SPATIALLY CARBON MONOXIDE INVESTIGATION IN BANGKOK METROPOLITAN

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KEY WORDS: Carbon Monoxide, thermal band, satellite

Abstract: Urban air pollution has been monitored; traditionally, based on ground-based measurement. Although, this data set provides an advantage on investigating temporal characteristics, the spatial feature has still been concerned in points. Recently, the advent of the satellite based system paves the way to investigate the spatially urban air quality. In this paper, CO and temperature obtained from ground-based measurement was used to estimate regression model in order to forecast CO from temperature values. According to the regression model, the CO map can be created from thermal data acquired from Landsat 7ETM+.

1. INTRODUCION

The increased awareness of air quality and its associated influence on urban dwellers and environment in cities has led researchers to investigate techniques by which their dynamics may be monitored. A major technique used to characterize the air quality is the use of ground-based measurements. The conventional approach involves isolating urban air quality anomalies by means of ground-based observations recorded by either fixed weather station networks or roaming car-based transect (Voogt and Oke, 2003). The advantage of this method is that it provides a high temporal resolution, and a long data record in the case of weather station recording (Streutker, 2003). However, it cannot provide a completely spatial coverage of targeted areas and time synchronized data in the case of vehicle-based recording. In addition, it may be argued that weather stations may not give a representation of an entire city's climate due to the influence of local microclimate which subsequently results in variation of intra-urban climate (Klysik and Fortuniak, 2003). Land covers in urban areas are thought to be heterogeneous, with various intrinsic thermal properties. This leads to variation of intra-urban temperatures; therefore, proper numbers and distribution of weather stations are necessary, and data collection of individual stations should be synchronous with no occasions of rain or fog (Upmanis and Chen, 1999). Point measurement data needs to be transformed to spatially continuous data by interpolation techniques such as weighting with distance; thus, averaging data which may lead to anomalies (Jones et al., 1986). Similarly, using vehicle transverse cross sections, it is not possible to collect data for the whole route at the same time and the whole area.

The advent of remote sensing provides a possible way to eliminate the above restrictions. The capacity of remote sensing to acquire spatially synchronized data with various spatial resolutions of thermal imagery allows detailed investigation of spatial characteristics of surface temperature across cities. However, there are a lack of air pollution values acquired by the high resolution satellite's images. The assumption was set up that temperature has a correlation with CO. The paper aims to investigate the possible way to map spatially carbon monoxide in Bangkok Metropolitan from thermal band dataset of Landsat satellite.

2. METHODOLOGY

2.1 Data Sources

2.1.1 Ground-Based Data

The study contains two major parts: the situation of air quality and the distribution of carbon monoxide. For the first part, weather dataset was obtained from the Pollution Control Department, Thailand. The 17 permanent stations in Bangkok (figure 1) have hourly recorded air temperature, relative humidity, and several pollutants such as particle matter, carbon monoxide, and ozone. The height of the measurement shelter box is set at 3 meters above ground surface. Since air pollutant dataset of 17 point measurement across Bangkok areas was limitation to transform it to spatially continuous data by interpolation techniques; therefore, the air pollution distribution image may lead to anomalies.

Ground-based hourly temperature data and CO was selected on 10 January 2008 at 10.00 am. which was the same time as satellite-based data. The ground-based temperature data derived from Pollution Control Department. The 11 monitoring stations was selected named as 1) Radchabhat Chaopraya University 2) Rajburana Post Office 3) Meteorological Department 4) Klongchan Public House 5) Huay Kwang Community Stadium 6) Nontri Wittaya School 7) Singharaj Wittayakom School 8) Chokchai Police Station 9) DinDang Public House 10) Public Relations Department and 11) Badindecha School. Geographic coordinate of each station was collected by GPS (Global Position System).

2.1.2 Satellite-based Data

With the limitation of ground based dataset, the research applied a thermal band of the Landsat ETM+ images in path 129, row 50 and 51; both images were recorded on January 9, 2008 at 09.48 a.m. These scenes had low covered cloud percentage. The visual checks were performed to ensure that the sky over the study area was clear for each scene.

