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**Air Quality Over Baghdad City Using Earth Observation And Landsat Thermal Data**

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**Key words:** Air Pollution, Remote Sensing, Correlation, Land Surface Temperature (LST).

**Abstract**

Air pollution problem is a major concern in many large cities and becomes increasingly critical in this present-day in developed or developing countries around the world. Mapping of urban air pollution dispersion is very complex as it depends upon various factors including weather conditions, urban structural features and their topologies. Air pollution dispersion distribution can be mapped by using mathematical models and interpolation methods based on ground local measurements of meteorological parameters. Recently, Satellite images data present a wide applicability for air pollution studies.

The rapid growth of Baghdad city in last years has resulted in significant increase in environmental pollution. Hence, effective and coordinated measures for controlling pollution need to be put in place without delay for the city.

This paper investigates the relationship between Land Surface Temperature from Landsat TM6 (thermal infrared) satellite data and ground base air quality parameters measurements of major primary pollutants over Baghdad city - Iraq. In-situ measurements of corresponding air pollution parameters were carried out at six different locations in the city during November, 2008. Those parameters were Total Suspended particles matter in the air (TSP), Carbon Monoxide (CO), Carbon Dioxide (CO2), Sulfur (sulphur) Dioxide (SO2), Nitrogen Dioxide (NO2).

A linear regression analysis was performed to establish the relationship between apparent Land Surface Temperature (LST) from satellite and in-situ monitoring of various air pollutants data.

The results showed significant linear relationships between grounds based measurements of air pollution parameters with temperatures from Landsat satellite data. Also, this study indicated that satellite imagery was capable for mapping of the pollution parameters concentrations.

## Introduction

It is estimated that thousands tone of air pollutants are emitted every year in main cities over the world. The main sources of air pollution in large cities around the worlds are: emissions from vehicles (60-70%), coal based thermal power plants (10-15%), industrial units (10-15%) and domestic (5-10%). There has been a rising trend in the air pollution each year due rise in population, growth in urban area and economic activity which have led to pollution increasing of the cities in the developed or developing countries.

In the present-day. Air pollution problem is a major concern and becomes increasingly critical in many large cities around the world. It is receiving more and more attention due to it's strongly impact on human health, human comfort and daily life. The effects of air pollution on public health are being felt worldwide.

Air quality for urban area is of great interest from health points of view as well as for future planning and decision making. Mapping of dispersion of air pollution is very complex as it depends upon various factors including weather conditions, urban structural features and their topologies. Urban air pollution is quite dependent on the ventilation condition in traffic corridors which is influenced by the aerodynamic roughness parameters of the ground.

Air pollutants can be measured from ground base stations with different type of instruments such as air sampler, sun photometer and optical particle counter. However these instruments are quite expensive, the cost of a measuring station and its maintenance limit the advantages of the stations. Further the limitation number of the air pollutant stations and scarcely distributed not allowed a proper mapping of the air pollutants. It is impractical if measurements are to be made over relatively large and risky unsecured areas or for continuous monitoring using ground instruments only.

So, they cannot provide a detail spatial distribution of the air pollutant over a city. Several studies have shown the possible relationships between satellite data and air pollution ( Ung, et al, (2001).Remote sensing technique was widely used for environment pollutant application such as air pollutant (Ung, et al., 2001b). Some studies showed that satellite data could be useful for revealing climatic and environmental implications of global air pollution (Akimoto, 2003).

Recent and planned technological advancements in remote sensing are demonstrating that space-based measurements can be a valuable tool for forecasting air quality, providing information not available from traditional monitoring stations. Satellite data can aid in the detection, tracking, and understanding of pollutant transport by providing observations over large spatial domains and at varying altitudes. Satellites can be the only data source in rural and remote areas where no ground-based measurements are taken (Wijeratna, C. 2006).

