city; TIRS; SO_2; LST

Introduction

Air pollution is a major concern in developing countries. The main sources of air pollution in developed cities are: emissions from vehicles (60-70%), coal based thermal power plants (10-15%), industrial units (10-15%) and domestic (5-10%) [1]. It causes a number of health problems and it has been linked with illnesses and deaths from heart or lung diseases [2]. Due to the high cost and limited number of air pollutant stations, it is difficult to provide a good spatial distribution of air pollutant measurements over a city. Although satellite measurements are a total column, not always correlated with surface air quality, satellite observations can help us in air pollution mapping with a high spatial distribution.

The objective of this study is to monitor Sulfur Dioxide pollutant over Kirkuk city, Iraq using free remote sensing data and in-situ measurements. The research uses Landsat 8 (TIRS) data to analyze the derived surface temperature and in-situ measurements of (17) ground stations around Kirkuk city. The relationship between satellite data and ground-based measurements will be investigated by correlation and regression analysis in GIS environment.

Related Works

The monitoring of aerosol concentrations becomes a high environmental priority particularly in urban areas [3]. Several local and international studies have shown the possible relationships between satellite data and air pollution.

A study by [4] investigated the applicability of measuring $PM_{2.5}$ concentrations using satellite data in a semi-empirical approach. The study compared daily $PM_{2.5}$ sampled on the ground surface over six stations and satellite data (MODIS). It showed good agreement (R^2=0.68) [5,6]. Therefore, the research confirmed the potentiality of using satellite remote sensing observations for AQ monitoring.

Rohayu Haron Narashid [7] used images from Landsat (ETM+) and (8) continuous air quality monitoring stations to determine relationships between satellite thermal band data and air pollutant concentrations measured on the ground surface. The research resulted that the generated models by regression analysis can be used by environment staffs to monitor air quality in urban area.

Another research by Qihao Weng [8] investigated the relationship of air pollution pattern with urban thermal landscape using a GIS approach. The relationship between the spatial pattern of air pollution and land surface temperature were sought through GIS and correlation analysis.

The study resulted that there is a good relationship between satellite derived surface temperature and air pollutant concentrations. It has been concluded that thermal imagery could play a significant role in monitoring air quality.

Locally, a research by Al-Abdraba addressed monitoring and assessing of air pollution at several sites in North Oil Company in Kirkuk city. The study also tried to construct a mathematical equation for concentrations that discarded from sources close to ground surface. SO_2 concentration exceeded the international standards limitation in many studied sites. While Ali, studied Kirkuk Oil Refinery to assess the air, soil and plants contamination regarding the Kirkuk refinery system. The average concentration of SO_2 is recorded at 0.075 (ppm) in October, slightly higher than the allowable Iraqi National standards and (WHO), rather than lower concentration (0.006 ppm) is observed in March of that year.

Furthermore, Salah Saleh [1] investigated the relationship between Land Surface Temperature (LST) derived from Landsat TM6 (thermal infrared) satellite data and ground-based air quality parameters measurements over Baghdad city, Iraq. A linear regression analysis was performed using least square method to model air quality of the city. The results showed significant agreements between ground-based measurements and Landsat satellite data. Also, the study indicated that satellite imagery is capable for air pollution mapping.

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Received August 30, 2014; **Accepted** September 19, 2014; **Published** September 26, 2014

Citation: Hasan G, Al Kubaisy MA, Nahhas FH, Ali AA, Othman N, et al. (2014) Sulfur Dioxide (SO_2) Monitoring Over Kirkuk City Using Remote Sensing Data. J Civil Environ Eng 4: 155. doi:10.4172/2165-784X.1000155

Citation: Hasan G, Al Kubaisy MA, Nahhas FH, Ali AA, Othman N, et al. (2014) Sulfur Dioxide (SO_2) Monitoring Over Kirkuk City Using Remote Sensing Data. J Civil Environ Eng 4: 155. doi:10.4172/2165-784X.1000155

Sulfur Dioxide

Sulfur Dioxide (SO_2) is a significant indicator for volcanic movements [9]. Is produced mainly by combustion of fossil fuels or smelting of minerals, and is an intermediate product from organic sources in the ocean.

