USING LANDSAT IMAGERIES FOR PARTICLE POLLUTION MAPPING IN HANOI CITY

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SUMMARY

Recently, particulate matter (PM) is a serious problem in terms of air pollution in Hanoi, Vietnam. For particle pollution mapping in Hanoi city, the study used Landsat images which were captured in 2011, 2015 and 2017 with practically monitoring data of suspended particle concentration at the same points of time. By using vegetation indices calculated from Landsat images, we generated maps of Air Pollution Index (API) that has been used as a simple and generalized way to describe air quality. Mapped APIs were extracted to compare with the corresponding practical APIs calculated from monitoring data station. The results showed that these APIs had significant similarities. In addition, particle pollution in Hanoi city was at heavily polluted level, especially in surroundings of populous areas, such as Vinhomes Village, Times City, Trung Hoa Ward of Cau Giay district, and main roads as Tran Duy Hung street and Nguyen Van Cu street. The results of the study provide additional data contributing to air pollution monitoring, evaluation and prediction that support to solutions to reduce negative impacts of suspended particles on the environment and public health.

Keywords: API, Landsat, particle pollution map, PM2.5, PM10, remote sensing, suspended particles.

1. INTRODUCTION

In recent years, air pollution is a persistent problem in Vietnam in general and Hanoi in particular. The rapid increases of transportation vehicles, industrial factories and building construction lead to increasingly high concentrations of particulate matters causing air pollution such as dust, suspended particles, and greenhouse gases such as SO_2, CO_2, and NOx. These matters are threats to public health (MNRE, 2015). Particle, especially aerosol particle, is one of the most considerable threats. Specifically, PM2.5 and PM10 are particulate matter (PM) with the ability to move into human respiratory systems. Moreover, nanoparticles, which are particles between 1 and 100 nanometres (nm) in size, can penetrate deep into organs of human body that increase the rate of mortality. Therefore, particulate matters have been of interest by scientists in many countries. The United States has issued the national standard for PM10 particle in ambient air since 1987. Thailand, which is a country in the same region of Southeast Asia, has monitored PM10 particles by the gravitational method since 1995 (Nghiem et al., 2004). In Vietnam, studies on PM2.5 and PM10 have been conducted in Hanoi and Ho Chi Minh City since 2001. However, particle monitoring and assessment are costly. On the other hand, a remote sensing image can contain information of the entire area of interest. Actually, each image is a continuous surface which comprises a large number of pixels covering the area. Each pixel provides information of the situation at its own location. Hence, results of image interpretation can represent air pollution value on each pixel at the point of time when the image was captured. As a result, using remote sensing image can reflect the air pollution situation in a large scale that empirically measuring stations cannot achieve because it is impossible to establish sufficient measuring stations to fully cover large areas such as a city. Therefore, study on particle pollution mapping in Hanoi city is very necessary.

2. RESEARCH METHODOLOGY

2.1. Study area

The study was conducted in the inner city of Hanoi - the capital city of Vietnam (Figure 1). This area had extremely high population density (Thai, 2016). Due to the availability of practical measurement, the study focused on six measuring stations located in four districts, including Thanh Xuan, Ha Dong, Long Bien, and Hai Ba Trung (Figure 1).