Landsat TM, ETM, SPOT, MODIS images data present a wide applicability for air pollution studies. Several studies have shown the possible relationships between satellite data and air pollution for more information's see Ung, et al, (2001a)]. Other researchers used satellite data in such environment atmospheric studies such as NOAA-14 AVHRR (Asmala, A. 2002) and TM Landsat (Ung, et al., 2001b). Recent studies of air quality using satellite data have been carried out mainly using MODIS data.

Baghdad, capital of Iraq, is one of the most polluted cites in the region due natural and artificial sources. Its geographical location made the city affected by heavy dust storms many times in year. Therefore, there is a layer of aerosols and other particulate matter in its atmosphere. Artificial sources of air pollution in Baghdad city are due to the highly population growth, the exhaust from more than million vehicles and heavy traffic in the city, private electric generators and pollutants from industrials.

The objective of this study is to investigate the possibilities of satellite data for mapping air quality by establish a relationship between ground base measurements of major primary pollutants concentrations and apparent land surface temperature extracted from Landsat 7 ETM+ satellite data for Baghdad city - Iraq. The aim of air quality monitoring is to get an estimate of pollutant concentrations in time and space.

Urban air Pollution mapping is strongly recommended and required for all large cites for many reasons such as (Wald, et al, 1998):

- Provides a complete air pollution survey of the city.
- Shows the main sources of pollution with their extension.
- Shows the areas that severely effect by pollution and indicates where efforts should be made to decreases the pollution level.
- Helps further analysis in showing relationship that might exist between city features and air pollution distribution.

Air pollution map can be serves as a basis for proper distribution of air pollution measurement stations by moving some stations to appropriate locations, or adding some or removing some stations.

**Back Ground**

Only a few studies seek for a relationship between satellite data and ground-based measurements. Recent studies have shown the relationship between Landsat thermal satellite data and ground based air quality parameter measurements (Ung,et al 2001). They have been made on the correlation between satellite measurements in thermal infrared and air quality parameters (Finzi and Lechi 1991, Retalis et al. 1999, Wald & Baleynaud 1999, Basly 2000, Ung,et al 2002). These satellite data are radiances observed by the sensor in thermal infrared band. These radiances are a function of the temperature and emissivity of the surface and also of the optical properties of the atmospheric column above the pixel and its surroundings. Most of the bodies of interest have an emissivity values larger than 0.8 . In that case, for the spectral band of interest, the emission by the surface is the most important phenomenon. The radiance emitted by the atmosphere towards the sensor after its reflection on the surface accounts for approximately 10% of the total radiance and may be neglected (Ung,et al 2002). Accordingly the temperature, (Tsat) observed by the space-satellite sensor (such as Landsat satellite) can be written as:

$$Tsat = \mathbf{t}\ \mathbf{e}\ Tsurf + Tatm$$

Where, (Tsurf ) is the surface temperature, **(e)** the surface emissivity, **(t)** the transmission factor of the atmosphere, and (Tatm) a weighted-average temperature modeling the emission of the atmosphere itself. More detail information is given by Ung,et al 2002.

From this equation, it appears that a decrease in the atmospheric transmission factor as caused by the appearance of a pollution layer results in a decrease in (Tsat). This decrease may be significant enough to be sensed by satellite sensors such as Landsat TM, the sensitivity of which is 0.5 °C. Actually the change would also have an impact on the radiance emitted by the atmosphere (modelled by Tatm) but the impact is negligible because the pollution layer is usually of very limited vertical extension and (Tatm) results from integration over the entire atmospheric column.

Wald and Baleynaud (1999) discussed about the relationship between the suspended particulates (PM10) measurements and the apparent temperature. Nevertheless if we assume that the pollution plays a major role in the pattern of temperature, two processes occur simultaneously which explain the relationship between the particulates measurements and the apparent temperature. The appearance of a pollution layer (more absorption and scattering) results in a decrease of the atmospheric transmission factor. On the one hand, this decay leads to a decrease of the solar radiation impinging on ground. The solar heating is thus decreased as well as the resulting temperature of the surface. Hence the emitted radiance is lower, and the signal sensed by the satellite is lower. On the other hand, this pollution layer absorbs as well the emitted radiance, causing a depletion of the upward radiance. This is the second process explaining the relationship. Both processes contribute to the decrease of the apparent temperature as the pollution increases. The authors concluded that the mapping of the black particulates is possible using TM6 image but positive correlations are not explained yet. Finzi and Lechi (1991) analysed two Landsat images of Milan. For the polluted day, the correlation coefficient is -0.84. For the unpolluted day, the correlation coefficient is very low (0.48). Even weaker correlation with SO2 was observed by Brivio et al. (1995) for Milan. Poli et al. (1994) found weak and negative correlation for Roma. As for Brivio et al. 1995).

