Cloud Publications
International Journal of Advanced Remote Sensing and GIS
2017, Volume 6, Issue 1, pp. 2246-2252
ISSN 2320 – 0243, Crossref: 10.23953/cloud.ijarsg.284

Research Article

Estimation of PM10 Distribution using Landsat 7 ETM+ Remote Sensing Data

Ajay Roy[1], Anjali Jivani[2], Bhuvan Parekh[2]

[1]MCA Department, D. D. University, Nadiad, India
[2]Department of CSE, The Maharaja Sayajirao University of Baroda, Vadodara, India

Publication Date: 24 July 2017

DOI: https://doi.org/10.23953/cloud.ijarsg.284

Abstract Remote sensing imagery is a rich source of information with applications in varied fields. Monitoring of environment pollution is one of them. The work presented in this paper is focused on estimation of the ambient concentration of pollutant using remote sensing. Particulate Matter with particle sizes less than 10 microns (PM10) is estimated for the study area Vadodara. Landsat 7 ETM+ data of different wavelength has been processed and analyzed for the relationship with coincident ground station PM10 data. The radiance values observed by the satellite and its difference with the radiance calculated after atmospheric correction for the same pixel is considered as a measure to estimate PM10. This difference, called path radiance is calculated and correlated with the ground station PM10 values. Using regression analysis on the calculated data and the ground station PM10 data, the algorithm for PM10 estimation is generated and PM10 map is generated for the study area. The algorithm shows good results for the test data. Pollution estimation through remote sensing is an efficient technique as it can be carried out in less time. Estimation and analysis for larger area is possible using remote sensing approach. The 30 meter resolution of Landsat satellite makes it more suitable for local and regional study.
Keywords: *Landsat ETM+; PM10; Remote Sensing*

1. Introduction

Air pollution is a major problem causing damage to human, animal, crops and water bodies (Kampa and Castanas, 2008; Kanakiya et al., 2015). Respirable Suspended Particulate Matter (RSPM) also known as particulate matter 10 (PM10) are particles with size less than 10 microns (Husar et al., 1981; Ayub and Sharma, 2011). The ambient concentration of PM10 is measured under the National Ambient Monitoring Program (NAMP) by Pollution control board under which, the data is collected for selected stations of the city periodically. Remote sensing can be effectively used to estimate the concentration of PM10 for air quality. The atmosphere affects satellite images of the Earth's surface in the solar spectrum (Lillesand and Kiefer, 1980; Saleh and Hasan, 2014). Hence, different algorithms applied to find about accurate concentration of PM10 particulate from the captured image from satellite of any given area.

Many scientists have used different algorithm to find out PM10 level in different areas of world using satellite image. Li et al., (2015) has used aerosol optical thickness (AOT) based Particulate Matter study. Lim et al., (2007) has used Landsat data for PM10 distribution. Emili et al., (2010) has used

SEVIRI and MODIS sensors for the study using AOD. In the present study, an algorithm has been proposed to estimate the distribution of PM10 using Landsat 7 ETM+ remote sensing imagery. This investigation is unique and differs from most previous studies in term of high data resolution, PM10 and temporal-spatial distribution capability. Most previous works used MODIS (low resolution) or ASTER data (high resolution). The low resolution (250 m) is not appropriate for small-area study (Gyanesh et al., 2010; Techarat, 2013). The availability of Landsat ETM+ is better in comparison with ASTER data.

The main objective of the research study is to test the suitability of the proposed algorithm for mapping PM10 using Landsat satellite images. In situ measurements were required for algorithm validation. PM10 data have been collected simultaneously during the satellite Landsat overpass the study area, which was recorded by GPCB at ground stations of the study area. An algorithm was developed to determine the PM10 concentration on the earth surface. The efficiency of the proposed algorithm was determined based on the correlation coefficient (R^2) and root-mean-squares deviation, RMS. The radiance generated through this process is compared with the radiance before atmospheric correction to calculate the atmospheric path radiance, based on which the estimation of the PM10 is carried out. Finally, the PM10 map was generated using the proposed algorithm. The PM10 map was classified using QGIS and color-coded for visual interpretation.