Global monitoring of sulfur dioxide gives information related to air quality, climate change, volcanology and volcanic hazards. Sulfate in air pollution is well known for production of acid rain and environmental degradation, as well as to reduce visibility and health effects.

It causes acidic pollution of lakes and streams and forms an aerosol that is important in climate change [10]. Other studies indicate that SO_2 causes nerve stimulation in the lining of the nose and throat. This can cause irritation, coughing and a feeling of chest tightness, which may cause the airways to narrow. People suffering from asthma are considered to be particularly sensitive to SO_2 concentrations.

Study Area

The study area of this research is Kirkuk city located in the north part of Iraq and it is a vital place as shown in Figure 1. Generally, this area consists of industrial, residential, oil fields places. The area of the region is approximately equal to (93.16 km^2) and the population of the city center currently is estimated to (784444) (Statistical Center of Kirkuk, 2011). Oil is the main source of its economic activities, it has the largest oil field in Iraq, natural gas and sulfur sources.

Geographically, it is located between the two great circles of (35 31 20 N) and (35 20 20 S), and two longitudinal circles of (44 26 10 E) and (44 16 30 W). It is 236 kilometers north of the capital Baghdad. Furthermore, the climate of Kirkuk city is generally continental, with hot and dry summers, and cool rainy winters.

The wind directions play an important role in the distribution of pollutants in air. The wind of the study area prevail north-western (Iraqi Meteorological Organization, 2011) and follows the climate of the Mediterranean Basin.

Data Sources

Ground-based measurements

SO_2 pollutant concentrations were collected at (17) measuring stations around Kirkuk city in 9th of January, 2014. The used device was NOVA instrument which designed to monitor different types of ambient air pollutants such as CO, CO_2, NH_3, NO_2, SO_2 and H_2S as shown in Figure 2.

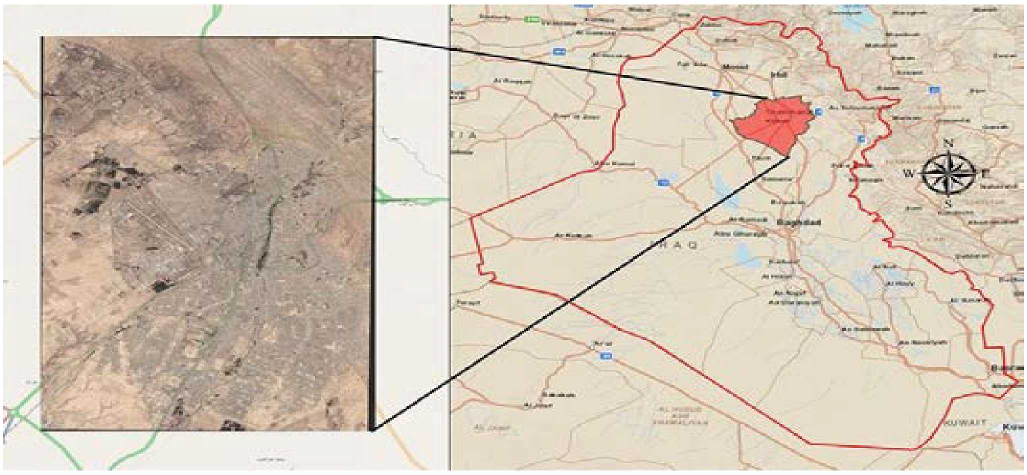

Figure 1: Study Area.

Figure 2: NOVA Device.

Table 1 below shows the average measurements of SO_2 pollutants concentration measurements of 9th of January, 2014 were higher than Iraqi and WHO standards air pollutants. So, air of Kirkuk city is polluted due to the traffic, personal and private electrical generators, industrial activities and poor vegetation cover in the city.

Satellite data

Two bands of thermal infrared region (10.4-12.5 µm) of Landsat8 image acquired on 9th of January, 2014 for Kirkuk city was used for land surface temperature extraction. The Digital Number (DN) value for the thermal infrared of the corresponding ground base measurements are converted into radiance and apparent surface temperatures using NASA model [11-13].