According to the satellite images, the radiance values recorded in pixel were calculated to temperature data. However, satellite images need to be operated pre-image processing before applying to other analysis.

2.1.2.1 Image Pre-Processing

There are three main basic requirements for converting and adjusting products of satellite imagery to temperature data. These image pre-processing steps consist of radiometric, atmospheric, and geometric correction.

a) Radiometric Correction: In accordance with the different processing levels in converting DN values to radiance, different steps are needed for radiometric calibration. For Landsat ETM+ L1G, radiometric correction is carried out prior to the supply of imagery to the customers by the USGS. However, the DN values of a 1G product need to be converted back to radiance unit as pixel values are scaled to byte values prior to media output (NASA, undated). The equation used to convert the DN to radiance unit can be expressed as follows:

$$L_\lambda = \left(\frac{(LMAX_\lambda - LMIN_\lambda)}{(QCALMAX - QCALMIN)} \right) \times (QCAL - QCALMIN) + LMIN_\lambda \qquad \text{Equation (1)}$$

where:

L_λ is Spectral Radiance at the sensor aperture in watts/($m^2 \cdot$ ster $\cdot$ µm)
QCAL is the quantized calibrated pixel value in DN
$LMIN_\lambda$ is the spectral radiance that is scaled to QCALMIN in watts/($m^2 \cdot$ ster $\cdot$ µm)
$LMAX_\lambda$ is the spectral radiance that is scaled to QCALMAX in watts/($m^2 \cdot$ ster $\cdot$ µm)
QCALMIN is the minimum quantized calibrated pixel value (corresponding to $LMIN_\lambda$) in DN
QCALMAX is the maximum quantized calibrated pixel value (corresponding to $LMAX_\lambda$) in DN = 255

The next step is to convert thermal radiation to at-sensor temperature. Markham and Barker's (1986) formula were used to convert spectral radiance to the effective at-sensor broadband temperature (T_B) which is referred to as brightness temperature, details shown in Equation 2.

$$T_B = \frac{K_2}{\ln\left(\frac{K_1}{L_\lambda} + 1\right)}$$

Equation (2)

Where:

L_λ is the spectral radiance ($Wm^{-2}\mu m^{-1}sr^{-1}$)
K_1 and K_2 are the pre-launch calibration constants.

b) Atmospheric Correction: At-sensor radiances are a combination of energy reflected and emitted from atmosphere and the Earth surface. The atmosphere and the Earth surface interact with solar radiation; that is, solar energy is scattered, reflected and absorbed by particles in the sky and the Earth's surface. Therefore at-sensor radiance values will be subject to atmospheric impacts, scattering and absorbing, which tend to both increase sensor-measured DN, and decrease DN.

Two main approaches have been applied to correct atmospheric distortion; physically-based and image based corrections. The physically based methods consist of physically based radiative transfer modelling and physically based empirical methods. The radiative transfer model with accurate atmospheric optical properties provides the highest accuracy levels for deriving surface reflectance and emittance while the accuracy can be slightly reduced if the atmospheric optical properties are not genuinely synchronous with the overpass of satellites. Similarly, the physical empirical method also provides high accuracy levels of data for deriving surface reflectance (Smith and Milton, 1999a) at visible to near infrared wavelengths.

In contrast, the image based correction, the dark-object subtraction (DOS), provides the lowest accuracy levels for deriving surface reflectance of which the RMSE reflectance is similar to uncorrected data. However, if the DOS method is supplied with atmospheric optical properties from the radiative transfer model - the so-called cosine of the solar zenith angle correction (the COST model) -, then the accuracy can be improved to be equivalent to the accuracy of the radiative transfer model (Chavez, 1996).

Physically based radiation transfer modelling requires accurate measurements or estimations of atmospheric optical properties which are synchronised with the time of image acquisition (Song et al., 2001). Meanwhile, the physically based empirical methods require synchronised ground spectral measurements during the sensor overpass (Moran et al., 1997). The radiative transfer modelling and empirical line approaches are applicable to a wide range of wavelengths, accounting for both scattering and absorption effects. This makes them suitable for VIS-SWIR imagery. However, the collection of ground data can be costly and time consuming (Chavez, 1996). The methods provide high accuracy levels of data for deriving surface reflectance if data is in visible to near infrared wavelengths. However, the study applied long wavelengths in thermal bands; therefore, there was no atmosphere correction in the research.

