MONITORING URBAN DUST POLLUTION BY USING REMOTE SENSING METHOD, CASE STUDY IN HO CHI MINH CITY

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ABSTRACT

Air pollution is one of the most important environmental problem which concentrates mostly in cities. Mathematical models and interpretation methods are widely use to map the dispersion of air pollution. These methods are limited by the number of ground station data. This paper investigates the potential of using satellite remotely sensed imagery for assessing atmospheric pollution. Landsat image was used with the reflectance and radiation value for detecting dust emission in Hochiminh city, where air pollution has growth with the progress of industrialization and urbanization. This study proved that satellite images can be used as a global tool for monitoring air pollution phenomena in the cities.

Keywords: *air pollution, correlation regression, PM10, reflectance, remote sensing*

1. INTRODUCTION

In recent years, the problem of thrived urbanization, of the birth of industrial parks invested by foreigners, bring about pollution of water and air environment is becomes more serious. Currently in Vietnam, air pollution is a pressing issue for the urban environment, industrial and even rural areas. Pollution problems in developing cities create a serious threat to human health as the substances in air emissions such as SO_x, NO_x, CO_2, PM10 (dust size <10μm) beyond the permissible limits of WHO and U.S. EPA

Information recorded on the remote sensing image is the result of the interaction of radiation (reflected and emitted) from the sun and the earth. Radiations reflected and emitted by the Earth passing through the thick atmosphere. In this process they interact with atmosphere constituents and then partially attenuated by the process of scattering, absorption and transmission prior to the sensors on satellites. Atmospheric constituents are H_2O vapour, gas and aerosols, including aerosol layer of polluted atmosphere. The applied research of remote sensing is now also aims to record and reflect information on air pollution to set up the map of spatial distribution.

This paper presents the results of research on capacity of detecting and monitoring dust component (PM10) in the air by remote sensing technology for the urban areas, based on band correlation and ground measurements.

2. STUDY AREA AND DATA SETS

2.1. Study area:

Study area is Ho Chi Minh City, located in the south of Vietnam, including only 13 districts inner city and six new ones. This is a city with high population density and rapid urban development. Urban development has changed profoundly urban landscape, the land surface characteristics, resulting in changes in the air circulation. Human, transport, industry activities have caused air pollution increasingly alarming and affecting the health of urban populations, as well as the intensity and labor productivity. At the same time, there is also a place where established most of the ground monitoring stations in automatic and semi-regular mode to monitor the air environment in the city.

Fig. 1. The study area in the northern part of Ho Chi Minh City (*Source:* The authors)

2.2. Data set

Satellite images: SPOT 5 images were used in this research in two periods: 23-03-2003 and 24-02-2011. They were obtained in the 1A level. SPOT 5 images have pixel resolution of band 1, 2, 3 and SWIR in 10m and panchromatic band in 2.5m. In the image pre-processing stage, the 2003 image was georeferenced in Universal Tranverse Mercator projection based on the topographical map with a root mean square (RMS) error less than 0.5 pixel. An image-to-image registration was conducted between the 2003 image and the 2011 images in order to keep registration errors to less than a pixel.

Air quality data: Air quality monitoring data, mainly PM10, has been acquired from Hochiminh City Environmental Protection Agency (HEPA). For this reasearch, PM10 was taken on the same day, as that of the satellite sensor data acquisition.

3. METHODOLOGY

3.1. Radiometric calibration

Radiometric calibration was a multi-step process that involved the use of standard equations to convert 8-bit satellite-quantized calibrated digital number (DN) to at-satellite reflectance. SPOT images were first converted to at-satellite radiance using band-specific absolute calibration gain (G in $m^2.sr.\mu m.W^{-1}$) and offset (b) coefficients supplied in the SPOT image metadata, and the simple equation as follows:

$$B_\lambda = (DN/G) + b \qquad (1)$$

After conversion to at-satellite radiance, each image was converted to at-satellite reflectance (assuming a uniform Lambertian surface under cloudless conditions) using equation:

$$\rho_\lambda = \frac{\pi B_\lambda d^2}{E_\lambda \cos(z)} \tag{2}$$

Where ρ_λ is at-satellite reflectance, λ is the spectral band; d is the Earth-Sun distance; E_λ is exoatmospheric solar constant ($W.m^{-2}.\mu m^{-1}$), and z is solar zenith angle.