2. Methodology

2.1. Study Area

The study was carried out in the Vadodara city and suburbs. Vadodara is located in the Gujarat state between $73^0 2'$ to $73^0 18'$ Eastern longitudes and $22^0 12'$ to $22^0 24'$ Northern latitude. Vadodara city and Nandesari town has many industries mainly chemicals, petrochemicals and biotechnology. With the industrial and urban development, the level of pollution has also been raised high (GPCB, 2010). The monitoring of pollutants is primarily required to initiate its control. The traditional method of its measurement is time consuming process. Also, the data may be collected only for selected locations identified as ground stations.

2.2. Data Acquisition

Landsat 7 ETM+ temporal data has been selected for the study from 2003 to 2014 of October month. There are other satellites available like MODIS, NOAA-AVHHR, ASTER and others. However, the spatial resolution of Landsat is 30 m for reflective bands, which is good compared to other satellites like MODIS. The temporal resolution of Landsat ETM+ is also reasonable. It is available since 1999, and follows a 16 days cycle. The Imagery of the study area was selected using USGS EarthExplorer interface. 14 Scenes for the dates with no cloud cover were ordered through USGS ESPA on demand interface. These higher level products included surface reflectance products which are atmospherically corrected using 6S method. Ground measurements of PM10 recorded at six locations of Vadodara were collected from GPCB office for the selected dates.

2.3. Data Processing

Satellite records the radiance of the surface received at sensor. The recorded radiance does not represent the true radiance of the surface. It is attenuated by aerosol and Particulate Matters. In order to get the true radiance, the recorded values need to be corrected using the sensor calibration values and then remove the noise added due to the atmospheric scattering. In several application of remote sensing, this noise is normally removed from the image during preprocessing. Instead, this noise was used to quantify and estimate the PM10 concentration in the air in the present study.

The total signal at the sensor consists of three components: (a) Reflected radiation from the viewed pixel, (b) Radiation from the neighborhood (c) Atmospheric Path Radiance. The atmospheric path radiance is the result of backscattering to space by particles and molecules in the atmosphere (Yoram, 1993). Based on path radiance an algorithm was derived to estimate the PM10 concentration in the study area.

The following equation was used to calculate the path radiance (Chuvieco and Huete, 2010)

$$L_{p,\lambda} = L_\lambda - \frac{\rho_\lambda ESUN_\lambda (\cos\theta)^2}{\pi\, d^2} \qquad \dots (1)$$

Where $L_{p,\lambda}$is the atmospheric path radiance (W/m^2/sr) for band λ, L_λ is at sensor radiance for band λ, ρ_λ is surface reflectance of band λ, $ESUN_\lambda$ is irradiance arriving at the top of atmosphere (W/m^2) in band λ, θ is the angle of incidence (degree), d is the correction factor for Earth-sun Distance, J is Julian day.

$$d = 1 + 0.01674\ \sin(2\pi(J - 93.5)/365) \qquad \dots (2)$$

The recorded values of the image are known as Digital Number (DN). The following equation is used to convert Digital Numbers (DNs) back to radiance (L_λ):

$$L_\lambda = Gain * DN + Bias \qquad \dots (3)$$

Where L_λ is the cell value as radiance, DN is the cell value digital number, gain is the gain value for a specific band, bias is the bias value for a specific band. The gain and bias values are available in the metadata file of the Landsat image.

After processing these remote sensing data, (a) Reflected radiation from the viewed pixel and (c) Atmospheric Path Radiance was calculated for selected stations remote sensing imagery. A relationship between the Path radiance and the ground station PM10 values has been established using regression analysis.

The surface reflectance was taken from the Landsat 7 ETM+ Surface Reflectance Product received through ESPA on demand interface of USGS. The surface reflectance products were already atmospherically corrected (Schmidt et al., 2013). So the radiance calculated using the atmospherically corrected data and the radiance before atmospheric correction quantifies as path radiance (eq. (1)). The path radiance was calculated for band 1, 2, 3, 4, 5 and 7 of Landsat data.