2.1.2.2 Geometric Correction

Generally, image data contain geometric distortions that make them unsuitable for creating maps (NASA, undated). Although distortion originating from internal sensor characteristic has been corrected at the receiving station, the residual distortion stems from topographic distortion that still remains in image data distributed to users. To achieve correction of the topographic distortions of the image, each feature in the imagery needs to be fixed to the correct position on the Earth's surface. This requires the determination of ground control points (GCP) to which the imagery can be referenced to the ground location in the Earth's coordinate systems. There are no exact numbers of GCPs per images suggested since the accuracy of geometric correction can vary depending on variables including spatial image resolution, and scale of reference map (Kardoulas et al., 1996). However, USGS (1999) suggest that the number of GCPs should be 24 – 30 positions per image, well-distributed across the imagery, while approximately 10 -12 positions should be used for independent accuracy checking. Following this criterion, this study used 20 GCPs per image for rectifying imagery, and another 12 independent positions per image for checking accuracy. The GCP positions were selected from vector digital maps of road and river networks at a scale 1:50,000, supplied by the Royal Thai Survey Department, Thailand.

Once the GCPs are assigned to images and the ground coordinates of images are known, the mathematical transformation can be established for registration of image data on the Earth's spheroid surface, for which a Universal Transverse Mercator coordinate system (UTM) was used in this study. In order to transform an image to surface coordinate system, polynomial equations need to be determined. Therefore, first order polynomial transformation was selected for rectifying the images of this study. All images were re-sampled to a pixel size of 60 by 60 meters for TIR bands by using the nearest neighbor re-sampling (NN) method. NN method does not change the brightness values of the original image which makes it 'ideal' for use pre-classification. Finally, the quality of the geometric correction of the images that are transformed into surface coordinate systems were evaluated by using the least squares first order polynomial transformation, with the condition that the total root means square error (rmse) value for each image does not exceed 0.5 pixels, with the ranges from 0.192 to 0.207, while the total rmse value for the check point does not exceed a pixel

2.2 Methodology

The datasets acquired from ground and satellite-based measurement were applied to find the correlation of temperature acquiring from ground-based measurement and remote-sensed temperatures in order to make a possible way to create spatially polluted map. The Paired t-test will be used to test the significantly correlation between satellite based and ground based temperatures with the assumption that there is no difference between satellite based and ground based temperatures so that both data sources can be represented each other. This study focus on CO because it is toxic gases and can reacts to Oxygen or other gases and transforms to CO2 which has the highest proportions among the green house gases. However, there are not enough measurement points of CO records to make correlation with satellite based temperature directly. Therefore, the result of significantly correlation between satellite based and ground based temperatures is important as it is the index to decide that the satellite based temperature can be used to make the spatially polluted map. By this means, the significant correlation between the temperatures and the CO values obtained from the similar point measurements provides the statistic regression model. This model presents the dependence of CO values on changing of temperature values. Then the regression model of significant correlation between the temperatures and the CO values will be applied to every pixel of Landsat's thermal band so that the spatially CO map can be presented.