Those studies add evidence on the correlation between satellite measurements in thermal infrared and air quality parameters. It has been shown that particulates concentrations are correlated to apparent temperature. But the number of values is too small to be conclusive.

**Study Area**

Baghdad is the capital and the largest city of Iraq. Baghdad is located in the central parts of Iraq on the both sides of Tigris River; it lies on latitude 43-East and longitude 34 north. Baghdad is suited in a plain area of an elevation between 31 - 39 m above sea level. There is natural boundaries exists that limits the aerial extension of the city.

The climate of Baghdad region (which is part of the a plain area at the central of Iraq and has same climatic characteristics) may be defined as a semi arid, subtropical and continental, dry , hot and long summer cool winters and short springs. The maximum recorded temperature was $51^0$ c in summer while the minimum was (- $10^0$ c). The average maximum temperature for the last 30 year is $31.95^0$ c and average minimum temperature is 18.05 $^0$ c for the same period.

Now, the area of Baghdad region covers 4555 sq. km. which represented 1.047 % from total area of Iraqi (435052 sq.km.). Baghdad population growth was reported through successive census during last 60 years; it was notice that the percentage of Baghdad population to that of total Iraq population was increasing continuously (from 10% in 1947 to more than 25% now). The population density of Baghdad city reach to 5233 prs/km$^2$ and it is between 6 - 190 prs/km$^2$ for other Iraqi cities see table (1).

| Census year | Baghdad population | % to Iraq population |
|---|---|---|
| **1947** | 503000 | 10.5 |
| **1957** | 1000000 | 16.6 |
| **1967** | 1884151 | 22.0 |
| **1977** | 2823844 | 23.5 |
| **1987** | 3844608 | 24.1 |
| **1997** | 5423964 | 24.4 |
| **2003** | 6386067 | 24.6 |

Table( 1 ) Population Growth for Baghdad City (1947-2003)

| Air pollutants | CO (ppm) | CO2 (ppm) | SO2 (ppm) | NO2 (ppm) | TSP ($ug/m^3$) |
|---|---|---|---|---|---|
| **Present study** | 21.668 | 366.2 | 0.615 | 1.006 | 633.4 |
| **Iraqi standards** | 35 | 250 | 0.14 | 0.25 | 350 |
| **WHO standards** | 9 | 250 | 0.01 | 0.11 | 150 |

Table (2) Averages of Nov- 2008 of primary pollutants concentrations measurements at Baghdad City with Iraqi and WHO standards