3.2. Relative radiometric calibration in multi-date imagery

The subjects in the multi-date imagery are very changeable and almost impossible to compare by the automatic method. To accurately detect the change of the landscape according to the change of surface reflectance from the multi-date imagery, it is needed to perform the radiance calibration. Relative radiometric normalization method does not required in-situ measures on atmospheric condition in the acquisition day. These procedures use one image in a time sequence of images as a reference image and adjust the radiometric properties of all other images (as a subject image) to the same datum in solar geometry, sensor calibration and environmental parameters as the reference image. One fundamental premise behind these methods is that the radiance reaching an airborne or satellite sensor in a given spectral channel can be expressed as a linear function of reflectivity [Schott et at., 1988]. For many sensors, the digital numbers (DN) in each band are a simple linear function of the radiance reaching the sensor. Thus, the atmospheric and calibration differences between scenes are linearly related [Schott et at., 1988; Casselles et al., 1989; Hall et al., 1991]. The linear equation used in the normalization can be expressed as following:

$$S_{ref-i} = a_i S_{sub-i} + b_i \tag{3}$$

Where, *ref* is the reference image (the 2003 image); *sub* is the subject image (the 2011 image); *a* is the slope for the linear transformation; and *b* is the intercept for the linear transformation.

Radiometric normalization using image regression (IR) simply involves relating each pixel of the subject image with that in the reference image band by band to produce a linear equation either through a least-squares regression and calculate the transformation coefficients a_i and b_i. Radiometric normalization using pseudo-invariant features was developed by Schott et al. [Schott et at., 1988]. Pseudo-invariant features are objects with nearly invariant reflectivity from one image scene to another. According to Schott et al. [Schott et at., 1988], these are typically man-made objects whose reflectance is independent of seasonal or biological cycles. Differences in the brightness distributions of these invariant elements are assumed to be a linear function.

After finding the a_i and b_i coefficients, the sub image was then normalized by the equation:

$$S'_i = a_i S_i + b_i \tag{4}$$

where S_i is the reflectance of band i in image on 2011, S'_i is the normalized reflectance of band i on 2011, a and b are the coefficients defined as over. The root mean square error (RMSE) was computed before and after normalization to indicate the effectiveness [Yuan and

Elvidge, 1996]. The RMSE values should decrease after a successful normalization. The RMSE is computed by:

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

where n is the number of pixels for RMSE computation.

3.3. Principal Component Analysis (PCA)

The PCA technique involves a mathematical procedure which transforms a number of (possibly) correlated variables into a (smaller) number of uncorrelated variables called principal components (PC). The first principal component PC1 accounts for as much of the variability in the data as possible, and each succeeding component accounts for as much of the remaining variability as possible. This maximizes the supportability of the feature and enhances the features for extraction and pattern recognition in the image. In order to extract features in the image data set PCA technique has been applied in 1-4 bands of the resultant images.

3.4. Regression analysis and mapping

Using regression method, we established relations between processed image outputs (reflectance) and PM10 ground data, considering PM10 as dependent variable and reflectance measured by SPOT satellite as independent variable. Minitab and Excel softwares were used to check the correlation and scatter plots to identify their relation. Different plots were used to evaluate the regression results. Regression analysis shows the best results under the nonlinear exponential regression. Therefore this regression equation is used to map spatial distribution of PM10 concentration

4. RESULTS AND DISCUSSION

4.1. Seeking the best correlation regression function

The ground automatic stations were digitized and placed on the satellite images, including 5 stations (DOSTE, Binh Chanh, Tan Son Hoa, Thong Nhat, So Thu) with measurements on the same day to 2003 SPOT image. Spectral reflectance values on each band are extracted to calculate correlation with measured PM10 concentrations from station.

It is necessary to perform principal component analysis PCA algorithm for 4 bands of SPOT image to create new image having uncorrelated bands and containing the most information. After PCA conversion, the new 4 principal components PC1, PC2, PC3, PC4 were created with main information concentrated in the first 3 components and especially in the first component PC1 (keep the information up to 0.90% of all images). Survey the statistical parameters of 4 principal components, it is showed that the best regression function is a function built by the relationship between the ground measures and PC1 with the highest correlation coefficient in the case of nonlinear regression reaches 0.99. It is crucial factor to select the function that calculates the PM10 concentration for whole satellite image. The equation as followed:

$$P = 24.632 * e^{10.502 * PC1} \quad (6)$$

RMSE error is evaluated for the case of PM10 dust concentrations from satellite images compared with PM10 concentrations measured at the ground stations to demonstrate the effectiveness of the method. The highest error was found in relation to the SWIR channel reached 28.7 µg/m^3, while that one on the GREEN band had the lowest value of 7.81 µg/m^3. This indicates that the spectrum with GREEN wavelength absorbs most PM10 dust. In case of PCA transformation image the error was very low with bias within 1.64 µg/m^3.