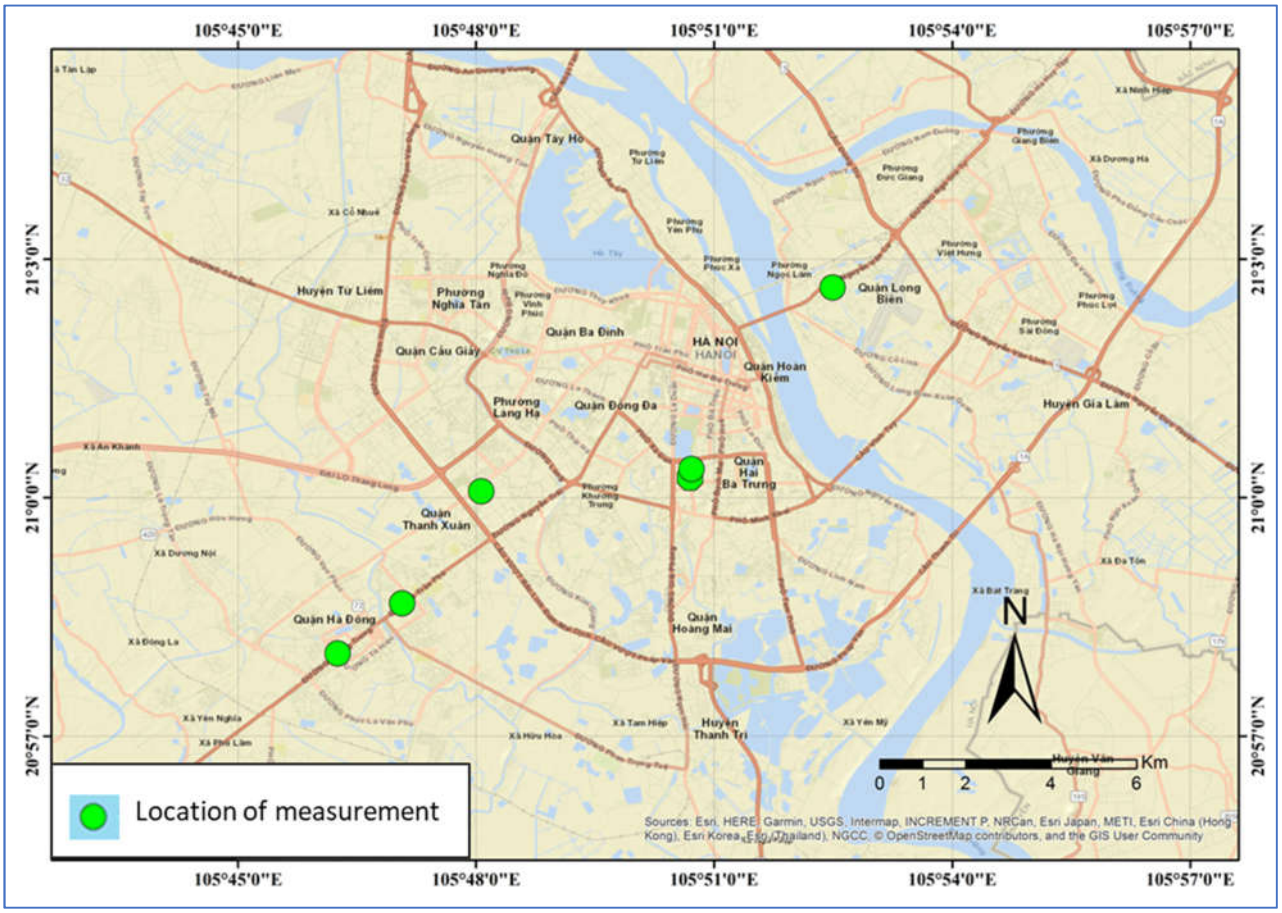

Figure 1. The study site and locations of actual air polution measurement

2.2. Materials

The study adopted data from empirically measuring stations in 2011, 2015 and 2017 to initially assess particle pollution in Hanoi. Besides, this data was also used to calulate practical APIs to compare with the results from image intepretation. In addition, Landsat images (Path/Row 127/45) captured at the same times of measurement were used for particle pollution mapping (Table 1).

Table 1. Landsat images used in the study

No.	Image ID	Time	Spatial resolution (m)	Path/row
1	LT05_L1TP_127045_20111010_20161005_01_T1	10/10/2011	30	127/45
2	LC08_L1TP_127045_20150701_20170407_01_T1	01/7/2015	30	127/45
3	LC08_L1TP_127045_20170604_20170615_01_T1	04/6/2017	30	127/45

Source: https://earthexplorer.usgs.gov

2.3. Methods

2.3.1. Air pollution mapping

The air pollution map was generated by using vegetation indices calculated from Landsat data after corrections. The map represented API patterns over the area of interest. The procedure of air pollution mapping is described in figure 2.