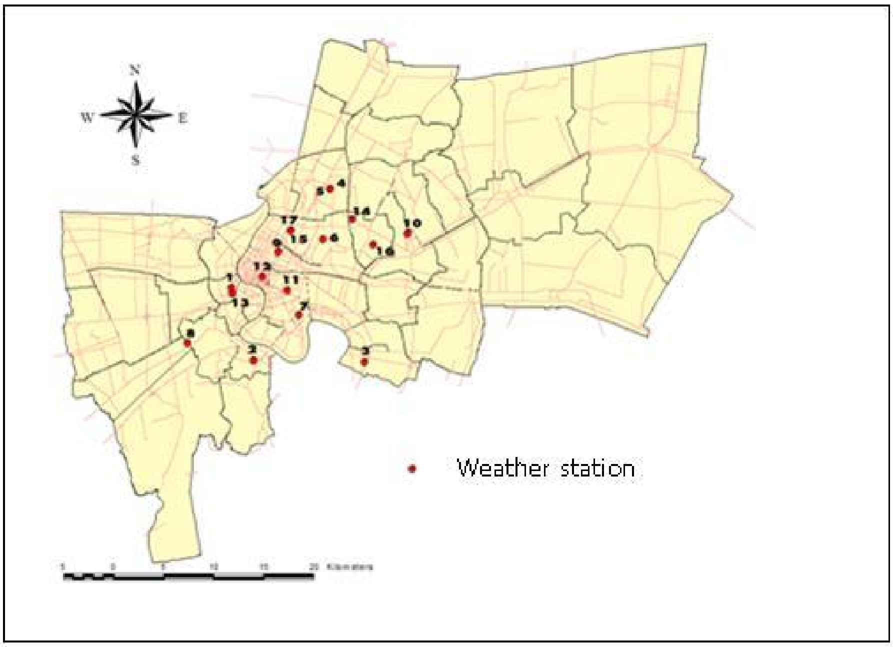

Figure 1 Bangkok Metropolitan areas and the weather station network.

3 Results

3.1 Carbon Monoxide Situation in Bangkok Metropolitan

The hourly average of air pollutants recorded by Department of Pollution Control during 01 May 2551 to 31 August 2551 showed that the carbon monoxide is high during 07.00–09.00 in the morning and 16.00-19.00 in the evening which are the rush hour of commuting between residences and working place. Office of Transportation Policy and Plan reports trip frequency in 2008 that there are 543,800 trips per hour during 07.00-09.00 in the morning and 494,400 trips per hour during 16.00-19.00 in the evening. Considering a day-time period, the carbon monoxide pollutant is highest in 08.00 at 1.358 ppm (part per million) then sharply decreases at 0.749 ppm at 13.00 after that it gradually increases to 1.00 ppm in 20.00 and finally goes down to the lowest at 0.539 ppm in 04.00 (see figure 2). As the result of the peak time of carbon monoxide, it indicates the influence of travelling frequency on the level of carbon monoxide occurring on Bangkok areas.

