ESTIMATION OF PM10 FROM AOT OF SATELLITE LANDSAT 8 IMAGE OVER HANOI CITY

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ABSTRACT

In this study we research about the potentialy of retrieving concentrations of particulate matter with diameters less than ten micrometer (PM10) in the atmosphere using the Landsat 8 satellite images over Hanoi city. The research focus on testing of process for air pollution determination, starting from the atmospheric correction of Landsat 8 by means of the DOS, calculated AOT, the relationship function between AOT and PM10, since then the model of PM10 can be calculated and selected from the Landsat 8 images in the central of Hanoi area.

Keywords: PM10, AOT, Landsat 8, atmospheric correction

1. INTRODUCTION

Air pollution is a concern of many countries around the world. Vietnam is a developing countries, the urbanization process is very fast, the continuous construction rises, the growth of the industry, the transport increases, so the pollution in the air is becoming ever more serious.

According to the World Health Organization (WHO), urban air pollution as 800,000 peoples dead and 4.6 million decrease life expectancy in the world each year. 2/3 of deaths and reduced life expectancy due to air pollution of the developing countries in Asia.

However, in the field of air pollution monitoring, now in Vietnam is mainly interpolated based on data from monitoring stations to measure the level of cover should not cost very large and expensive.

Studies worldwide have shown that the use of multispectral satellite images absolutely can detect air pollution in the area which we are interested. Effectively brought from the application of remote sensing technology in the field of environmental monitoring of air pollution, should be addressed first at the macro level to support leaders and managers in planning regions, the development of industrial zones and urban areas; reduce air pollution affect the environment and public health.

On the other hand, the regular supply of indicators related to air quality in urban areas, allowing all agencies, organizations and individuals can harness information and make sure the scene, the responses to air pollution.

Through this analysis we can see that the world has used satellite imagery to monitor air quality in urban areas has advantages standout Vietnam techniques, technologies, have broad and wide economic efficiency, but in Vietnam, there is no research on this matter.

Therefore, in this study we presents the potentiality of retrieving concentrations of particulate matter with diameters less than ten micrometer (PM10) in the atmosphere using the Landsat 8 satellite images over Hanoi city.

2. METHODOLOGY

The methodology process generally was divided into the following steps: data acquisition, pre-processing, data processing and validation of results. All data preprocessing and processing steps were carried out using MathLab and ERDAS image.

2.1 Pre-processing

Radiometric correction is applied by transforming the values of DN to radiance or reflectance values. There are different levels of radiometric calibration. The first converts the sensor DN to at-sensor radiances and requires sensor calibration information. The second is the transformation of the at-sensor radiances to radiances at the earth's surface. Radiometric correction is applied by transforming the values of DN to radiance or reflectance values through the algorithm as follows: (https://landsat.usgs.gov/Landsat8_Using_Product.php)

2.1.1 Conversion to TOA Radiance

OLI and TIRS band data can be converted to TOA spectral radiance using the radiance rescaling factors provided in the metadata file:

$$L_\lambda = M_L * Q_{cal} + A_L \quad (1)$$

where:

L_λ = TOA spectral radiance (Watts/(m2 * srad * μm))
M_L = Band-specific multiplicative rescaling factor from the metadata (RADIANCE_MULT_BAND_x, where x is the band number)
A_L = Band-specific additive rescaling factor from the metadata (RADIANCE_ADD_BAND_x, where x is the band number)
Q_{cal} = Quantized and calibrated standard product pixel values (DN)

2.1.2 Conversion to TOA Reflectance

OLI band data can also be converted to TOA planetary reflectance using reflectance rescaling coefficients provided in the product metadata file (MTL file). The following equation is used to convert DN values to TOA reflectance for OLI data as follows:

$$\rho\lambda' = M_\rho * Q_{cal} + A_\rho \quad (2)$$

where:

$\rho\lambda'$ = TOA planetary reflectance, without correction for solar angle. Note that $\rho\lambda'$ does not contain a correction for the sun angle.
M_ρ = Band-specific multiplicative rescaling factor from the metadata

(REFLECTANCE_MULT_BAND_x, where x is the band number)
A_ρ = Band-specific additive rescaling factor from the metadata (REFLECTANCE_ADD_BAND_x, where x is the band number)
Q_{cal} = Quantized and calibrated standard product pixel values (DN)

TOA reflectance with a correction for the sun angle is then:

$$\rho\lambda = \frac{\rho\lambda'}{\cos(\theta_{SZ})} = \frac{\rho\lambda'}{\sin(\theta_{SE})} \quad (3)$$

where:

$\rho\lambda$ = TOA planetary reflectance
θ_{SE} = Local sun elevation angle. The scene center sun elevation angle in degrees is provided in the metadata (SUN_ELEVATION).
θ_{SZ} = Local solar zenith angle; $\theta_{SZ} = 90° - \theta_{SE}$

For more accurate reflectance calculations, per pixel solar angles could be used instead of the scene center solar angle, but per pixel solar zenith angles are not currently provided with the Landsat 8 products.

