

Assessing Green City-based Tree Cover Change in Nakhonratchasima City Municipality

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Abstract

Many cities has set goal of green city with tree increasing. The objective of this study is to assess green city-based tree cover change in Nakhonratchasima City Municipality (NCM). In analysis, Google Earth (GE) imagery during 2012-2020 was used for visual interpretation but the result of Urban Tree Canopy (UTC) cover interpretation on GE image in year 2020 only was evaluated accuracy in field and was used to be the base map for supporting GE photo-interpretation in the past (2012-2019). The result of annually UTC cover layers would be taken to estimate air pollutants ((CO, NO₂, O₃, PM10, PM_{2.5} and SO₂) via i-Tree Canopy on web. As results, the accuracy assessment of UTC cover map in year 2020 is 96.5517%. Tree cover change during the varying periods were found that there were ranged from dramatic reduction in percent tree cover of 17.2873% in year 2013 (because of built-up areas' increasing in that time) and slight reducing 0.0561% in year 2015 to an increase in percent tree cover of 0.3122% in year 2016 and 0.0488% in year 2017 while percent tree cover has been gradually decreased between 2018 and 2020. At the same time, NCM's UTC cover included the highest total removal value of CO (17.0 x 10⁻⁷ % per year) in year 2017; of NO₂ (74.0 x 10⁻⁷ % per year) in year 2013, 2014 and 2017; of O₃ (711.0 x 10⁻⁷ % per year) in year 2015; of PM10 (240.0 x 10⁻⁷ % per year) in year 2013 and 2014; of PM_{2.5} (38.0 x 10⁻⁷ % per year) in year 2017; of SO₂ (48.0 x 10⁻⁷ % per year) in year 2013 and 2014. This assessment of such pollutant removal should not only be considered by tree cover but also the concerned factors (i.e., pollution concentrate, length of in-leaf season, amount of precipitation, and other meteorological variables). The mentioned results above, they will be used for spatial information for planning green city in area of NCM and guiding other green cities. Consequently, this study suggests for next work as: (1) study relationship between tree cover and land use/land cover and (2) study other related factors for UTC cover change.

Keywords: Green city, Tree cover change, Spatial and temporal change, Google Earth imagery

1. Introduction

According to the global urban population is expected to grow approximately 1.84% per year between 2015 and 2020, 1.63% per year between 2020 and 2025, and 1.44% per year between 2025 and 2030 (World Health Organization (WHO), 2020). Population growth in cities is an indicator of the growing importance of urban environments to public health in general (WHO, 2009; Food and Agriculture Organization of the United Nations (FAO, 2018). Cities would have to adopt to the changes in livability, safety, health, climatic quality and another environment (Potz and Bleuze, 2013). Therefore, the study of green city should be required and focuses on the analysis of the relationships among the green components and, so that to emphasize their role in promoting the future sustainability of the cities (Tirla et al., 2014). Similarity, the solution of city should have started to change towards green city, more sustainable and more resilient model of urban development with investing in forests and other green spaces (FAO, 2018), as example of green cities of Europe in theme of global lessons on green urbanism (Beatley, 2012), US and Canada green city index (Stein et al., 2011) and green city planning and practices in Asian cities in theme of sustainable development and smart growth in urban environments (Shen et al., 2018). Using remote sensing and Geographic Information System (GIS) techniques, these modern and effective investigation tools have been implemented for revealing the specific context of the green city-based qualitative and quantitative analysis methods (Tirla et al., 2014). For example, assessment of green city's characteristics was defined by a numerical analysis method knowingly called, 'the Green City Index' (Shields and Langer, 2009; Stein et al., 2011; Batten & Edwards, 2015). Moreover, monitoring of tree cover changes is important to understand how tree cover and various environmental benefits derived from the trees may be changing (Nowak & Greenfield, 2012a). Therefore, Photo-interpretation of digital aerial images can provide a simple and timely means to assess urban tree cover change to help cities monitor progress in sustaining desired urban tree cover levels (Nowak & Greenfield, 2012a; 2012b). Therefore, this paper investigates tree canopy cover change in urban area that Nakhonratchasima City Municipality (NCM) is selected as case study because, in the past, Nakhon Ratchasima province faced a flood crisis in the year 2007, 2010 (Tangprasit, 2010; THAIRATH online, 2010; Thai PBS NEWS, 2010) and 2017 (THAIRATH online, 2017) that this event affected to NCM because of Lam Takhong river flowing through the heart of NCM area.