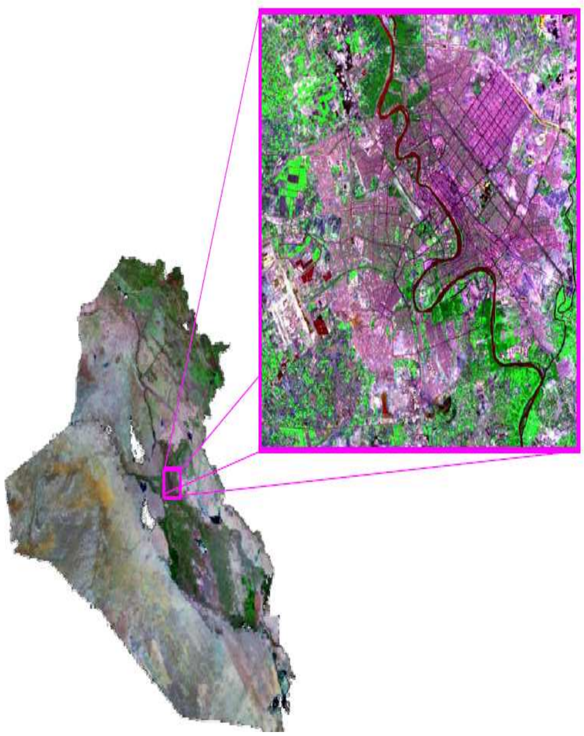


Figure ( 1 ) Landsat Image of Baghdad City – November , 2008

**Materials**

This study involved the usage of two types of data namely; ground base measurements and satellite data.

**Ground-Base Measurements**

Major daily primary pollutant concentrations were collected at six measuring stations around Baghdad city during November, 2008. Concentration Measurements of major primary pollutant include Total Suspended Particles (TSP) in micrograms per meter cube ($ug/m^3$). Carbon Monoxide (CO) in parts per million (ppm), Carbon Dioxide (CO2) in (PPM), Sulfur Dioxide (SO2) in (ppm) and Nitrogen Dioxide (NO2) in (ppm) .

Table (2) shows that the average measurements of pollutants concentrations measurements during November 2008 were very high for all air pollutants and they are extremely exceeded Iraqi and WHO standards air pollutants. So, air of Baghdad city is highly polluted due to the traffic, personal and private electrical generators, chemical transformation of some pollutants in industrial activities and poor vegetation cover and green areas in the city.

**Satellite Data**

Thermal infrared region (10.4-12.5 µm) of landsat7 ETM+ image acquired on November, 2008 for Baghdad city was used for 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. In this study we estimated the surface temperature using NASA model. The following procedure was carried out to extract the surface temperatures.

**Conversion of the digital numbers (DN) to Spectral Radiance (Lλ):**

The spectral radiance is calculated using the following expression (NASA,2002):

$$L\lambda = [(Lmax - Lmin)/255] * DN + Lmin \quad \dots (1)$$

Where: Lλ is the spectral radiance, Lmin and Lmax [$mW\ cm^{-2} sr^{-1}\ \mu m^{-1}$] are spectral radiances for thermal band (band 6) at digital numbers 0 and 255 respectively. For the new sensors in Landsat7 the following reference values are given:
ETM+ Spectral Radiance Range:
Low Gain: Lmin - 0.0 Lmax - 17.04 watts/(meter squared * ster * µm)

High Gain: Lmin - 3.2 Lmax - 12.65 watts/(meter squared * ster * µm)

**Conversion of spectral radiances (Lλ ) to temperature**

The ETM+ spectral radiances (Lλ ) were converted into effective at-satellite temperatures (T) by (NASA,2002):

$$T = K2 / \ln ( K1 / L\lambda + 1) \quad \dots\dots(2)$$

Where: K2 = 1260,56 K were taken; for Landsat ETM+ the NASA-handbook gives K1 = 666,09 $w*m^{-2} *sr^{-1} *\mu m^{-1}$ and K2 = 1282.71 K respectively.

Figure ( 2 ) shows Landsat ETM+ Thermal band (band 6) for Baghdad area at November 2008.

Figure (2) ETM+ Thermal band (band 6) for Baghdad city at November 2008

**Correlation Analysis**

Relationship between land surface temperature (LST) extracted from Landsat ETM+ satellite image with November 2008. average major primary air pollution parameters concentration from six ground base stations measurements around Baghdad city were analyzed and investigated through correlation analysis .Table (3) summarize the linear correlation coefficient analysis between surface temperature from thermal band of Landsat ETM+ satellite data and ground based air pollution concentrations parameters.

Analysis of Correlation shows that significant correlations between all primary air pollution parameters with surface temperatures derived from satellite thermal band. The sign of correlation coefficients is negative, which means an increase of pollutants concentrations cause decrease in temperatures measured by thermal infrared band of Landsat images.

Thermal radiances observed by satellite sensors are function to the temperature and emissivity of the surface and also to the optical properties of the atmospheric above the imaged area. If we assume that the pollutants plays a major role land surface temperature, two processes occur which explain the relationship between the pollutants concentration and temperature.