2.1.3 Atmospheric Correction

It is worth pointing out that Landsat 8 images are provided with band-specific rescaling factors that allow for the direct conversion from DN to TOA reflectance. However, the effects of the atmosphere (i.e. a disturbance on the reflectance that varies with the wavelenght) should be considered in order to measure the refletance at the ground. As described by Moran et al. (1992), the land surface reflectance (ρ) is:

$$\rho = \frac{\pi * (L_\lambda - L_P) * d^2}{T_V * \{(ESUN_\lambda * \cos\theta_{SZ} * T_Z) + E_{down})\}} \quad (4)$$

where:

L_P = path radiance

T_V = atmospheric transmittance in the viewing direction

T_Z = atmospheric transmittance in the illumination direction

E_{down} = downwelling diffuse irradiance

$ESUN_\lambda$ = mean solar exo-atmospheric irradiances

d = earth_sun distance (provided with Landsat 8 metadata)

The Dark Object Subtraction (DOS) method (Chavez 1996) and the path radiance is given by (Sobrino, et al., 2004), the path radiance Landsat 8 image is:

$$L_P = L_{min} - 0.01 * \frac{T_V * \{(ESUN_\lambda * \cos\theta_{SZ} * T_Z) + E_{down}\}}{\pi * d^2} \quad (5)$$

Where, L_{min} is the calibration constant (RADIANCE_MINIMUM_BAND_x, where x is the band number)

There are several DOS techniques (e.g. DOS1, DOS2, DOS3, DOS4), based on different assumption about T_V, T_Z , and E_{down}.

In this study, using the method simplest technique is the DOS1, where the following assumptions are made (Moran et al., 1992): $T_V = 1$; $T_Z = 1$; $E_{down} = 0$. Therefore the path radiance is:

$$L_P = L_{min} - 0.01 * \frac{ESUN_\lambda * \cos\theta_{SZ}}{\pi * d^2} \quad (6)$$

And the resulting land surface reflectance is given by:

$$\rho = \frac{\pi * (L_\lambda - L_P) * d^2}{ESUN_\lambda * \cos\theta_{SZ}} \quad (7)$$

2.2 Aerosol Optical Thickmess (AOT) anh PM10 Correlation

After undergo radiometric correction, the reflectance measured from the satellite (reflectance at the top of atmospheric, TOA) was subtracted by the amount given by the surface reflectance to obtain the atmospheric reflectance. On that basis, calculate AOT as follows is given by Nadzri O et al (2010).

$$AOT(\lambda) = a_o R(\lambda) \quad (8)$$

With:

$$R(\lambda) = \rho_a(\theta_{SZ}, \theta_V, \phi)$$

$$a_o = \left(\frac{4\mu\mu_o}{\omega_o P_a(\theta_{SZ}, \theta_V, \phi)}\right)$$

Where:

$R(\lambda)$ = atmostpheric reflectance corresponding to wavelength (λ) for satellite

$\rho_a(\theta_{SZ}, \theta_v, \phi)$ = aerosol scattering phase function

θ_{SZ} = Local solar zenith angle

θ_v = Viewing zenith angle

ϕ = Relative azimuth angles

μ = Cosines of the view directions

μ_o = Cosines of the illumination directions

ω_o = sing- scattering albedo

Equation (8) is rewrite into three band equation as Equation (9).

$$AOT(\lambda) = a_o R_{\lambda 1} + a_j R_{\lambda 2} + a_2 R_{\lambda 3} + a_3 R_{\lambda 4} \ldots\ldots \quad (9)$$

Where $R_{\lambda i}$ is the atmospheric reflectance (i = 1, 2 and 3 corresponding to wavelength for satellite), and a_j is the algorithm coefficient (j = 0, 1 and 2) are empirically determined.

The relation between PM and AOT is derived for a single homogeneous atmospheric layer containing spherical aerosol particles. The mass concentration at the surface is obtained after drying the sampled air is given by Koelemeijer et al. (2006).

$$PM_X = \frac{4}{3}\pi\rho \int_0^{X/2} r^3 n(r) dr \quad (10)$$

Where n(r) describes the aerosol size distribution under dry conditions and ρ is the aerosol mass density.