4.2. Performing relative normalization

2003 image was selected as the reference image, due to there were PM10 concentrations data at the same acquisition day. 2011 image had no measurements at ground monitoring stations, so, after it was relatively normalized by 2003 image, we can use the best regression function found from 2003 image applying to that one. The samples were selected for the relative normalization process is invariant or pseudo-invariant objects band by band from 2003 image scene to 2011 images. They are the intersection point lies on the roads, the roofs, the longstanding historical points... The linear regression function is determined from the sample data set to calculate the empirical coefficients a and b according to the formula (3). Then the coefficients were associated with the independent variable being the reflectance value of 2011 image to calculate the new dependent value by the formula (4). 2011 normalized image is converted to PCA image. Then the regression function (6) was applied to the first principal component PC1 for mapping of spatial distribution of PM10 dust.

4.3. Discussion

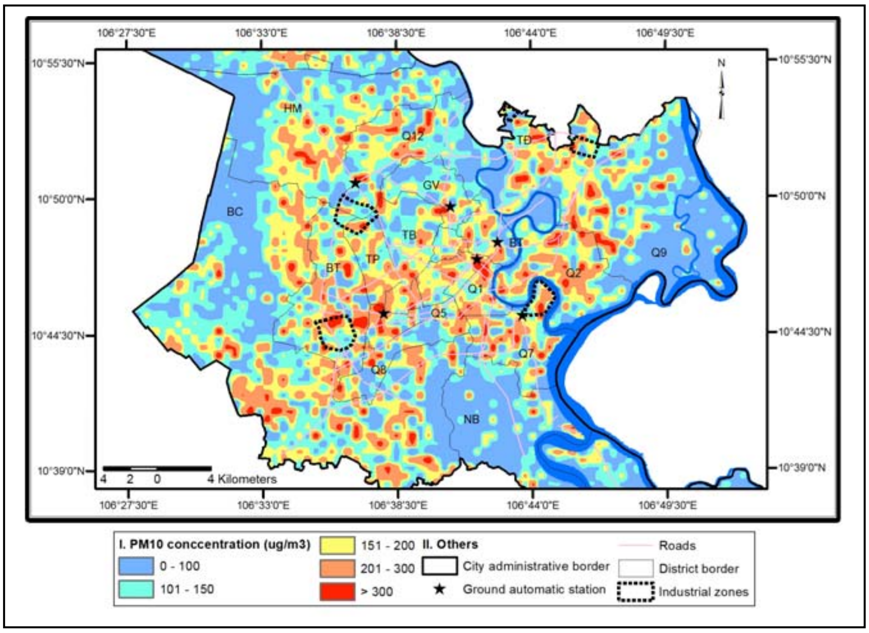

Fig. 2. Spatial distribution map of PM10 concentration at 10:00 on 24-02-2011 from SPOT 5 image

Spatial distribution map of PM10 concentration by SPOT 5 image on 24-02-2011 was established for the center area of Ho Chi Minh City (Figure 2). This picture shows the air environment at 10 am (which is now the trucks are allowed to move in urban areas). Assess the overall picture shows that, on the whole region, the value of PM10 dust concentrations low < 100μg/m^3 found on moist areas, farmland in northern Binh Chanh district border Long An, in west district Hoc Mon border Long An, in Nha Be, South District 9, Thanh Da peninsula and along the Saigon river in District 12. Areas of high PM10 concentration are concentrated in the main traffic routes, roads, industrial areas with values higher than 200μg/m^3, somewhere over 300μg/m^3. There is a number of survey locations with PM10 dust concentrations > 300μg/m^3 including areas in Tan Binh, Tan Tao, Linh Trung EPZ, stretch of the National Highway 1A from Go Dua crossroad to the Song Than station, stretch of road sloping to overpass Tan Thoi Hiep to An Suong, Dan Chu Square, Nga 6 Go Vap, Phu Lam traffic-circle.

5. CONCLUSIONS

The results of this study have demonstrated the application of remote sensing technology using satellite imagery combined ground measurements giving simulation results of PM10 spatial concentration. It can give us an overview of a large area compared to the traditional methods. Meanwhile, the measurement of ground observation only says the atmosphere at a point, can not fully assess the entire region. Model approach requiring the input data with fairly large and complex measures is a limitation. Therefore, the application of remote sensing satellite imagery for the mapping of air environment supporting environmental management will bring high economic efficiency.

6. REFERENCES

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