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Estimation of air pollution concentration over Jharia coalfield based on satellite imagery of atmospheric aerosol

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ABSTRACT

Air pollution concentration over Jharia coalfield was estimated based on satellite imagery of the atmospheric aerosol. The imagery was acquired by the earth observation satellite Landsat-5 during December 2009. In the process , radiation data from the earth surface stored in the imagery in the form of digital number were converted into surface reflectance values which were then used to estimate concentration of particular matters of radius less than 10 µm (PM_{10}) as indicators of air pollution concentration .The calculated data on PM_{10} were also compared with ground PM_{10} data estimated from different locations of the Jharia coalfield and a linear relationship was established between them having correlation coefficient of 0.8423. The derived equation was used to determine air pollution concentration in those places where air pollution survey was not carried out.

Keywords: Aerosol optical thickness (AOT), Landsat-5 TM image, Jharia coalfield (JCF), PM_{10} mass concentration.

1. Introduction

Air pollution has been identified as a problem since last a few centuries. Major industrialisation in the 18th century made the problem more severe and complex. It has now emerged as a true menace due to its detrimental effects on natural environment and consequently on human life. It causes several health problems particularly related to heart and lung. Though air is polluted by some natural phenomena also, the contribution of human activities in this respect is much more particularly due to industrialisation which in the most of the cases prerequisites large scales deformation. The problem is more pronounced in mining area due to different mining operations such as drilling, blasting, movement of the heavy machinery on haul roads, transportation of mineral, screening and this sizing etc. In many coal mines, mine fire adds to the problem to a great extent by contemning the surrounding air. As a result of these activities particulate matters and noxious gases like CH_4, SO_2, NOx, etc are released into the atmosphere. Consequently, suspended tiny particulate matters of diameter less than 10µm (PM_{10}) and liquid droplet form aerosol. Atmospheric turbidity due to aerosol is considered as an overall indicator of air pollution and it is measured by calculating the aerosol optical thickness (AOT) followed by PM_{10} mass concentration. In the present study air pollution concentration over Jharia coalfield at Dhanbad in India was determined based on AOT and PM_{10} values obtained after the processing imaginary acquired in December 2009 by the earth observation satellite Landsat -5 thematic mapper (TM) .

2. Literature Review

An algorithm was proposed by Hadjimitsis (2009) for assessment of aerosol optical thickness. It was based on Landsat TM imagery acquired in 1984-1986 over an urban area very near to Heathrow airport (UK) and in July-August 2008 of surroundings of Paphos airports in Cyprus. By comparing multi-temporal satellite data sets, the radiometric alterations due to the optical atmospheric effects of aerosols were evaluated. An improved dark object method for removing atmospheric effect from hyper-spectral remotely sensed images was presented by Xiang et al. (2008). They used the Hyperion data of Yangzhou city, Shandong Province. In this method they simultaneously removed the influence of the aerosol and water vapour. Gupta et al. (2006) evaluated air quality based on aerosol optical thickness data retrieved from two satellites namely Terra and Aqua. The results were validated with ground values of $PM_{2.5}$ mass concentration over different locations across the world. To quantify the effects of atmospheric mixing height, relative humidity and cloud cover, they performed a sensitivity study over selected locations. Mishra.et.al 2011 described an integrated satellite remote sensing approach for detection of coal fire from Landsat-7 data. The study concludes that the eastern part of Jharia coalfield was more affected due to coal mine fire in comparison to western part, so the above study indicates that eastern part is more environmental pullulated in comparison to western part.

3. Study area

Jharia coalfield is situated at the heart of Damodar river valley towards NW of Kolkata at about 250 km distance and about 1150 km in SE of Delhi. It is confined between latitudes 23°38' N and 23°50' N and longitudes 86°07' E and 86°30' E. The maximum extent of the coalfield is about 38 km from East to West and 19 km from North to South with an area of 435.24 km^2. Location plan and satellite imagery of the Jharia coalfield is shown in Fig.1.

