Conference Proceedings Paper

Remote sensing-based Aerosol Optical Thickness for monitoring Particular Matter over the city

Tran Thi Van [1,*], Nguyen Hang Hai [2], Vo Quoc Bao [1], Ha Duong Xuan Bao [1]

[1] Ho Chi Minh City University of Technology, Vietnam National University Ho Chi Minh City; tranthivankt@hcmut.edu.vn
[2] Ho Chi Minh City University of Science, Vietnam National University Ho Chi Minh City; nghanghai@gmail.com
* Correspondence: tranthivankt@hcmut.edu.vn ; Tel.: +84-028-091-918-8485

Academic Editor: name
Published: date

Abstract: Urban development driving the air pollution matter is one of the reason which is seriously affecting on public health. Besides the traditional ground observation methods, the current space technology has been contributed to monitoring and managing environment. This research used Landsat satellite image to detect PM10 from by Aerosol Optical Thickness (AOT) method for Ho Chi Minh City area. The regression analysis was used for establishing the relationship between the PM10 data obtained at ground stations and AOT values from processed image in 2003. The analysis showed a good correlation coefficient (R = 0.95) for the case of AOT calculated from spectral reflective green band. The relative radiation normalization was carried out for satellite image 2015 in order to simulate the spatial distribution of PM10 with the same regression function. The distribution for PM10 aerosol pollution is focused on the urban area, traffic booth and industrial zones. The results of this study provided a picture of general distribution for current pollution status and also supported to determine the specified polluted areas. It is very helpful and good supported to zoning and urban environmental management in accordance with urban development.

Keywords: air pollution; AOT; PM10; reflective band; relative radiation normalization; urban development

1. Introduction

As society develops, along with the urban development and industrialization, transportation activities become overloaded. The formation and development of export processing zones, and industrial parks makes the problem of pollution in general, and the problem of air pollution in particular increasingly serious. Air pollutants in the aerosol form can be SO_2, NO_2, CO, or PM10 dust. The emission of air pollutants is often difficult to control because it is governed by many factors such as wind direction, geomorphology of the area, and the presence of construction works. Therefore, air pollution is often especially variable in space, even over short distances.

At present, there are many pieces of research on the application of remote sensing to assess the air quality. The methods based on radiation data in the Earth's surface are stored in a digital image, which is then converted into surface reflectance values. It then estimates the concentration of PM10 dust by a number of direct or indirect methods and compares them with the data at the ground stations at the same time to establish a relationship between them.

Currently, research related to the determination of aerosol optical sensitivities is being explored to find correlations with atmospheric pollution components. The spatial resolution of Landsat and SPOT imagery allows some researchers to develop a series of methods based on radiation equations, atmospheric models, and image-based methods.

Kaufman et al. (1990) have developed an algorithm that determines AOT (use of soil and water black objects) from differences in upward radiation received by satellites during a clear day in (zero pollution) and a misty day (with pollution). This method assumes that the surface reflectivity between the clear day and the misty day does not change [1].

Sifakis and Deschamps (1992) use SPOT images to estimate the distribution of air pollution in the city of Toulouse in France. They developed an equation for calculating the aerosol optical depth difference between a reference image (well-weathered) and a polluted image. Their method is based on the fact that after adjusting the observation angles and the sun, the remaining deviation of the apparent radiation is due to the pollutant [2].

In addition, Hadjimitsis and Clayton (2009) developed a method combining the Darkest Object Subtraction and radiated equations for calculating AOT values for bands 1 and 2 of Landsat TM. They used a new method to determine AOT through darkest atmosphere correction in the London Heathrow airport area and in the Pafos airport area in Cyprus [3].

There are many studies on the air environment in Vietnam, especially the assessment of air pollution in big cities such as Hanoi, Ho Chi Minh City, Da Nang, Can Tho; However, research focuses on analysis Statistics from measurements at ground monitoring stations, or on the basis of modeling for spatial simulation. Yet, the quantitative results are not detailed.

Luong Chinh Ke et al. (2010) studied the scientific basis of the ability to detect and monitor certain components of air pollution, based on a combination of satellite imagery and observation station data. At the same time, the group has proposed a technological process to establish an air pollution map for a specific area [4].

Tran Thi Van et al. (2011) carried out the project "Research on remote sensing of air quality (dust component) in urban areas, test for Ho Chi Minh City". They demonstrated that the green wavelength spectrum of the Landsat satellite image correlated well with PM10 dust measurements from ground stations [5].