3. Results and Discussion

After processing, the derived path radiance values for all bands were analyzed for suitability of the algorithm based on their sensitivity to PM10. Using SPSS, Principal Component Analysis was performed for reduction of independent variables. The correlation for band 1, 3 and 4 was 89%, 47% and 47% respectively. Thus, the sensitivity of blue, red and NIR band to the ambient pollution has been ascertained by the results. Band 1 (blue) explains 61% of variance with eigenvalue 2.44 and 98% variance is explained with cumulative effect of the three bands. Techarat (2013) has given the PM10 algorithm for landsat images using the path radiance of band 3. It is evident with the present study that confirms the sensitivity of band 3. However, band 1 and band 4 have marginal effect of PM10 on the radiance reaching the satellite, which is evident from the results. Multiple linear regression analysis between the calculated band values and ground station PM10 data was performed using SPSS 17. The coefficient of determination (R^2) of the regression model was 0.89, which indicates a good model fit. The following algorithm was derived for PM10 estimation using the regression analysis.

$$PM10 = (-46.60 * L_{p,1}) - (0.374 * L_{p,3}) - (8.021 * L_{p,4}) + 1943.24 \quad \ldots (4)$$

Where $L_{p,1}$, $L_{p,3}$ and $L_{p,1}$ are path radiance of band 1, 3 and 4 respectively. The model was evaluated with test data which shows good results. The PM10 distribution map for the study area was generated using the derived algorithm using QGIS software ver. 2.18.7. The map was classified in 5 classes for visual interpretation. The PM10 map shows a good match with the available ground station average PM10 data. The month average data recorded by GPCB for October 2015 is 82 for Gotri and 72 for GPCB office station respectively, which matches with the derived PM10 classified map results.

Table 1: *Test data results for different ground station values and Landsat ETM+ Scene values*

Station	PM10 (µg/m^3)	PM10 Estimated (µg/m^3)
GPCB Office	51.00	44.21
GPCB Office	84.00	88.97
Gotri	83.00	96.50

Research on using remote sensing based PM10 estimation has been done using different sensors and methods. Commonly used approach for PM10 estimation is Aerosol Optical Thickness based retrieval using remote sensing. However, AOT input requires complex calculation and ancillary data. Atmospheric correction is normally applied to remote sensing images before using them for specific applications. The present study has been carried out using the selected Landsat images October month of the year 2003 to 2014. Similar study has to be carried out using the data of different months of the year to take seasonal variations into consideration.

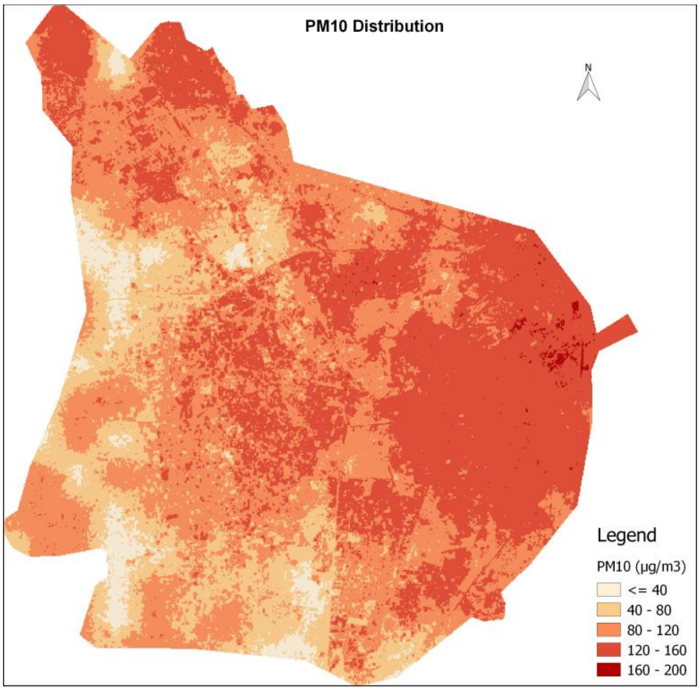

Figure 1: *PM10 classification map generated using the algorithm for Landsat ETM+ image of 16-Oct-2015 Vadodara city*