Firstly, the appearance of a pollution layer results in a decreased of the atmospheric transmission factor. This will decrease of the solar radiation impinging on the ground. The solar heating is thus decreased as well as resulting temperature of the earth surface. So, the emitted radiation by earth surface is lower, and the signal detected by satellite thermal sensor is lower.

Secondly, pollution layer absorbs parts of emitted radiation from the earth surface causing a depilation (reduction) of the upward radiance. These two processes contribute to the decrease of the temperature as the pollutant increases. So any increases in air pollutants results a decrease in the atmospheric transmission of a pollutant atmospheric layer and a decrease in the temperature extracted by satellite sensors.

| | (k) Temp | CO (ppm) | CO2 (ppm) | SO2 (ppm) | NO2 (ppm) | TSP (ug/m$^3$) |
|---|---|---|---|---|---|---|
| **Temp** | 1.00 | | | | | |
| **CO** | -1.00 | 1.00 | | | | |
| **CO2** | -0.98 | -0.99 | 1.00 | | | |
| **SO2** | -1.00 | 1.00 | -0.98 | 1.00 | | |
| **NO2** | -1.00 | 1.00 | -0.97 | 1.00 | 1.00 | |
| **TSP** | -0.96 | -0.95 | 0.96 | -0.94 | -0.94 | 1.00 |

Table ( 3 ) Correlation coefficients among Nov, 2008 average ground base pollutants measurements and surface temperatures from Landsat data.

**Regression Analysis and Mapping**

A linear regression analysis was performed to establish relationship between surface temperatures from Landsat data as independent variables against the in-situ November 2008 averaged air pollutants measurements concentrations data.

A linear relationship between major primary air pollution parameters concentrations and surface temperatures extracted from thermal band of Landsat data were determined using a least – square regression analysis method as shown in table (4).

| | Correlation Coefficient | Regression line slop | Regression line offset |
|---|---|---|---|
| **C0 - TEMP** | -0.89 | 1.3082 | -360.52 |
| **CO2 - TEMP** | 0.89 | -9.3529 | 3133.6 |
| **SO2 - TEMP** | -1.00 | -0.0307 | -8.8313 |
| **NO2 - TEMP** | -1.00 | 0.0385 | -10.208 |
| **TSP - TEMP** | 0.66 | 116.68 | -32093 |

Table ( 4 ) Parameters of the regression line between averaged air pollutants and temperatures

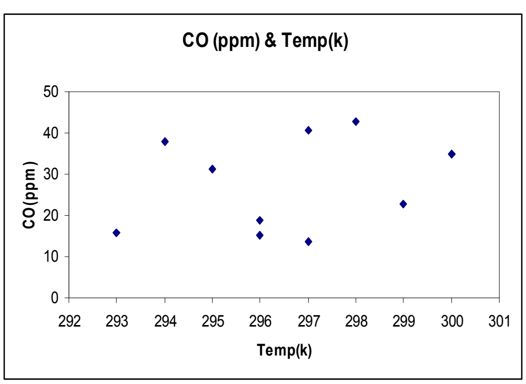
The linear regression models can be expressed as:

CO (ppm) = 1.3082 * Temp(k) - 360.52…(3)
CO2 (ppm) = - 9.3529 * Temp(k) + 3133.6…(4)
SO2 (ppm) = - 0.0307 * Temp(k) - 8.8313…(5)
NO2 (ppm) = 0.0385 * Temp(k) - 10.208…(6)
TSP (ug/m$^3$) = 116.68 * Temp(k) - 32093…(7)

The above relationships can be applied to any pixel of the TM6 band (thermal band) of Landsat data in order to find air pollutants and hence to map the concentration of the air pollutants over Baghdad city.

These types of simple models can be used to retrieve pollutants quantities from space imagery. Given Landsat satellite thermal signal, the models can compute the expected a pollutant quantity. These simple models will provide not very accurate but acceptable approximation of the pollutant concentrations.