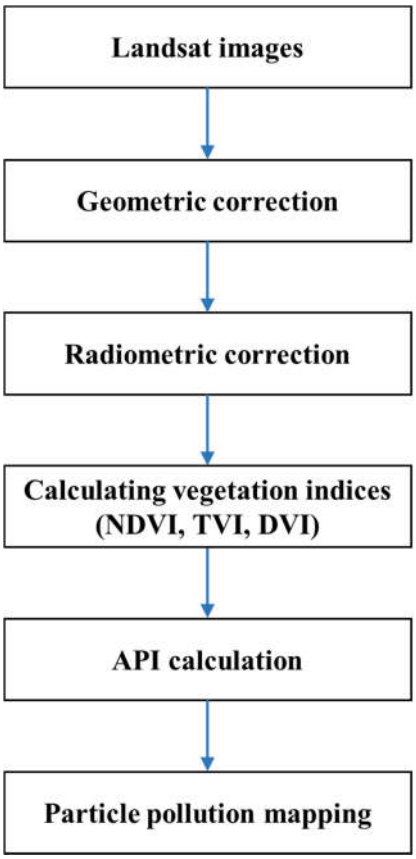

Figure 2. Flow chart of air pollution mapping procedures

Step 1: Geometric correction

In this step, Landsat images were pre-processed. The process involved band composition, image enhancement, geometric correction and image extraction by area of interest.

Step 2: Radiometric correction

Data of Landsat TM, ETM+ was achieved by radiometric resolution of 8 bit. This pixel depth contains 256 shades of gray (i.e. grayscale including values from 0 to 255). In image processing, dididal number values (i.e. integer values) are usually converted to spectral radiance value (Wm-2 μm-1). This conversion is compulsory before calculating spectral reflectance from satellite images.

Step 3: Index calculation

NDVI (Normalized Difference Vegetation Index) (Rouse et al., 1974):

$$NDVI = \frac{(\text{BandNir}-\text{BandRed})}{(\text{BandNir}+\text{BandRed})} \quad (1)$$

Where: Nir = Near Infrared; RED = Red[1]

TVI (Transformed Vegetation Index) (Deering et al., 1975): to eliminate negative values and to transform NDVI values into a normal distribution:

$$TVI = \sqrt{NDVI + 0.5} \quad (2)$$

DVI (Difference Vegetation Index) (Tucker, 1979):

$$DVI = \rho_{NIR} - \rho_{RED} \quad (3)$$

API (Air Pollution Index): From radiometric reflectance values of Nir and SWIR1, and vegetation indices (i.e. DVI, TVI), API was calculated following the function described by Mozumder et al. (2012):

$$API_{Landsat} = -460.0 - 10.4 \times SWIR1 + 1.0 \times NIR - 6.4 \times DVI + 851.6 \times TVI \quad (4)$$

After API calculation, levels of pollution were determined and symbolized according to the classification as in table 2.

[1]In Landsat 8: Red (Band 4), NIR (Band 5), SWIR (Band 6 and Band 7); In Landsat 7: Red (Band 3), NIR (Band 4), SWR (Band 5).

Table 2. Air pollution classification by API

No.	Class	API	Symbology
1	Clean	0 – 25	
2	Fairly clean	26 – 50	
3	Moderately polluted	51 – 75	
4	Heavily polluted	76 – 100	
5	Severely polluted	>100	

Source: Rao et al. (2004)

2.3.2. API evaluation from measured data

API was calculated from empirical measured data as following (Mozumder et al., 2012):

$$API_X = \frac{1}{n}\sum_{X=1}^{n}\frac{C_X}{S_X} \times 100 \quad (5)$$

Where: API_X – Air pollution index for the pollutant X;

C_X – Observed value of the pollutant X;

S_X – Standard value of ambient air quality of the pollutant X.

Selecting criteria to evaluate air pollution in an area depends on which main pollutants exist within the area. According to the National State of Environmental Report by MNRE (2015), air quality in Hanoi, as well as municipalities in Vietnam, was not improved as compared with the corresponding in the period 2006 - 2010. Among agents causing air pollution, particulate matter is the most considerable. Hence, we selected three criteria for consideration, including Total Suspended Particulate (TSP), PM10 and PM2.5. The function to be applied is as following:

$$API = \frac{1}{3}\left[\frac{C_{TSP}}{S_{TSP}} + \frac{C_{PM_{10}}}{S_{PM_{10}}} + \frac{C_{PM_{2.5}}}{S_{PM_{2.5}}}\right] \times 100 \quad (6)$$