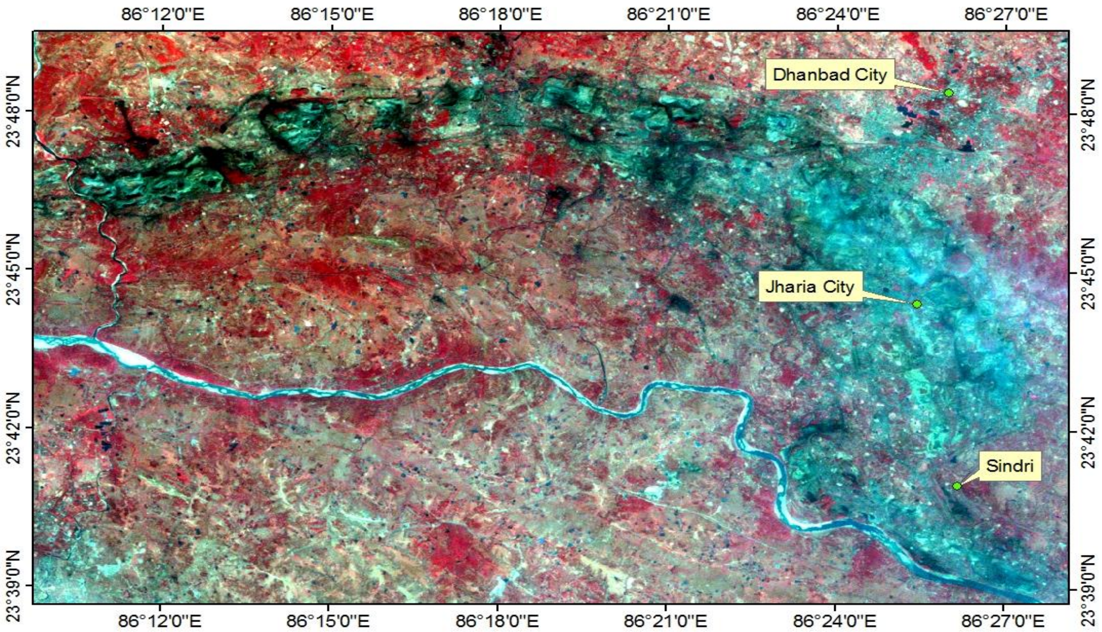

Figure1: Location plan and satellite imagery of the Jharia coalfield

4. Calculation of AOT and PM_{10} from Landsat-5 data

The Landsat data was imported and geo-referenced with the help of survey of India toposheet as base map. The area of interest of Jharia coalfield was extracted from the satellite data .The estimation of aerosol path radiance was carried out from satellite data stored in image by pixel value or digital number (DN) value with the help of dark object subtraction method .It is applicable for shortwave length of Landsat TM band 1 and 2 in which water vapour absorption is negligible .This method assumes that within satellite image there exits features of near-zero percent reflectance from water, dense forest ,shadow etc, so that the signal recorded by the sensor from these features is solely a result of atmospheric scattering (path radiance). After processing the satellite imagery aerosol path radiance was estimated using equation (1).

$$L_p = G * DN_{dark} + B - 0.01[E_0 * \mu_s * T_z + E_{down}] T_v / \pi \quad (1)$$

where, L_p = aerosol path radiance (Wm^{-2} sr^{-1} µm^{-1}); G = band specific gain (m^2 sr µm W^{-1}); DN_{dark} = darkest DN values in spectral band with at least one thousand pixels; B = band specification bias in DN ; E_0 = exoatmospheric solar constant (Wm^{-2} µm^{-1}) ; μ_s = cosine of solar zenith angle; $T_z = e^{-\pi/\mu_v}$ atmospheric transmittance in the illumination direction; E_{down} = downwelling diffuse irradiation (Wm^{-2} µm^{-1}); $T_v = e^{-\pi/\mu_s}$ atmospheric transmittance from the target towards the sensor.

Then optical thickness for Rayleigh scattering (τ_r) was determined by equation (2) proposed by Sturm, (1982).

$$\tau_r = 0.00879 * (\lambda_c)^{-4.09} \quad (2)$$

where, λ_c = band centre wavelength in µm;
It was followed by calculation of AOT by putting the values of L_p and τ_r in equation (3) proposed by Yil-Yi(1982) .

$$L_p = \omega_a \left\{ \frac{E_0 * \mu_s * P_a}{4\pi(\mu_s + \mu_v)} \right\} \left\{ 1 - \exp\left[-\tau_a \left(1/\mu_s + 1/\mu_v \right) \right] \right\} * t_{H2O} * t_{O3} * \exp\left[-\tau_r \left(1/\mu_s + 1/\mu_v \right) \right] \quad (3)$$

where, τ_a = Aerosol Optical Thickness(AOT); ω_a = aerosol single scattering albedo 0.80; P_a = aerosol scattering phase function ; μ_v = cosine of sensor viewing angle; t_{H_2O} and t_{O_3} = the transmittance factor due to water and ozone=1,
Finally, PM_{10} mass concentration was calculated from equation (4) proposed by Retails & Sifakis, 2010.

$$PM_{10} = 195.7\tau_a + 14.5 \quad (4)$$

The calculated AOT and PM_{10} mass concentration have been presented in Table 1. While Fig. 2 shows the AOT map of Jharia coalfield, a view of the PM_{10} concentration over Jharia coalfield is shown in Fig. 3 (Chaudhary, 2011).