Methodology

DN conversion to surface temperature: In order to convert the raw data of Landsat thermal bands DN into surface temperature brightness [14], equation (1) provided by Chander and Markham and the Landsat 7 Science Data Users Handbook was used first to convert the DNs to spectral radiance.

$$TOAr = M * DN + B \quad (1)$$

Where: M is the Radiance Multiplier

B is the Radiance Add

The M, B values are in the metadata file of Landsat8 data. Table 2 shows the used parameters.

Where: K1 and K2 are parameters of band-specific thermal conversion constant.

After we have got the TOAr values, then brightness temperature is calculated using equation (2) below [15].

$$T\ (Kelvin) = K2/\ln(K1/TOAr+1) \quad (2)$$

After calculating temperature brightness in (Kelvin) unit, it is converted to Celsius and mapped in ArcGIS software as shown in Figure 3 [16].

Correlation analysis: Before investigating correlation analysis for ground-based and satellite data, the descriptive statistics are analysed for further understanding the nature of the collected data. Table 3 below shows important statistical parameters for two types of used data.

Relationship between Land Surface Temperatures (LST) [17] extracted from Landsat 8-TIRS satellite data with ground-based measurements of SO_2 concentrations around Kirkuk city were analyzed by correlation analysis. Table 4 summarizes the linear correlation coefficient analysis between surface temperature of thermal bands and ground-based air pollution concentrations of SO_2 pollutant.

The correlation analysis indicates to there are significant correlations

ID	Station	X	Y	$SO_{2\,(ppm)}$	Iraqi Standard	Who Standard
1	Chorao control	443138	3929753	0.696		
2	Eternity Fire	441111	3937665	1.105		
3	Compration gas station AB_3	440030	3932208	1.645		
4	Baba residential	438943	3933565	0.871		
5	Araffa	443362	3926437	0.501		
6	Alamal Alshaby	439376	3929069	0.733		
7	Sharow hospital	441948	3921311	0.276		
8	Rahimawa	445035	3928489	0.517		
9	Sahat ihtifalat	441948	3921311	0.276	0.14	0.01
10	Sharow compound	445386	3930344	0.434		
11	Baglar health centre	443337	3925749	0.33		
12	Iraqi drilling company	442724	3928192	0.461		
13	Almas	444792	3926332	0.301		
14	Rzgary	446694	3927582	0.595		
15	Imam qasim	445321	3926091	0.484		
16	Khassa 2	444241	3923971	0.923		
17	Hay mualmeen	444058	3920336	0.601		

Table 1: Ground-based Measurements.

	Band 10	Band 11
Radiance Multiplier (M)	0.0003342	0.0003342
Radiance Add (B)	0.1	0.1
K1	777.89	480.89
K2	1321.08	1201.14

Table 2: Ground-based Measurements.

Variable	Mean	SD	Minimum	Median	Maximum
Temp Band 10	11.587	2.258	3.880	11.856	14.367
Temp Band 11	9.801	2.112	2.712	10.249	12.273
SO_2	0.6463	0.3416	0.276	0.5170	1.645

Table 3: Descriptive Statistical Parameters.

r	Temp Band 10	Temp Band 11	SO_2
Temp Band 10		0.99	0.465
Temp Band 11	0.99		0.417
SO_2	0.465	0.147	

Table 4: Correlation between in-situ measurements and satellite data.