This paper presents the results of research on the possibility of detecting PM10 dust from remote sensing technologies in urban areas, based on correlation and regression between AOT values calculated on satellite imagery and ground measurements from auto-observation stations. Based on the built regression equation integrated with the relative radiometric normalization method. This study monitored the dust environment in two years 2003 and 2015. Area of application is the middle of Ho Chi Minh City (HCMC).

2. Methods

2.1. The basis for determining AOT

Techniques used to calculate AOT were developed by Sifakis and Paronis [6]. According to this method, AOT should be calculated from remote sensing to detect PM10. Then, by regression analysis, the relationship is established between PM10 data obtained at the stations on the ground and AOT values from the processed image. Two types of data must have the same date and time acquisition. Method of determining the AOT is determined based on the standard deviation reflection on pollution days, and reference date (day clean). In this study, two satellite images were compared according to the value of radiation. One image was captured in pollution and the other one called reference images were obtained in clean air conditions. The origin of calculations based on basic equations of reflection in satellite and AOT values are determined by the formula [2]:

$$\Delta\tau = \tau_2 - \tau_1 = \ln[\frac{\sigma_1(\rho)}{\sigma_2(\rho)}] , \quad (1)$$

Where, $\Delta\tau = \tau_2 - \tau_1$ - Optical thickness (not units) of clean days and days corresponding pollution; $\sigma_1(\varrho)$ - The standard deviation of the reflectance of clean days; $\sigma_2(\varrho)$ - The standard deviation of the reflectance of polluted days.

On the other hand, the optical thickness is approximately equal to 0 days clean, because there is no or very little pollution components, while $\tau_1 = 0$, formula (1) becomes:

$$\Delta\tau = \tau_2 = \ln[\frac{\sigma_1(\rho)}{\sigma_2(\rho)}] , \quad (2)$$

Or, only remaining component τ_2 which is AOT on the image of pollution day.

2.2. Relative radiometric normalization to multi-temporal images

The objects in the multi-temporal image are changed and almost impossible to perform comparative automated methods. To accurately detect the change of the landscape according to the changes of surface reflectance from multi-temporal images, it needs to implement radiometric normalization. There are two methods to standardize radiation, in this case, it is the absolute and relative normalization. Absolute normalization method requires the use of ground measurements at the time of data acquisition. This can not be done because there is no measured data in parallel on the ground for the different images. Relative radiometric normalization method requires no ground measurements of the atmosphere at the image acquisition time. Accordingly, an image is used as a reference image, and the rest will be subject images. It means that the subject images will be adjusted according to the atmospheric, geometry, lighting and environment conditions by the reference image. Base premise of this approach is that the radiation reaching the satellite sensor can be represented as a linear function of the albedo [7]. For many sensors, spectral values in each band a linear function of radiation reaching the sensor. Thus, the difference in atmosphere and spectrum between the images is also linearly related. The linear expression is applied to the process of normalization as follows:

$$S_{ref-i} = a_i S_{sub-i} + b_i, \quad (3)$$

Where S_{ref-i} is the pixel value of the ith band in the reference image; S_{sub-i} - the pixel value of the ith band in the subject image; a_i, b_i - regression coefficients will be calculated according to S_{ref-i} and S_{sub-i}

One of the important methods to be able to determine the coefficients ai and bi is the method of linear regression analysis according to the pair of unchanged points extracted from two images. The point does not change or hardly changed over time is selected as artificial objects such as roads, roofs, and parks. According to Schott et al (1998) [7] they are artificial objects with reflection independent of the season and the ecological cycle. The difference in the value of the object spectrum is assumed to be the linear function.

After determining the coefficients a_i and b_i, subject image will be normalized according to the following formula:

$$S'_i = a_i S_i + b_i, \quad (4)$$

Where S'_i is pixel value normalized in the ith band; S_i - the pixel value in the original image in the ith band; a_i, b_i - regression coefficients calculated from the above equation; RMSE (root mean square error) was evaluated for the case before and after normalization to demonstrate the efficiency [8].

$$RMSE = \sqrt{\frac{1}{n}\sum(S' - S)^2} , \quad (5)$$

Where n is the number of pixels taken to calculate the RMSE. S'- pixel value normalized; S - value in the original image pixel respectively. RMSE values have decreased after standardization, and are regarded as successful results.