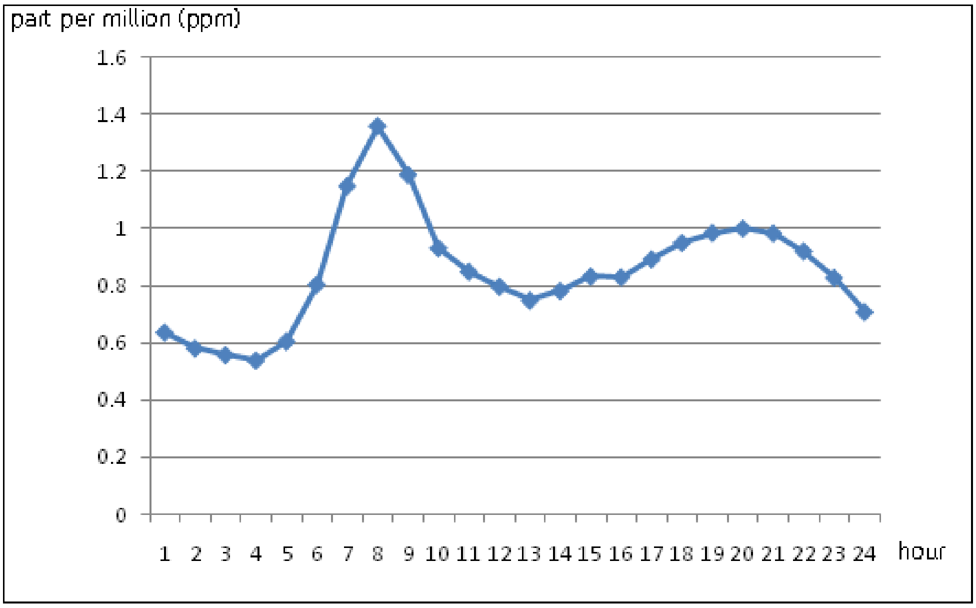

Figure 2 Average Hourly Carbon Monoxide in Bangkok

3.2 The Difference of Temperature from Ground-based Measurement and Satellite Images

Due to the fact that the spatial distribution of carbon monoxide map cannot be created from the only data recorded from point measurement, data incorporation between point measurement and satellite images was applied. The temperature map received from Landsat 7ETM+ was manipulated to create the carbon monoxide map. Firstly, the study starts with the investigation of the relation of temperature from air monitoring stations and thermal data from satellite image. Then, the correlation between temperature and air pollutant which their data were from ground-based measurement was built to get the regression model. If there is no significant difference of temperature between ground-based and satellite based, the satellite-based temperature can be applied to the correlation model of air pollutant (carbon monoxide) and ground-based temperature. Finally, the model will be used to convert satellite-based temperature data to spatially air pollutant distribution.

The first step finds out the difference of temperature from ground-based measurement and satellite images. Since Landsat 7 ETM+ passes Thailand about 10.00 am, therefore the temperature data from ground stations was selected at 10.00 am. The paired t-test statistics was applied in order to investigate the temperature difference between ground-based and satellite-based. The dataset was shown in table 1 and satellite-based temperature image was made in figure 3.

Table 1 Ground-based and Satellite-based Temperature at Air Monitoring Stations

Station	X	Y	Ground-based temperature	Satellite-based temperature
Radchabhat Chaopraya University	660676	1518679	27.85	27.5
Rajburana Post Office	662861	1511566	27.35	28.1
Meteorological Department	673673	1511376	26.86	30
Klongchan Public House	670332	1528372	29.31	26.5
Huay Kwang Community Stadium	669612	1523437	26.0	26.7
Nontri Wittaya School	667326	1515973	27.85	30.8
Singharaj Wittayakom School	656379	1513271	29.79	27.8
Chokchai Police Station	672535	1525366	28.82	27.9
DinDang Public House	666527	1524284	28.82	28.8
Public Relations Department	666523	1524294	27.85	27.6
Badindecha School	674551	1522837	28.33	28.6