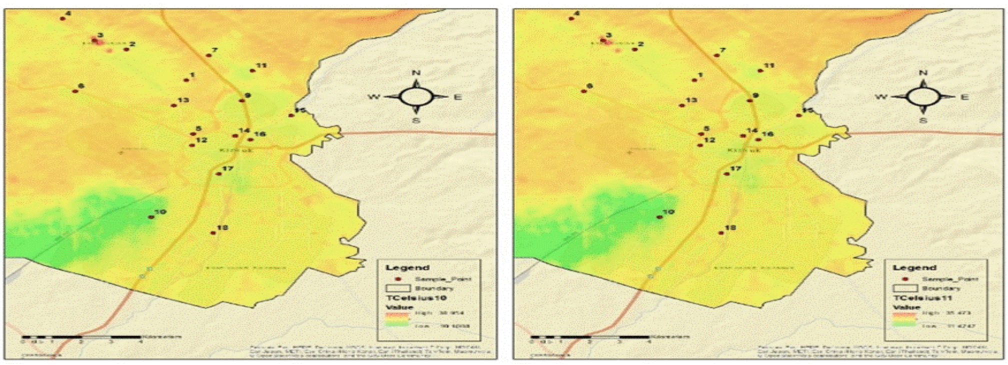

Figure 3: Surface Temperature Over Study Area.

between SO_2 pollutant concentrations and surface temperatures derived from satellite thermal bands. It also shows that the correlation between SO_2 ground-based concentrations and band 10 is stronger than band 11. The resulted correlation is accepted in terms of accuracy for monitoring purposes over large spatial distribution.

Regression analysis: A non-linear regression analysis was performed to establish relationship between surface temperatures from Landsat data as independent variables against the in-situ SO_2 measurements concentrations data.

A third-order polynomial expression between SO_2 pollutant parameter and surface temperatures extracted from thermal bands of Landsat data were determined using regression analysis in Excel Software. Figures 4 and 5 shows the scatter plot of in-situ and satellite data and the fitting line.

Results

The regression analysis resulted an aerosol reflectance model for estimating SO_2 concentrations from raw DNs of thermal bands of Landsat 8 satellite data using the equations below:

SO_2 (ppm) = $0.0117T^3$- $0.3282T^2$ + 2.837T - 6.4733…. *For band 10*

SO_2 (ppm) = $0.0157T^3$ - 0.362T2 + 2.524^2T - 4.219….*For band 11*

Then, the two expressions above are used to calculate the SO_2 derived concentrations and it results as Table 5 below shows. The last

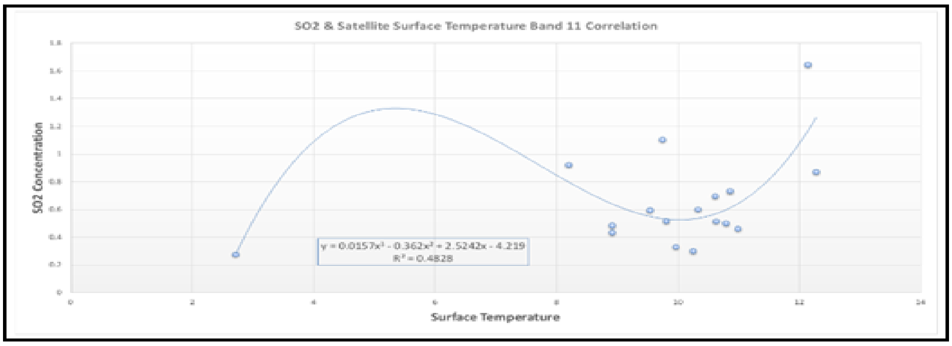

Figure 4: In-situ SO_2 & satellite data regression, Band 11.

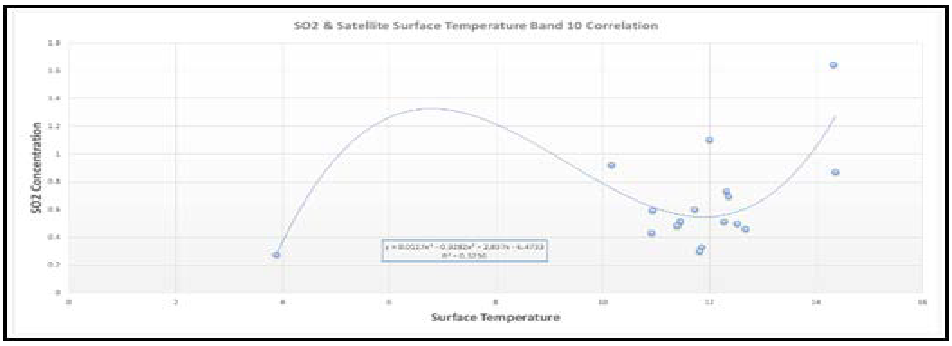

Figure 5: In-situ SO_2 & satellite data regression, Band 10.