3. RESULTS AND DISCUSSIONS

3.1. Air pollution situation in Hanoi city

We used observed data from the measuring station placed at 556 Nguyen Van Cu street to assess the status of particle pollution. The results showed that ambient air condition at this location has been polluted by PM10. Indeed, most observed values of PM10 from 2010 to 2017 exceeded the figure in the standard QCVN 05:2013/BTNMT (i.e. 50 µg/m^3). Observed values of PM2.5 were going on the same trend with PM10 when exeeding the standard value of 25 µg/m^3.

In figure 3, the concentrations of monitored particulate matters in 2017 were going downwards. In the same year, the daily values of PM10 was below the standard value of 150 µg/m3 as in figure 4. On the other hand, the figures for PM2.5 in 2017 contained 23 value surpassing the standard of 50 µg/m^3 that made up to 6.7% of total observations.

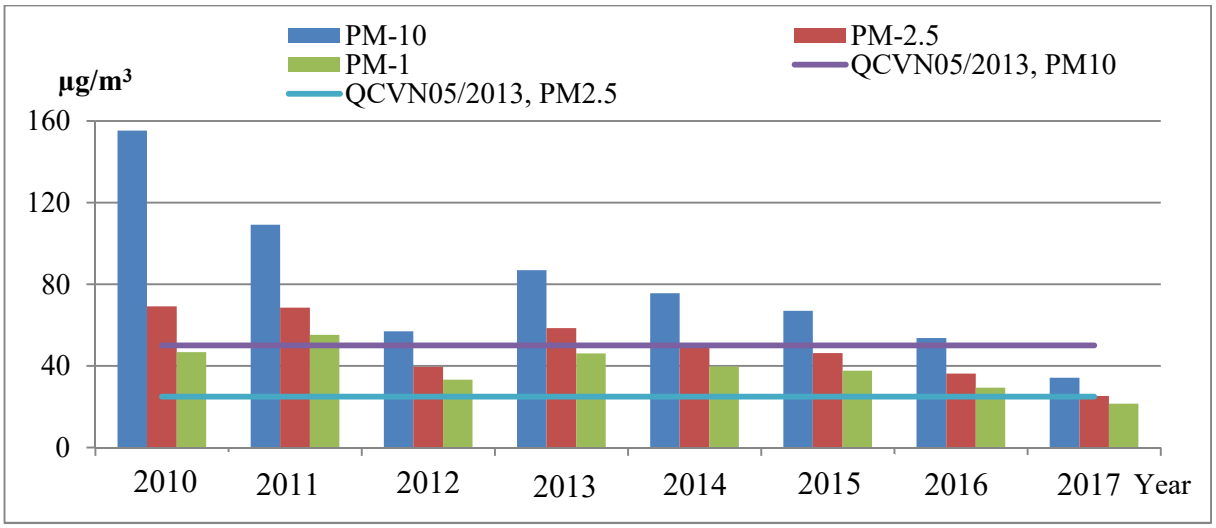

Figure 3. Annual average values of PM10, PM2.5, PM1 from 2010 to 2017

(Source: Centre for Environmental Monitoring, 2017)