Hence, it can be expected that the parameter PM correlates better with AOT directly. Using the information, obtained by the spectral AOT retrieval, a method has been developed to retrieve particulate matter concentrations. By substitute AOT in term of PM10, Equation (9) into (11), and the algorithm for single band or wavelength (X) of PM10 is simplified as follows is given by Lim HS et al (2004) and Nadzri O et al (2010)

$$PM10 = a_o R_{\lambda 1} + a_j R_{\lambda 2} + a_2 R_{\lambda 3} + a_3 R_{\lambda 4} \ldots\ldots \quad (11)$$

Where $R_{\lambda i}$ is the atmospheric reflectance (i = 1, 2 and 3 corresponding to wavelength for satellite), and a_j is the algorithm coefficient (j = 0, 1 and 2) are empirically determined.

The atmospheric reflectance was then related to the PM10 using the regression algorithm analysis, from there build calculate models PM10. PM10 maps were generated using proposed algorithm based on the highest R and lowest RMSE values, where the highest value of correlation coefficient, R is 0.888 and the linear regression model as follow is given by Nadzri O et al (2010)

$$PM10 = 396R_{\lambda 1} + 253R_{\lambda 2} - 194R_{\lambda 3} \quad (12)$$

Where PM10 is equal to PM10 concentration in ($\mu g/m^3$), $R_{\lambda 1}$, $R_{\lambda 2}$ and $R_{\lambda 3}$ are equal to the atmospheric reflectance/path radiance in blue, green and red band

3. STUDY AREA

Hanoi is Vietnam's capital, has geographic coordinates: latitude from 20 ° 53'N to 21 ° 23'N and longitude from 105 ° 44'E to 106 ° 02 'E , with an area of 3328.9 km2 and with a population of 6,699,600 people (2011).

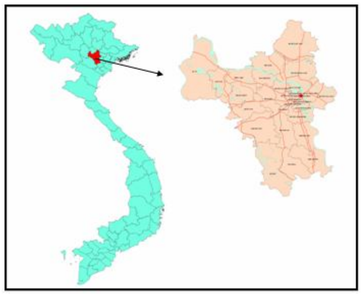

Figure 1. Study area

4. DATA

- Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) **images** consist of nine spectral bands with a spatial resolution of 30 meters for Bands 1 to 7 and 9. New band 1 (ultra-blue) is useful for coastal and aerosol studies. The resolution for Band 8 (panchromatic) is 15 meters. Thermal bands 10 and 11 are useful in providing more accurate surface temperatures and are collected at 100 meters. Approximate scene size is 170 km north-south by 183 km east-west (106 mi by 114 mi) http://landsat.usgs.gov .

- Landsat 8 OLI image used in this work have Scene ID: LC81270452013352LGN00, the acquisition date of the Landsat 8 OLI image at Path/Row 127/45 on 18th December 2013. Landsat 8 OLI scene was downloaded from the United States Geological Survey (USGS).

5. EXPERIMENTAL RESULTS

Using MathLab, ERDAS, Arcgis and compare index AQI (air Quality Index), we have maps of PM10 with respect to atmospheric reflectance for the red band (b4), green band (b3) and blue band (b2) show in Figure 3. The density of PM10 concentration in urban areas are building and heavy traffic.

Figure 2. Landsat 8 image of Hanoi

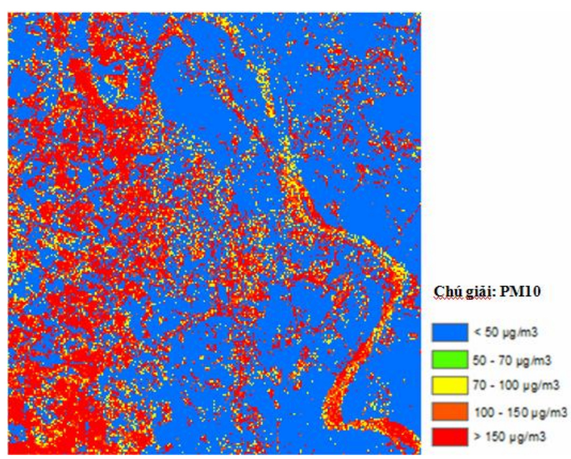

Figure 3 . Maps of PM10 of Hanoi

6. CONCLUSION

The results of this study indicates that air pollution can be mapped using satellite information to provide a bigger area of coverage.

Landsat8 image was successfully used for calculation of PM10 concentration over Hanoi city. Our proposed multispectral algorithm of PM10 algorithm is based on the aerosol optical reflectance model. The result indicates that the air pollution PM10 can be calculated, by propose on, using the visible bands reflectance value of Landsat 8 image.

However, the use of computer modeling of PM10 area for other regions will affect the accuracy of the calculated results.

Future study will consider of using more air pollution stations and other value-added ancillary data, since then calculating a regression model to determine PM10 calculated from Landsat 8 for the area to be studied. As well as the method of atmospheric correction of Landsat 8 in order gain better and reliable accuracy.

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