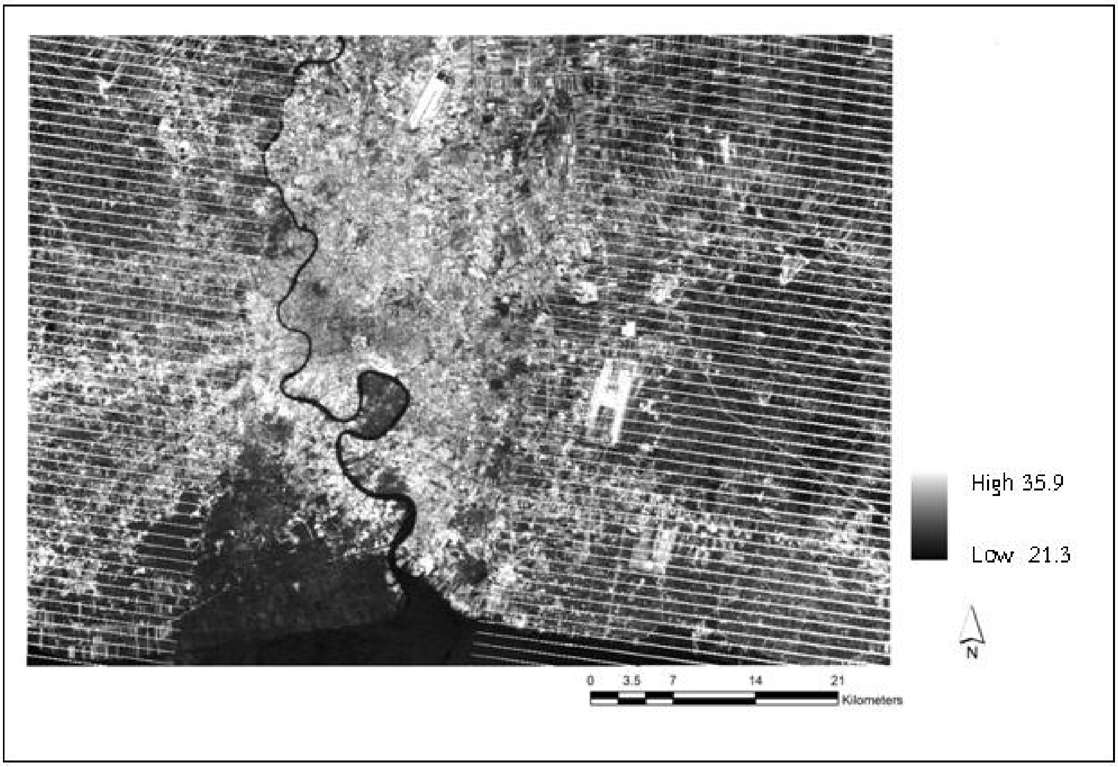

Figure 3 Satellite-base Temperature from Landsat TM Thermal band at 9 January 2008

The paired t-test value at 95 confidence interval shows that there is no difference between temperature from ground-based and satellite based as shown in table 2.

Table 2 Paired t-test statistic of Ground-based and Satellite based temperature

Temperature	Mean	SD	N	t		Confident level
				Value	prob	95%
Satellite-based	28.0913	1.12937	11	0.109	0.915	-1.22927 to
Ground-based	28.1545	1.38374				1.35582

3.3 Correlation between Temperature and Carbon Monoxide

Temperature and Carbon Monoxide dataset from ground-based measurement was used to test their correlation and to get linear regression model. The dataset of 11 air monitoring stations was applied. Unfortunately, Huay Kwang community stadium has no carbon monoxide data; it needs to remove this station for the study. However, the result of temperature and carbon monoxide had low correlation only 0.0662 which came from their highly asymmetrical distribution (see figure 4). In fact, if temperature increases, air pollutant should also go up. However, consideration to the dataset, five stations were not line in with the hypothesis which they could be categorized into two major groups: high pollutant but low temperature (Rajburana post office) and low pollutant but high temperature (Dindand public housing, Public Relations department, Badindecha School, and Klongchan public housing). The influence factors are physical environments around the stations such as building density, the proportion between open space or vegetation and capability of air circulation. The building density areas are high;, the air pollutants are also high even though temperature in that areas is low. Therefore, the physical surroundings have the influence on the difference of temperature and air pollutants which is in line with the study of Wald (1999). He investigated air quality by applying satellite images of Landsat 7TM band 6 and used ground-based data from 14 air monitoring stations in order to estimate regression equation. He also faced the problem of dataset variation from different locations of stations such as stations located in the park or stations got the shading from the tree or stations covered vegetation surroundings. He cut some stations and kept only six stations for estimation the regression model. For this study, the five stations were cut since they got the impact of tree shading and traffic congestion. The five remaining stations were calculated in order to find out the regression model.