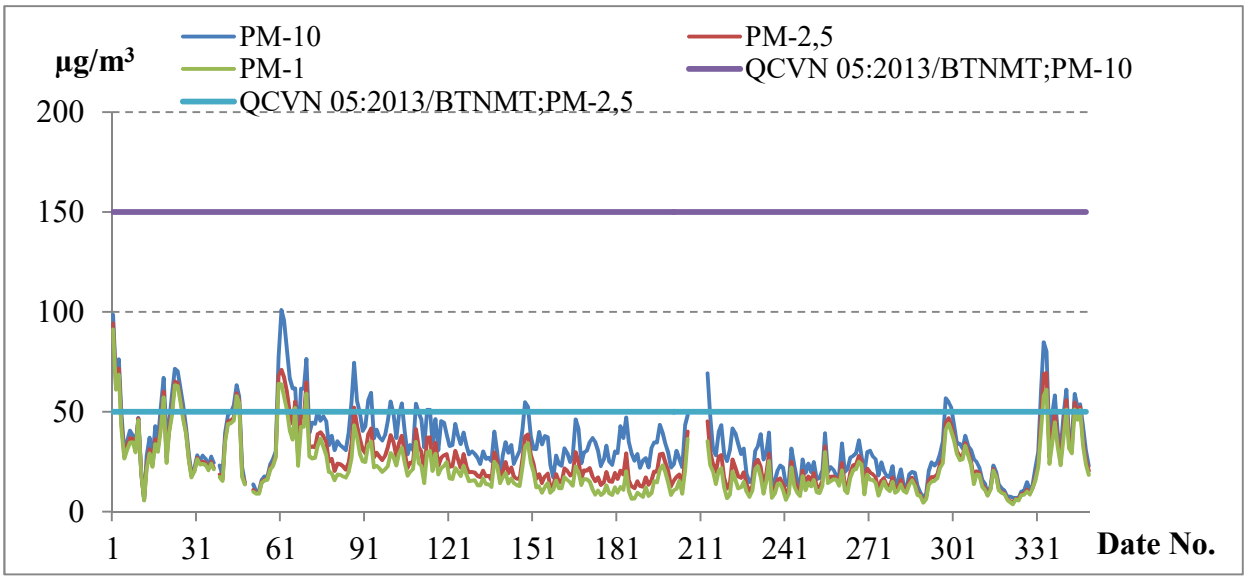

Figure 4. Variation of daily average values of PM10, PM2.5, PM1 in 2017

(Source: Centre for Environmental Monitoring (2017))

Monthly average concentrations of particulate matters, especially PM2.5 in 2017 were considerably high in January, March and December (Figure 5). The average value of PM10 in the year was 34.1 µg/m^3, less than the corresponding standard of 50 µg/m^3 by approximately 32%. Concurrently, the figure for PM2.5 was 25.3 µg/m^3 that exceeded the standard value of 25 µg/m^3.

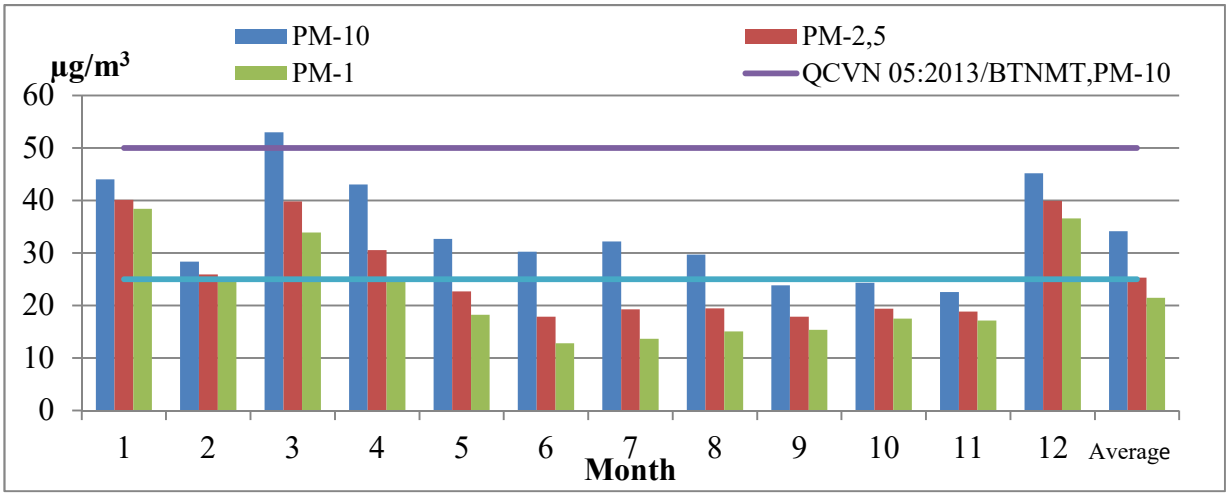

Figure 5. Monthly average values of PM10, PM2.5, PM1 in 2017

(Source: Centre for Environmental Monitoring (2017))

The observations showed signals of particle pollution in the surrounding area. However, there is only one monitoring station for air environment that operates continuously and has ablility to monitor sufficient parameters in terms of air quality. Other stations only record several basic parameters without stability. Therefore, to thoroughly evaluate air environment quality, the study aimed to use geographic information systems and remote sensing technique to create an air quality map as a contribution to appropriate solutions to minimize the problem of air pollution in Hanoi.