The objective of this paper is to investigation green city of NCM with rate of Urban Tree Canopy (UTC) cover change for increasing trees and supporting ecosystem services. In addition, this study selected periods from 2012 to the current year (2020) because, in year 2007 and 2010, high-resolution photo images on Google Earth Pro are not available so this research has selected such periods.

2. Literature review

2.1 Using remotely sensed data and geospatial tools for studying UTC

UTC is a measurement which encompasses the layer of leaves, branches and stems of trees that shelter the ground when viewed from above (Center for Watershed Protection, 2018; Edmond, 2017). This measurement is expressed as a percentage of ground area that is covered by tree crowns and relates to the branching spread of the trees in an urban forest. Some urban tree canopy covers natural areas or gardens and lawns, while other canopy spreads across impervious surfaces such as roads, buildings and parking lots (Hwang & Wiseman, 2020; Nowak & Greenfield, 2020; Norwak et al., 2012; Poracsky & Banis, 2005). Moreover, UTC plays an important role in contribution of the Surface Urban Heat Island (SUHI) effect which UTC is associated to help reducing urban temperatures and energy use in cities (Elmes et al., 2017). In such importance and benefits of UTC, this study has recently reviewed relevant to papers and reports analysis of UTC using remotely sensed data, geospatial tools and auxiliary data as **Table 1**. Most studies of UTC use high-resolution satellite imagery such as Google Earth (GE) images, aerial photos, Light Detection and Ranging (LiDAR), WorldView-2/3 satellite imagery and Landsat. Geospatial tools and techniques are used for studying UTC as: using GE imagery on GE program for UTC' classification; using i-Tree Canopy for assessing UTC cover and tree benefits (air pollution and hydrology); using QGIS-based Object-based image analysis (OBIA) mean-shift segmentation for analyzing UTC, etc.

Table 1. Examples for studying UTC using remotely sensed data and geospatial tools

No.	Papers and authors	Remotely sensed data	Geospatial tools and techniques
1	The increase of impervious cover and decrease of tree cover within urban areas globally (2012-2017) by Nowak & Greenfield (2020)	High resolution on Google Earth imagery	Google Earth Pro and i-Tree Canopy for estimating tree cover and tree benefits (air pollution and hydrology)
2	Geospatial methods for tree canopy assessment: A case study of an urbanized college campus by Hwang & Wiseman (2020)	- The three high-spatial resolution (8 cm, 15 cm, and 30 cm) from Virginia Information Technology Agency - Aerial photos from the web-based application i-Tree Canopy	- Urban tree canopy and land cover with visual photo interpretation on i-Tree Landscape and i-Tree Canopy
3	Detecting long-term urban forest cover change and impacts of natural disasters using high-resolution aerial images and LIDAR data by Blackman & Yuan (2020)	Light Detection and Ranging (LiDAR)	Object-based image analysis (OBIA) and non-image classification methods (such as random point-based evaluation) accurately determine urban canopy coverage using high-spatial-resolution aerial images
4	Health impact assessment of Philadelphia's 2025 tree canopy cover goals by Kondo et al. (2020)	Landsat 8-based 30 m x 30 m spatial resolution	- Using ordinary least-squares quadratic regression for deriving a linear relation at the census tract level for UTC - Using Normalized Difference Vegetation Index (NDVI) $= -0.03 + (0.51 \times \text{UTC})^2$ with R^2 was 0.85 for estimating tree cover change
5	Mapping seasonal tree canopy cover and leaf area using worldview-2/3 satellite imagery: a megacity-scale case study in Tokyo urban area by Kokubu et al. (2020)	- WorldView-2/3 satellite imagery at the individual tree level (2 m resolution) - Aerial photography	Mapping urban trees based on a simple pixel-based classification method
6	Toward operational mapping of woody canopy cover in tropical savannas using Google Earth Engine by Anchang et al. (2020)	Sentinel-1 (C-band synthetic aperture radar) and Sentinel-2 (optical reflectance) data	- GE engine - A Python application programming interface - Collect Earth Online (CEO) - ArcGIS Pro - QGIS
7	China forest cover extraction based on Google Earth Engine by Yan-Tao et al. (2020)	Landsat-8 Surface Reflectance Tier and Landsat-8 Operational Land Imager (OLI) and thermal Infrared Sensor (TIRS)	- GE engine - C Function of Mask (CFMASK) - Index computation-based NDVI
8	Observed canopy evapotranspiration enhancement of green patches in Chinese metropolis by Zhao & Zhao (2020)	- High-resolution Google Earth images and thermal images - Cloudless Landsat 5/8 surface reflectance images-based 30 m spatial resolution	- GEE - Using a simple Taylor skill fusion method - Time series analysis combined with robust regression
9	Object-based delineation of urban tree canopy: assessing change in Oklahoma City, 2006-2013 by Ellis & Mathews (2019)	LiDAR-derived data product from the Army Geospatial Center (AGC) as three one-meter spatial resolution rasters for 2006 and 2013: first-return DSM (DSM ^{first}), last-return DSM (DSM ^{last}), and intensity, which were stacked as one image	OBIA mean-shift segmentation was performed using the OrfeoToolbox (OTB) in the Monteverdi software package (free, open source)
10	Effect of urban tree canopy loss on land surface temperature magnitude and timing by Elmes et al. (2017)	- A fused LiDAR/WorldView-2 dataset-based fine spatial resolution 0.5 m - Landsat data for analysis time series	- Using image segmentation - Fractional UTC change per unit area - NDVI
11	Determinants of urban tree canopy in residential neighborhoods: Household characteristics, urban form, and the geophysical landscape by Lowry et al. (2012).	Color-infrared digital orthophotography with 1-m spatial resolution	Using an object-oriented image segmentation approach
12	Street trees in the urban forest canopy: Portland, Oregon by Poracsky & Banis (2005)	Digital aerial camera images with one-meter resolution based on three bands (green, red and near infrared), acquired in June of 2002	Street tree canopy was analyzed by visual interpretation-based field observation experiences on the computer screen and digitized as polygons.