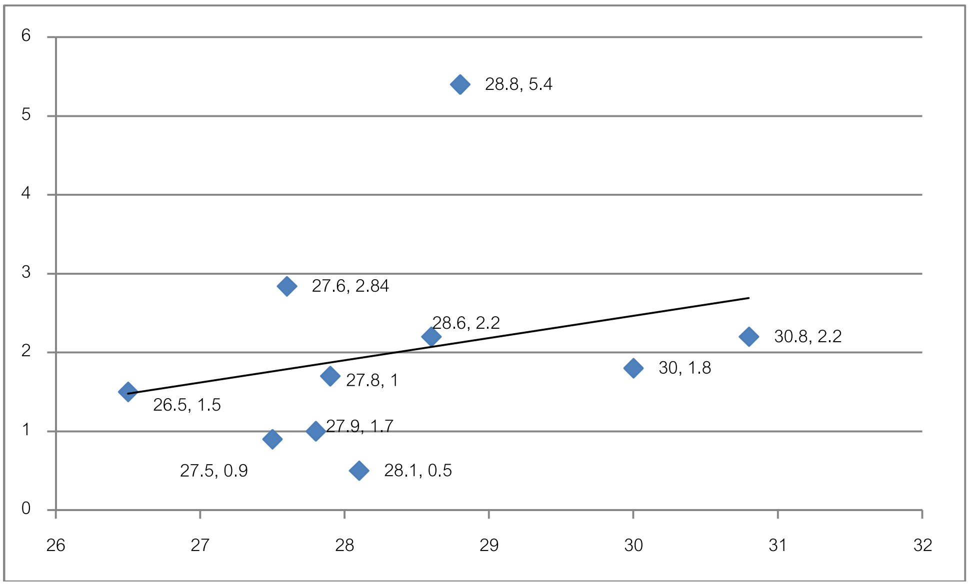

Figure 4 Distribution of dataset of Temperature and Carbon Monoxide from Air Monitoring Stations

The results of F-test statistics at 0.1 significant level have shown that the temperature has an influence on carbon monoxide (F-Prob = 0.059) with high correlation (r = 0.863) and can deliver impact on carbon monoxide change in 74.51 percent (see table 3 and figure 5). Changing of Carbon monoxide values are developed on temperature values which means every changing of one degree Celsius will affect to changing of carbon monoxide by 0.3199 as in equation 3.

$$Y_{\text{Carbon Monoxide}} = 0.3199 * X_{\text{temperature}} - 7.6934$$
Equation (3)

Table 3 Linear Regression model between CO and Temperature

Variable		Coefficient b_0		t-value	t-prob
Constant		-7.6934		-2.470	0.090*
Temperature		0.3199		2.961	0.059*
F-value, FProb	8.768	0.059*			
R, R Square, R Square Adjusted	0.863	0.745	0.660		
Std. err of estimate	0.32304				

* refers to reject hypothesis at 0.1 significant level

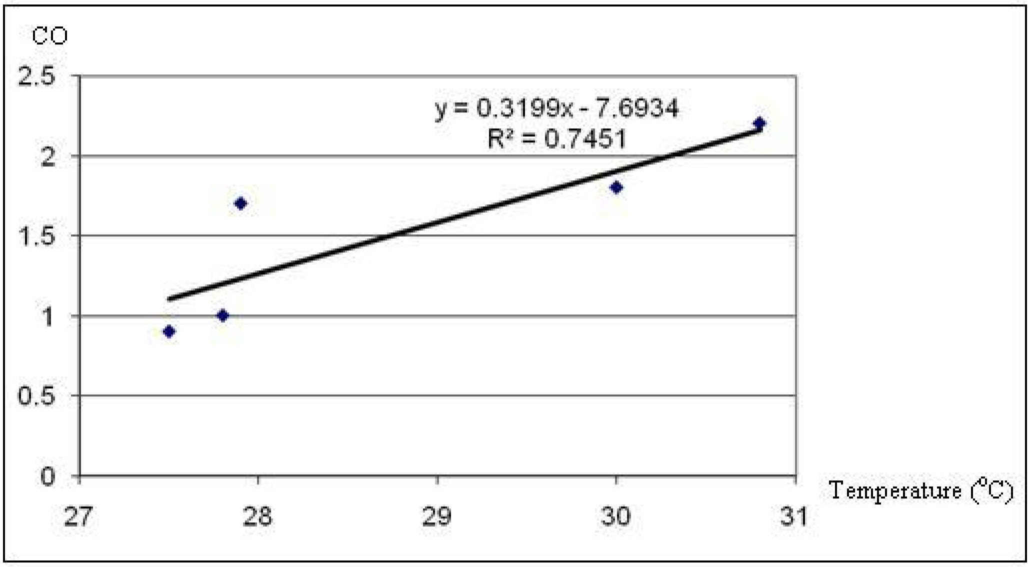

Figure 5 the correlation between CO and temperature

The regression model of temperature and carbon monoxide was applied to temperature's pixels satellite images then the CO distribution was created spatially as shown in figure 5. The brightness represents low CO areas and the darkness indicates high CO areas. The low CO areas found in outer Bangkok and along Chaopraya River since the areas covered mostly openspace which is easy for air ventilation and somewhat low transportation. Whereas, high CO areas were come across in downtown (white to gray areas) because of high transportation and dense building which can blocked air circulation. It is considered that Rattanakosin areas or heritage areas had low CO since those areas were limited building height.