3.2. Particle pollution mapping in Hanoi city

Following the mapping procedure describe in methodology section, the study generated particle pollution maps of Hanoi in 2011, 2015 và 2017 from Landsat data (Figure 6).

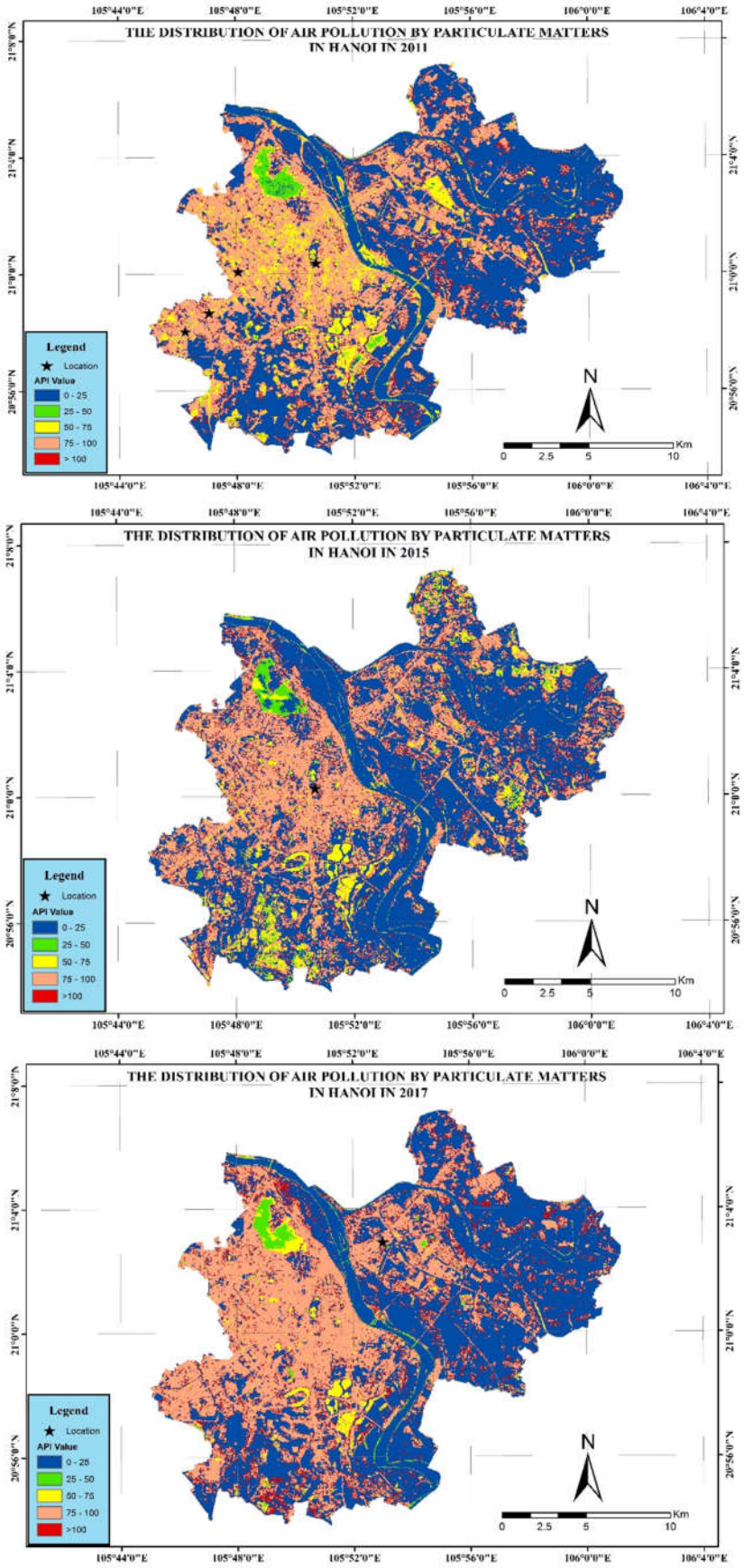

Figure 6. Spatial distribution of air pollution by particulate matters in Hanoi in 2011, 2015 and 2017