Table 1: Calculated AOT and PM_{10} mass concentration from satellite image data and PM_{10} ground measurement at different location of Jharia coal field.

Ground Station	Calculated AOT from Satellite Image	PM_{10} concentration estimated from imagery ($\mu g/m^3$)	Monthly average PM_{10} concentration measured at ground station ($\mu g/m^3$)
R.O. Dhanbad	0.972	204.803	161.39
MADA, Jharia	1.965	399.072	351.28
PDIL, Sindri	0.879	186.623	172.56
EMTI, Bastacola	1.965	399.072	394.01
CGM, Kusunda	0.909	192.499	250.88

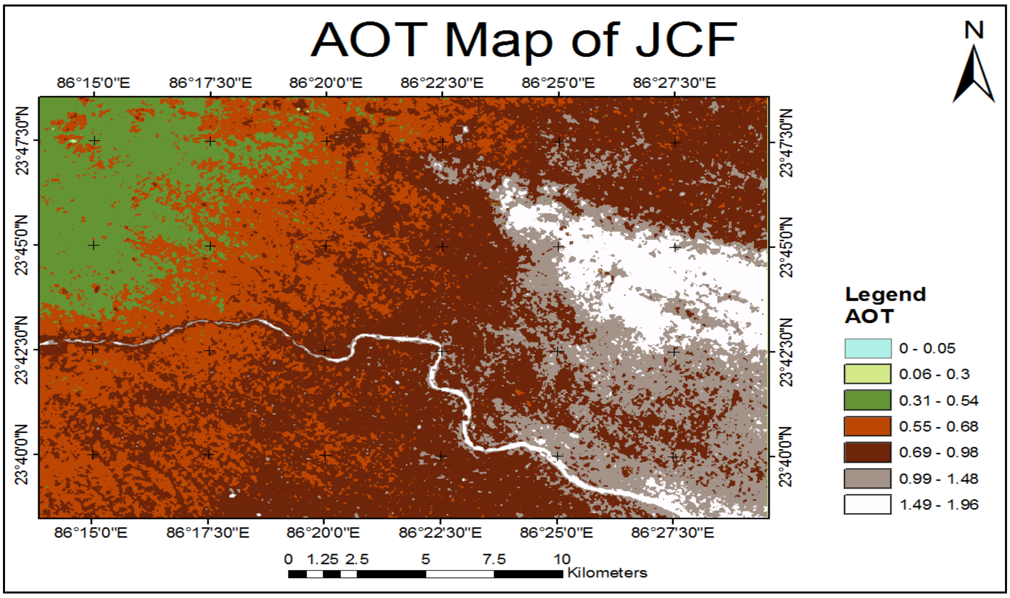

Figure 2: Detection and mapping of AOT of Jharia coal field by Landsat-5 TM data.