3. Results and Discussion

Satellite images taken in this study were the Landsat ETM+ and Landsat / OLI & TIRS with acquisition time as follows: LANDSAT / ETM - 16/2/2003; LANDSAT / OLI & TIRS - 09/02/2015.

Currently, the auto-observation stations were mostly no longer active, so in the past time (before 2003) and up to now (after 2009) there were no ground PM10 data to find correlations to images. To perform the PM10 distribution in 2015 in this study, the authors have used a relative radiometric normalization method to convert the environmental and atmospheric conditions on the images in 2015, according to the 2003 image conditions. Since then we calculated AOT values for the appropriate band and applied the regression equation to determine PM10 values, finally mapped the simulation of PM10 spatial distribution in 2003 and 2015:

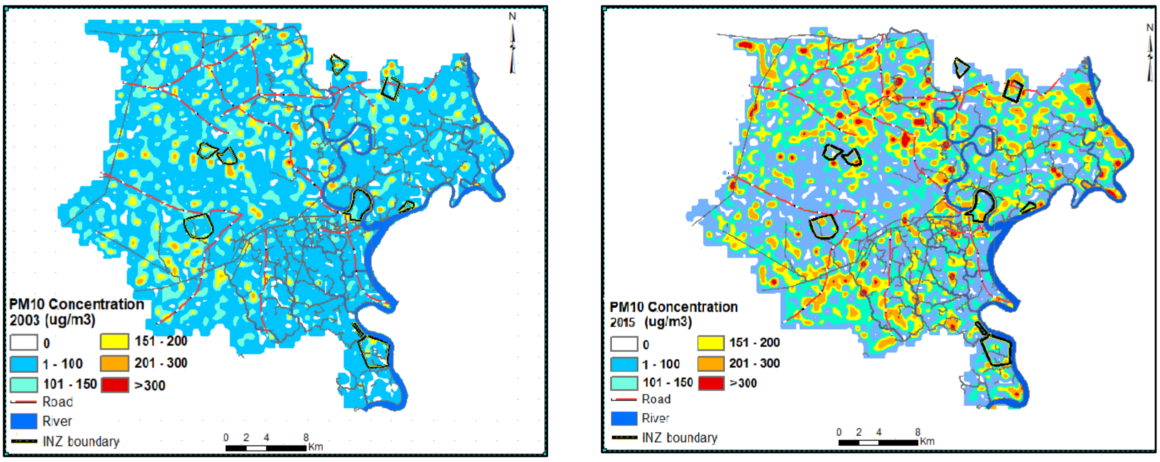
$$PM10 = 15.639*AOT2^2 + 87.147*AOT2 + 75.803, \quad (6)$$

Currently, the auto-observation stations were mostly no longer active, so in the past time (before 2003) and up to now (after 2009) there were no ground PM10 data to find correlations to images. To perform the PM10 distribution in 2015 in this study, the authors have used a relative radiometric normalization method to convert the environmental and atmospheric conditions on the images in 2015, according to the 2003 image conditions. Since then we calculated AOT values for the appropriate band and applied the regression equation to determine PM10 values, finally mapped the simulation of PM10 spatial distribution in 2003 and 2015.

Checking the error of the results was done by the absolute error, the difference between the PM10 concentrations at each observation station and the corresponding PM10 concentration calculated on the Landsat image. From there, the root mean square error RMSE was determined with sample number N = 6 corresponding to 6 observation stations with a value of 11.07.

Table 1. Correlation coefficient between spectral reflectance values of AOT images and PM10 dust concentration data at ground observation stations on March 16, 2003.

AOT band	AOT-Band 1	AOT-Band 2	AOT-Band 3	AOT-Band 4
Correlation coefficient	$R^2 = 0.1981$	**$R^2 = 0.9051$**	$R^2 = 0.3995$	$R^2 = 0.342$



2003 2015

Figure 1. Spatial distribution of PM10 concentration on the time of image acquisition in the middle of HCMC. *(INZ – Industrial zone)*

The map of PM10 dust concentration distribution according to satellite images was established for the middle of Ho Chi Minh City. The results from the LANDSAT image taken on February 16, 2003, and February 9, 2015 are shown in Figure 1. This is a snapshot of the PM10 dust environment at 10 am, not the average result of a measuring period. Therefore, the study has no comparison with the standards. The results will be the estimates of the spatial distribution of PM10 dust concentrations from satellite imagery, which demonstrate the ability to detect dust from satellite images in accordance with appropriate digital image processing.