ID	Station	X	Y	$SO_{2\,(ppm)}$	Temp Band 10	Temp Band 11	Derived SO_2-10	Derived SO_2-10
1	Chorao control	443138	3929753	0.696	12.3572146	10.60898601	0.545	0.563
2	Eternity Fire	441111	3937665	1.105	12.00282186	9.741107607	0.528	0.532
3	Compration gas station AB_3	440030	3932208	1.645	14.32778856	12.13584507	1.213	1.161
4	Baba residential	438943	3933565	0.871	14.36668769	12.27267818	1.238	1.257
5	Araffa	443362	3926437	0.501	12.51904401	10.78968171	0.562	0.594
6	Alamal Alshaby	439376	3929069	0.733	12.32087008	10.85511311	0.542	0.608
7	Sharow hospital	441948	3921311	0.276	12.27251023	10.62541247	0.539	0.566
8	Rahimawa	445035	3928489	0.517	11.45078024	9.803459561	0.546	0.528
9	Sahat ihtifalat	441948	3921311	0.276	3.880497196	2.711614217	0.277	0.277
10	Sharow compound	445386	3930344	0.434	10.91460935	8.911683558	0.606	0.638
11	Baglar health centre	443337	3925749	0.33	11.85561683	9.963183437	0.527	0.523
12	Iraqi drilling company	442724	3928192	0.461	12.68085875	10.98347322	0.584	0.638
13	Almas	444792	3926332	0.301	11.81584764	10.24863329	0.528	0.529
14	Rzgary	446694	3927582	0.595	10.93845311	9.536156362	0.603	0.548
15	Imam qasim	445321	3926091	0.484	11.39168989	8.914164909	0.550	0.638
16	Khassa 2	444241	3923971	0.923	10.16220027	8.1970426	0.742	0.796
17	Hay mualmeen	444058	3920336	0.601	11.72208342	10.32468207	0.530	0.533

Table 5: SO_2 Derived Concentrations.

two columns are SO_2 concentrations in (ppm) unit that derived from the model which generated by regression analysis.

After that, the information that we have got from the generated model are used to map SO_2 pollutant dispersion over Kirkuk city using GIS tools. The below maps (Figure 6) are produced using ArcGIS 10.2 software.

First of all, the SO_2 ground-based measurements are mapped to be compared with the derived SO_2 concentrations maps later and to assess the model applicability and accuracy for different purposes.

The highest concentration of SO_2 is found in the north of Kirkuk city and this is expected due to the oil fields and industries in the north part of the study area.

As we see from the Figure 7, the results of generated models using satellite thermal and in-situ data are reliable for large spatial distribution area. It can be seen that the highest concentration of SO_2 pollutant is emphasized in the West-North of the city in three maps. In addition, the resulted models will provide the Directory of Environment Kirkuk with low-cost and quickly produced maps for spatial decision making.

Air pollution Patterns & Landscape Temperature

Urban areas are associated with sources of a variety of air pollutants. In addition, cities are major contributors to global air pollution related to ozone depletion and carbon dioxide (CO_2) warming. Understanding air pollution patterns and thermal landscape patterns are important to better manage the cities [18].

Air pollution patterns in cities are mainly relate to the distribution of different land use and land cover categories. Land use of Kirkuk city are consists mainly of industrial, built-up, oil refinery and fields, bare areas with poor vegetated zones. It can be seen from Figure 7 that the high-concentrated of SO_2 is in the north and middle parts of the city which mostly are oil fields and built-up areas.