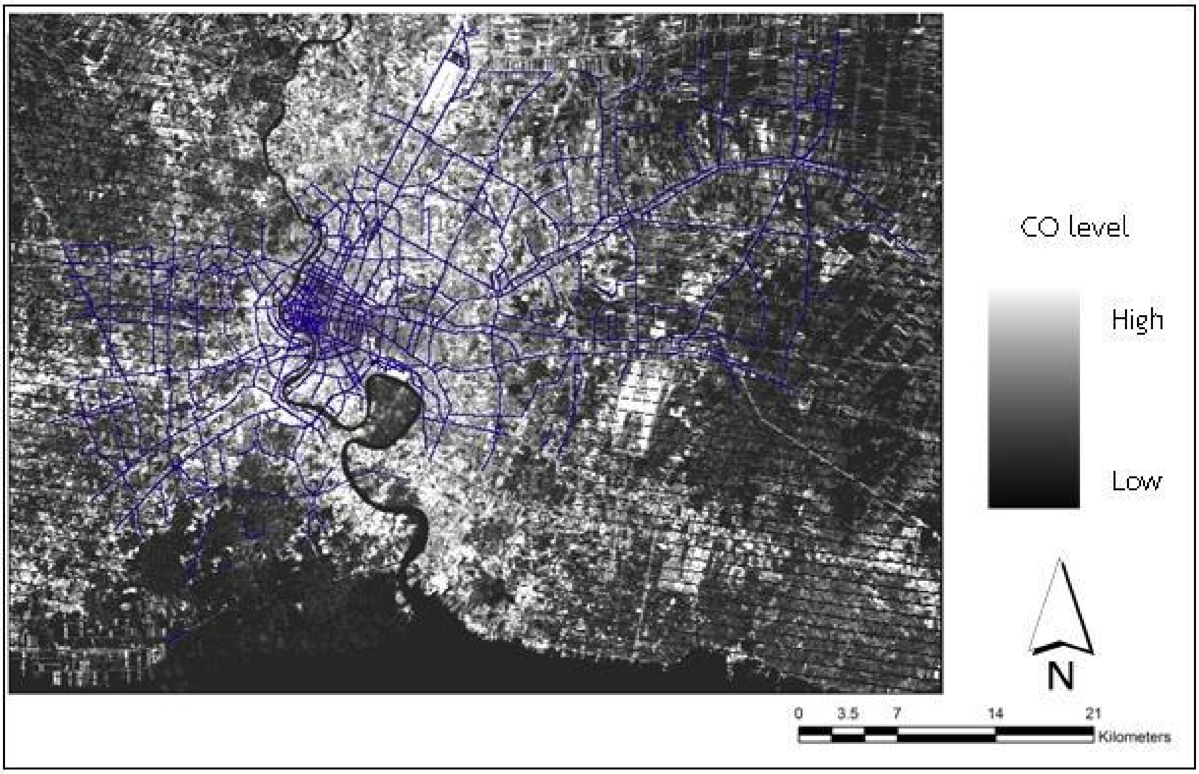

Figure 6 CO distribution and major transportation

4 Conclusions and Discussions

This study adds evidence on the correlation between satellite measurements in thermal infrared and air pollution parameter. It has been shown that the Carbon Monoxide is highly correlates to the apparent temperature. It can be concluded that the mapping of the CO is possible using the TM6 image. Although, this study faced with the limitation of the temporal resolution of Landsat; particularly, images are received for Bangkok area every 16 days, at 10.00 LST. This limitation restricts the operation application of the methodology to qualitatively assess the distribution of air pollutants in more frequent time. It should be also mentioned that this application will be further improved with the high spatial resolution. The pixel size of TM6 is 60m, which is rather large for explanation of Bangkok city and may be not relevant to study the air quality. The pixel value may not necessarily represent the value measured by the station due to the influence of other elements: pavement, streets, buildings, trees, other vegetation, and vehicles. The better correlation was obtained when applying the highest spatial resolution. Further studies are needed to promote on the relationship between satellite observations and air pollutants in relation to other parameters, including urban morphology and street networks.

5. References

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