The results show that spatial distribution of particle pollution in the study area insignificantly changed during 2011 to 2015. Most of urban areas were at highly polluted level, especially especially in populous areas such as Vinhomes Village, Times City, Trung Hoa Ward of Cau Giay district, and main roads as Tran Duy Hung street and Nguyen Van Cu street. Around Yen So park, West Lake and Van Dien district, air conditions were slighly polluted by particulate matters eventhough these areas were covered by numerous trees. Sub-urban areas, including Gia Lam district, had clean air environment.

Until 2017, the air quality in Hanoi city had considerablly decreased. Highly polluted areas remained at that level. There were a transition that areas at faily clean level in 2015 became moderately or even highly particle-polluted, such as areas surrounding West Lake and Yen So park. In particular, there were dense areas at severely particle-polluted level appearing in Van Dien district. This may be caused by the rapid industrial development in this district that lead to increases of residential villages. Moreover, traffic jams ocurred more often due to traffic capacity overloaded. Especially, the operation of the crematorium in this district has emitted massive amount of particuate matters and gases into the environment.

3.3. Air quality assessment based on comparison between results from measurement and remote sensing data

The study identifies the differences between air pollution determined by image intepretation and which calculated from measured data. API values at measuring station's location were extracted from the map layers. To ensure the precision of the assessment, we tried to use data measured in the same days as the images were captured. However, this matching may involve time gaps of several days because of image quality and avaiability. The comparisons are represented in table 3.

Table 3. The comparion between measured and image-intepreted values

Year	Address	Location		Measured value	Image-intepreted value
		X	Y		
2011[1]	Trung Hoa - Nhan Chinh residential area	21°00'4.7"	105°48'3.9"	API = 78.0 (Highly polluted)	API = 96.0 (Highly polluted)
	Phung Hung street	20°58'05.2"	105°47'14.3"	API = 51.5 (Highly polluted)	API = 84.32 (Highly polluted)
	Ha Dong bus station (former)	20°58'40.2"	105°47'4.1"	API = 60.0 (Moderately polluted)	API = 66.19 (Moderately polluted)
	Residential area near Ha Đong beer factory	20°58'02.5"	105°46'15.4"	API = 71.3 (Moderately polluted)	API = 76.96 (Highly polluted)
2015[2]	Hanoi University of Science and Technology	21°00'15.0"	105°50'43.0"	API = 60.6 (Moderately polluted)	API = 83.66 (Highly polluted)
2017[3]	556 Nguyen Van Cu street	21°02'56.3"	105°52'58.8"	API = 76.8 (Highly polluted)	API = 84.3 (Highly polluted)

(Sources: [1]VEA (2011); [2]Thai (2016); [3]Centre for Environmental Monitoring (2017))

Table 3 shows the general trend that the image-intepreted APIs are slightly higher than the actual values. However, we have set the limit of this study that the number of observations for model validation was only six due to the lack of measurement. Indeed, six validating points were insufficient and it was high potential to be solved by further measurements in further studies.

Particularly, in the Trung Hoa - Nhan Chinh residential area, there were many skyscrapers in construction at the time of measurement that strongly impacted on air environment quality.

In general, there are high similarities between results from the two methods of API evaluation. Among six samples assesed, the

maximum difference of APIs was 18 recorded at Trung Hoa, Nhan Chinh residential area in 2011. The minimum difference of approximately 5.6 was at the tesidential area near Ha Đong beer factory in the same year. These differences may derive from diverse factors.

The most important factors influencing these differences between APIs calculated by the two methods are the spatial and temporal variabilities of air environment. The problem of spatial variability may be solved by using GIS applications while others are not figured out. Indeed, air environment is variable and unstable because it contains air flows within. Exact time matching is rarely possible and the time gaps between measurement and capturing remote sensing image, which always exists, in association with within-day variations of air conditions may lead to the differences. Other factors may include image quality and availability, cloud and atmospheric effects, and the measurement's accuracy.