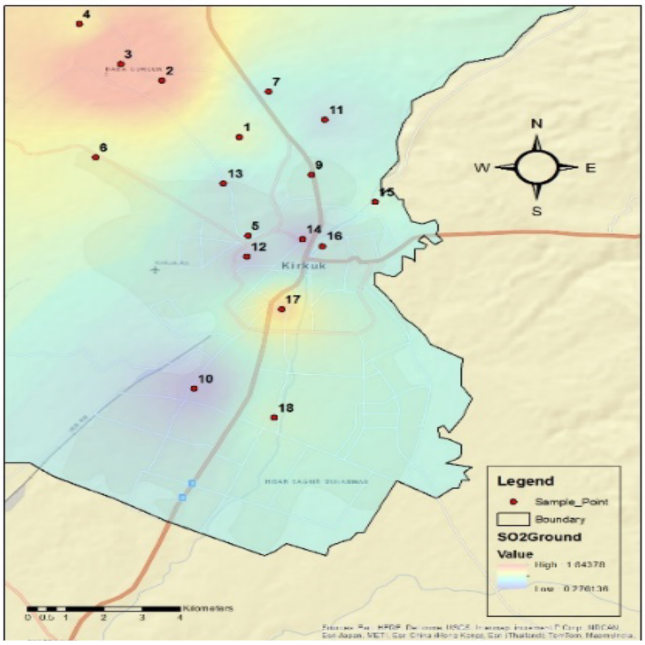

Figure 6: SO_2 Ground-based Dispersion.

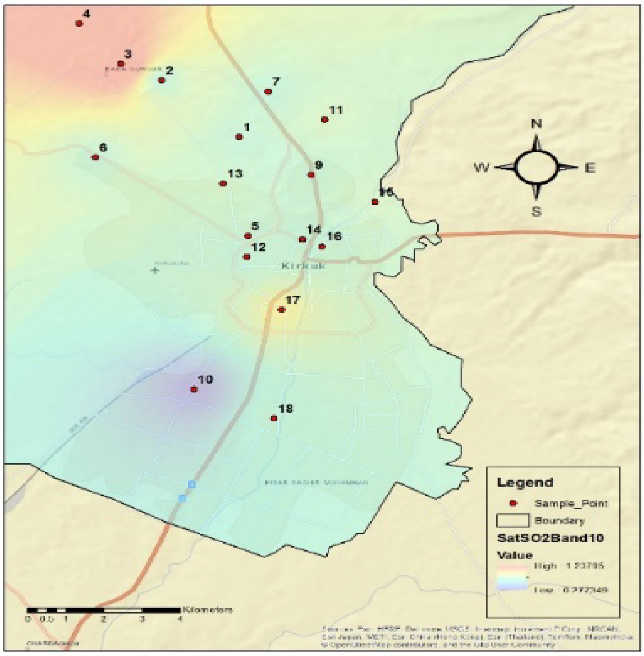

Figure 7: SO_2 Satellite Data Dispersion.

Investigating thermal landscape patterns that derived from satellite data of the study area gave us an imagination on how air pollutants are distributed in the city. Spatial pattern of air SO_2 pollutant is positively correlated with urban built-up density, oil refineries and with satellite derived land surface temperature in the study area.

Conclusion

This research showed good agreements in the relationship between Landsat-8 (TIRS) [19,20] data and in-situ SO_2 pollutant measurements in Kirkuk city. The correlation and regression analysis performed using "Analysis it" plug-in in Excel software and it showed the ability to analysis multi-variant data and also in plotting scatter diagrams, PCA analysis and curve fitting as well. While GIS technique is used in the study to map the collected and derived data. The IDW interpolation used in GIS environment to produce maps for SO_2 concentrations dispersion over Kirkuk city. The technique indicates to reliable results over the large spatial distribution when it compared with other researcher results.

The research resulted two models for SO_2 concentration over Kirkuk city, one for band 10 of Landsat TIRS data and the second is for band 11. However, the band 10 model is more accurate than band 11. Also the study generated three maps for SO_2 pollutant concentration over the study area using ground-based, values of the model of band 10 and 11. It showed a high correlation between three maps and by this we could conclude that remote sensing is a powerful tool for air quality mapping [21,22].

The results of this research indicate that air pollution can be mapped using satellite data to provide a larger area of coverage. Further research can be done to enhance the models using numerical and statistical analysis.

Acknowledgment

This research is supported by Mr. Ahmed Qusay providing the ArcGIS software and Analysis it plug-in. Also we thank the ministry of higher education of Iraq granting us for study in Malaysia to complete MSc degree.

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