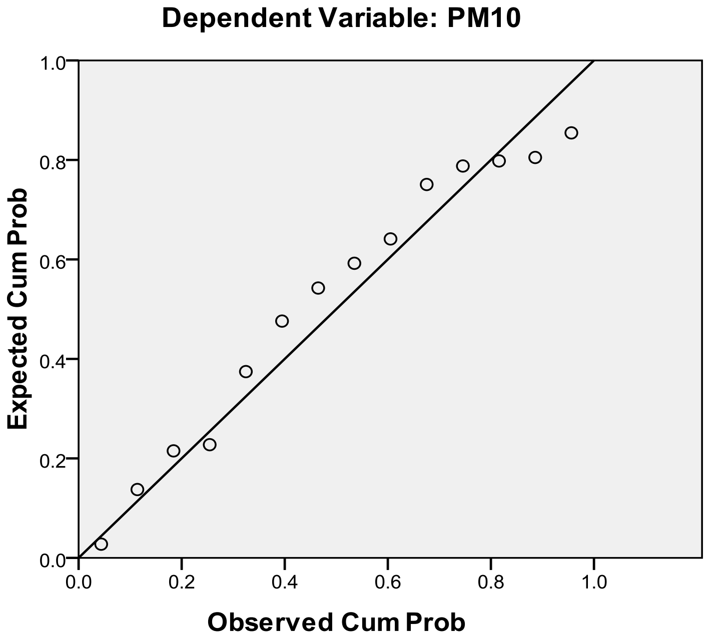

Figure 2: *Normal P-P plot of regression standardized residual*

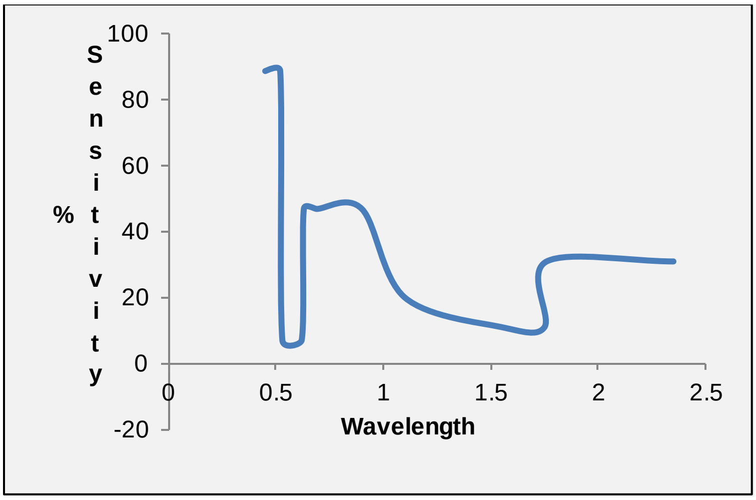

Figure 3: *Observed sensitivity plot for PM10 in different wavelength range of Landsat ETM+ sensor*

Techarat (2013) suggested that Landsat TM/ETM+ data can successfully be used as inputs of the derived algorithm to map the spatial distribution of PMs and SO2 concentrations with high efficiency. The Landsat ETM+ data should be used because they have high resolution, availability spatially and temporally, and easy to get (Techarat, 2013; Sotoudeheian and Arhami, 2014; Wang et al., 2017). The atmospheric correction, which is generally taken as preprocessing in remote sensing applicaions, has been effectively used for pollution distibution mapping (Marcello et al., 2016). The derived equation can be used for PM10 distribution mapping using Landsat ETM+ data for the study area. The remote sensing approach will save time taken in ground measurements. However, it will not give precise results, but good results for the purpose of estimation (Matthew et al., 2013). The main advantage is the entire study area may be covered for the distribution mapping based on the availability of Landsat ETM+ data for the desired time.

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