3.4. Solutions for enhancing the quality of air environment in Hanoi city

Air pollution in Hanoi city has been mainly due to practiculate matters emitted from vehicles, industrial factories, construction activities and building material transportation. In addition, biomass and household coal burning also contribute to a low-quality air environment (Thai, 2016). Based on the causes identified above, we propose solutions to improve the quality of air environment in Hanoi city as following:

- Providing trainings in terms of air environment management for staffs working on the systems of enviroment quality management in Hanoi;
- Investigating heavily fining sources of air pollution;
- Keeping control of particle sources in respect to building material transportation, especially during night time;
- Raising awareness for the community to involve in environmental protection;
- Focusing on improving the systems for air environment monitoring in the area, especially the automatic system;
- Developing public transportation systems to reduce emissions from personal vehicles;
- Regularly testing transportation vehicles to ensure they satisfy the requirement of environmental standard; banning vehicles not passing the test;
- Applying techniques in terms of pollution treatment in industrial activities in and around the city;
- Developing urban forestry;
- Using alternative heat sources such as electricity instead of household coal and firewood burning;
- Introduce alternative methods to recycle straw in stead of burning.

4. CONCLUSION

The air quality in the inner city of Hanoi has been gradually improving compared to the period 2010 - 2016. However, some criteria were not satisfying the permitted limits of the standard QCVN 05:2013/BTNMT. In particular, the annual mean value of PM2.5 was 25.3 $\mu g/m^3$, 1.1 times higher than the permitted limit. The 24-hour mean value of the PM2.5 parameter in 2017 had 23 values exceeding the allowable limit, accounting for 6.7% of the total number of observation days.

The study used Landsat images captured in 2011, 2015 and 2017 to develop a map of concentration distribution of pollutants in the inner city of Hanoi. The results show that it was clear to detect areas with air pollution at different levels on the map. Verification results revealed the difference between the actual measured values and the values calculated from satellite image data. However, it was noticed that the number of observations for model validation was insufficient. The validation required more data in further studies.

The study has produced a number of potential solutions for improving the quality of the air environment in Hanoi such as: improving the quality of management; installing and operating additional monitoring stations; strictly punishing activities that pollute the air environment in the research area.

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ỨNG DỤNG ẢNH VIỄN THÁM XÂY DỰNG BẢN ĐỒ Ô NHIỄM BỤI KHU VỰC THÀNH PHỐ HÀ NỘI

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TÓM TẮT

Trong những năm gần đây, ô nhiễm bụi là vấn đề nhức nhối của ô nhiễm không khí tại Việt Nam nói chung và Hà Nội nói riêng. Để xây dựng bản đồ phân bố mức độ ô nhiễm bụi tại khu vực nội thành Hà Nội, nghiên cứu đã sử dụng ảnh Landsat năm 2011, 2015 và 2017 cùng với số liệu quan trắc nồng độ bụi thực tế tương ứng của ba năm. Qua các chỉ số thực vật ở ảnh Landsat, nghiên cứu đưa ra được chỉ số API trên ảnh của từng khu vực nội thành Hà Nội tương ứng với các chỉ số API thực tế được tính toán từ các số liệu quan trắc. Kết quả cho thấy, chỉ số API trên ảnh và thực tế có mức độ tương đồng lớn, chênh lệch không nhiều. Kết quả phân tích ảnh cho thấy ô nhiễm bụi ở nội thành thành phố Hà Nội đang ở mức ô nhiễm nặng, đặc biệt là khu vực đông dân cư như xung quanh khu đô thị Vinhomes, khu đô thị Times City, khu vực Trung Hòa và các trục đường giao thông chính như Trần Duy Hưng, Nguyễn Văn Cừ... Kết quả của nghiên cứu góp phần cung cấp thêm cơ sở dữ liệu cho việc theo dõi, đánh giá và dự báo xu thế diễn biến mức độ ô nhiễm bụi phục vụ cho việc đề ra các giải pháp giảm thiểu tác động của bụi đến môi trường và sức khỏe con người.

Từ khóa: API, bản đồ mức độ ô nhiễm bụi, bụi lơ lửng, Landsat, PM2,5, PM10, viễn thám.

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