Results on the map show that the contours of the PM10 values have localized shape, do not spread far, and distribute in many directions. This is explained by the process of dispersal of suspended matter in the air affected by the local wind. The urban area has quite a large surface roughness of terrain, and several high buildings close together. Therefore, seasonal prevailing wind and "vicious wind" do not impact much in the urban areas. Features of this wind are blowing in different directions under the effect of the flow of the vehicles as well as the anthropogenic heat waste. Comparison of the PM10 simulations between 2003 and 2015 reflects both a general picture, that is, in urban areas, concentrated urban areas, traffic points, and industrial parks, there was a high PM10 distribution. While they have a dispersed shape in the suburbs.

The satellite image is taken at 10 am, which is the time of busy traffic when trucks are allowed to travel in the inner city, and production activities are also available and stable. The overall picture shows that in the whole area, low PM10 concentrations <100μg / m^3 were found in wetlands, in the north of Binh Chanh district, bordering with Long An, in the west of the district. Hoc Mon is bordered by Long An, Nha Be, south of District 9, Thanh Da Peninsula and along the Saigon River in District 12. Areas with high PM10 concentrations are concentrated in main roads, industrial parks with a value higher than 200μg/m^3, and even some places above 300μg/m^3. Generally, the expansion of high-value PM10 spatial distribution in 2015 compared to 2003 is increasing, focusing in areas outside the urban core, where the new residential areas have been developing with the new traffic routes. Today, the increasing traffic density in these areas, along with the immigration from other provinces into the HCMC, causes the air environment uncontrolled.

4. Conclusions

The paper presents a simulation study on PM10 concentration distribution from the method of combining LANDSAT satellite image analysis with ground measurements through the aerosol optical thickness. The results of the study are the map of simulated PM10 dust for the two shooting years of 2003 and 2015. In the absence of ground measurements for calculation, the relative radiometric normalization method was used to standardize the 2015 image according to the 2003 image conditions, and then simulate the distribution by the defined regression function. The results of this study provide an overview of the distribution of pollutants in a large area compared to previous methods. With the ground-based method, only the environmental situation at the location is measured, so it is not possible to measure the whole area. With the modeling approach, results are limited due to the complexity of inputs (meteorology, emission sources, etc.). Therefore, the application of remote sensing technology to create a map of air quality for environmental management will bring about higher economic efficiency.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

The following abbreviations are used in this manuscript:

AOT: Aerosol Optical Thickness
PM: Particular Matter
RMSE: Root Mean Square Error

References

1. Kaufman, Y.J.; Fraser, R.S.; Ferrare, R.A. Satellite measurements of large-scale air pollution: methods, *Journal of Geophysics Research*, **1990**, 95, pp.9895—9909.
2. Sifakis, N.; Deschamps, P.Y. Mapping of air pollution using SPOT satellite data. *Photogrammetric Engineering and Remote Sensing*, **1992**, 58, 1433—1437
3. Hadjimitsis, D.G.; Clayton, C.R.I. Determination of aerosol optical thickness through the derivation of an atmospheric correction for short-wavelength Landsat TM and ASTER image data: an application to areas located in the vicinity of airports at UK and Cyprus. *Applied Geomatics Journal*, **2009**, 1, pp. 31—40
4. Luong Chinh et al. *Application of remote sensing technology to study the ability to detect and monitor some components of air pollution in urban and industrial areas*. Ministry research projects in 2010, belonging to the National Remote Sensing Center under the Ministry of Natural Resources and Environment
5. Tran Thi Van; Trinh Thi Binh; Ha Duong Xuan Bao. *Research on application of remote sensing to air quality (dust component) in urban areas, testing for Ho Chi Minh city*. Scientific research project at the National University of Ho Chi Minh City, 2011
6. Sifakis, N. and D. Paronis. Quantitative mapping of air pollution density using Earth observations: A new processing method and application on an urban area. *International Journal of Remote Sensing*, **1998**, 19, 3289 – 3300
7. Schott, J.; Salvaggio, C.; Volchok, W. Radiometric scene normalization using pseudo invariant features. *Remote Sensing of Enviroment*, **1998,** 26, 1-16
8. Yuan and Elvidge. Comparison of relative radiometric normalization techniques. *ISPRS Journal of Photogrammetry and Remote Sensing*, **1996**, 51, 117-126