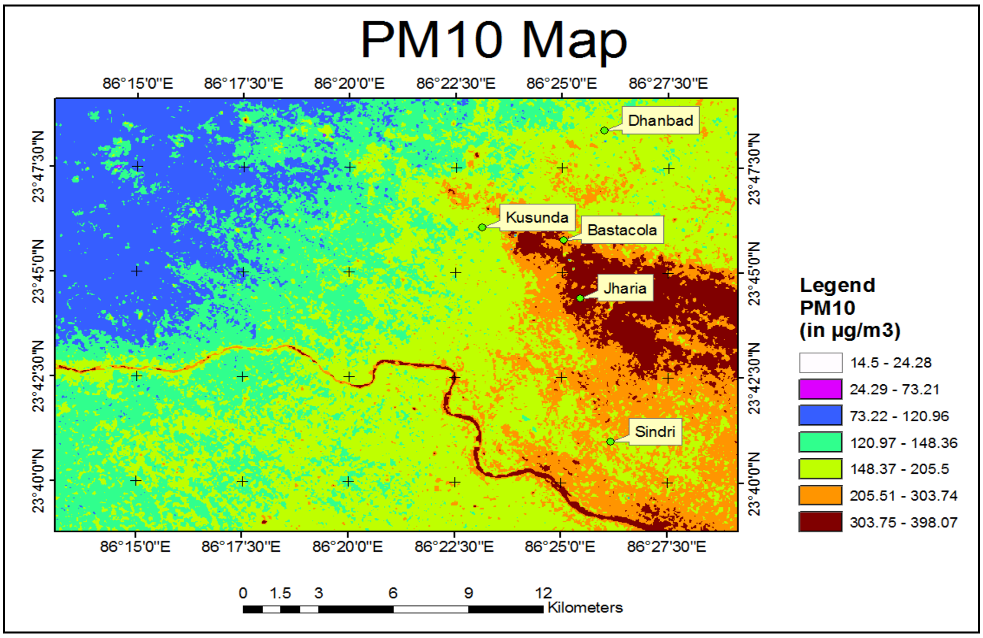

Figure 3: PM_{10} concentration mapping of Jharia coal field by Landsat-5 TM data

5. Data analysis and result

Table 1 shows that the maximum concentration of PM_{10} as calculated based on satellite imagery was 399.072 µg/m^3 at EMTI in Bastacola as well as MADA in Jharia indicating maximum pollution load in the stretch of Bastacola to Jharia. This finding corroborates well with the observation at ground station of the two places. Minimum concentration of calculated PM_{10} observed was 186.623 µg/m^3 at PDIL at Sindri. It has also close proximity with estimated figure of 172.56 µg/m^3 at this ground station.

When the estimated PM_{10} data and calculated PM_{10} data were plotted in x-axis and y-axis respectively in a graph paper following linear relationship was found to establish having a correlation coefficient of 0.8423 in Figure 4.

$$Y = 0.853X + 31.181 \qquad (5)$$

This equation was used to calculate the PM_{10} concentration in those places where ground survey was not carried out.

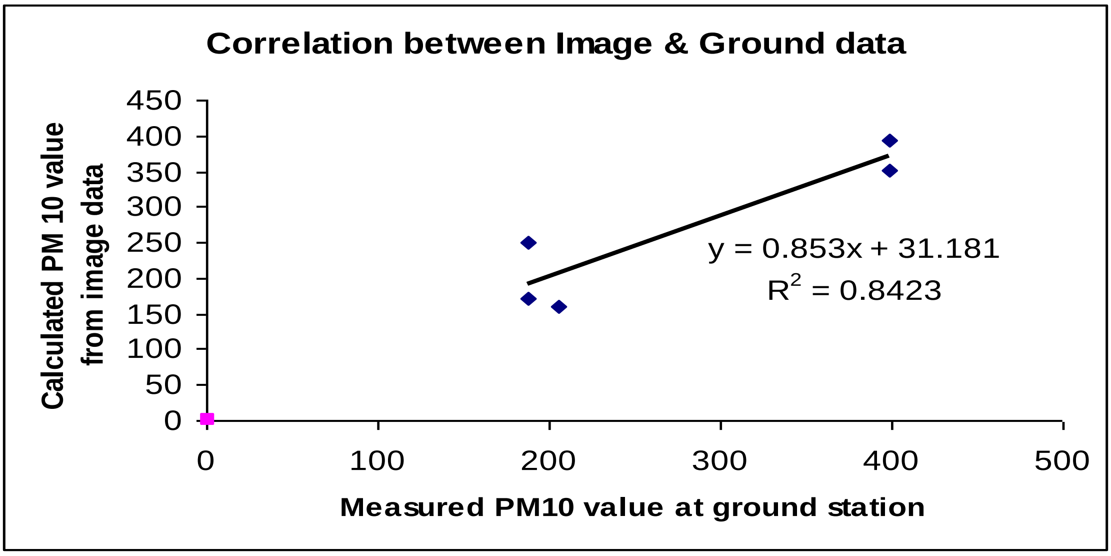

Figure 4: Correlation between the PM_{10} concentration of satellite and ground station data

6. Conclusion

Based on the study it was conclude that the eastern part of Jharia coalfield was more polluted in comparison to the western part due to extensive mining activities as well as a large number of coal fires. The study also proved the efficiency of the method of estimation of air pollution concentration based on satellite imagery of atmospheric aerosol. This relationship is true for the study carried out in December 2009.

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