The plot of the relationships between the temperatures and major primary air pollutants concentrations are shown in Figures 3,4,5,6 and 7..




Fig(3) correlation between temperature With CO concentration

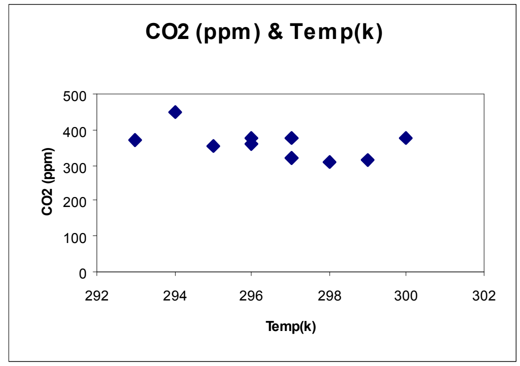
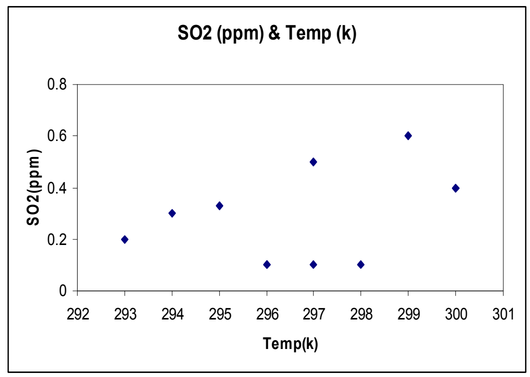



Fig (4) correlation between temperature with CO2 concentration




Fig(5) correlation between temperature
With SO2 concentration

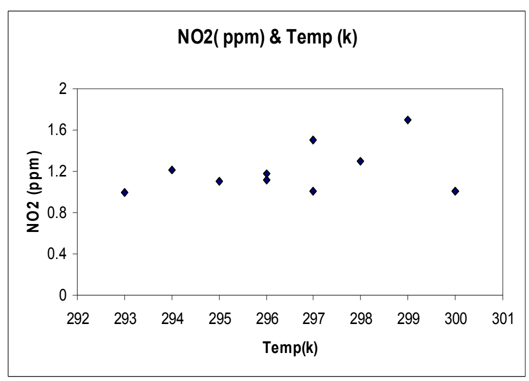
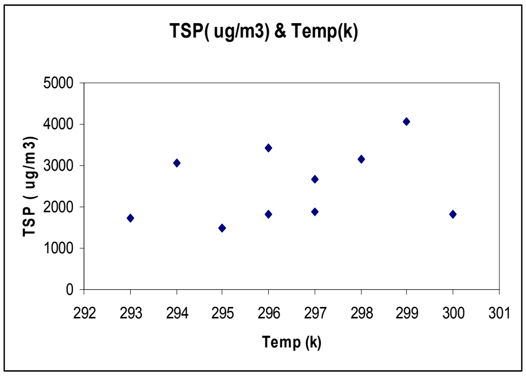



Fig (6) correlation between temperature with NO2 concentration




Fig(7) correlation between temperature With TSP concentration

## Conclusion

1-From this study we conclude that the mapping of the pollution parameters concentrations is possible using Landsat image. This mapping is not very accurate but acceptable approximation of the pollutant concentrations. A fusion of the estimated map with measuring stations will improve the results.

2- Satellite temperature of thermal infrared band show statistically significant relationships with pollution parameters concentrations. Such analysis is of great importance for urban micro-climate and environmental quality assessment.

3- Correlations were found between all primary air pollution parameters concentrations with surface temperatures derived from satellite thermal band. The sign of correlation coefficients is negative, which means an increase of pollutants concentrations cause decrease in apparent surface temperatures.

4- The spatial resolution of the thermal sensor of Landsat 7 ETM+ (60 m) may has strong influence upon the results. The higher spatial resolution images can be use to improve estimates based on interpolation between ground measurements and satellite data.

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**Appendix:** At the end of the paper

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