2.2 Using i-Tree Canopy

This study focuses on using high-resolution GE imagery for visual interpreting UTC's cover-based GE Pro and estimating removal air pollution-based i-Tree Canopy on web. GE images were selected for this study because they are freely available remote sensing data with high-resolution images on GE Pro. This GE Pro is free software and always used for urban study because of providing clear view of urban land use and land cover (Malarvizh et al., 2016). Moreover, GE Pro provides a variety of spatio-temporal images from local to national scales. For i-Tree Canopy, it is web browser application that is developed by USDA Forest Service and partnerships, is approved and accepted for assessing tree cover and pollution removal values, and can be used to determine the amount of an area of interest covered by tree canopy and other user-defined surfaces (Urban Forestry Research Group, 2020; USDA Forest Service et al. 2006). Moreover, this i-Tree Canopy is one of eleven components of i-Tree software suite, allows users to easily photo-interpret Google aerial images to produce statistical estimates of tree and other cover types long with calculations of the uncertainty of their estimates, and can be used anywhere in the world where high-resolution, cloud-free GE images exist (Hirabayashi et al., 2011). In pros of i-Tree Canopy, it provides greater accessibility to UTC assessment: faster UTC assessment; little knowledge required; no specialized software or remote sensing data required (Hwang, 2013). There are examples for studying UTC-based i-Tree Canopy (<https://canopy.itreetools.org/>) such as Hwang & Wiseman (2020), Nowak & Greenfield (2020), Nowak et al. (2013a), Nowak et al. (2013b), Nowak et al. (2012); Nowak & Greenfield (2012a), Nowak & Greenfield (2012b), can conclude 3 mainly basic steps to estimate UTC and other ground cover as follows:

- 1) Define study area: import a file that delimits the boundary of your area of analysis (e.g. city boundary, boundary of tree canopy cover).

- 2) Define cover classes: input name for the land cover classes to classify (e.g. tree/shrub, grass/herb, impervious building, impervious road, impervious other, water and soil). In this study, we used only tree/shrub because other cover classes do not absorb air pollutants.

- 3) Define sample size & interpret random points: start classifying (interpreting) each point that will be located randomly within the boundary file.

In part of pollution removal-based i-Tree Canopy, this study is based on research guideline of Nowak et al. (2006), Nowak et al. (2012) and Nowak et al. (2013a), stated that the amount of tree cover (increased tree cover leading to greater total removal), pollution concentration

(increased concentration leading to greater downward flux and total removal), length of in-leaf season (increased growing season length leading to greater total removal), amount of precipitation (increased precipitation leading to reduced total removal via dry deposition), and other meteorological variables that affect tree transpiration and deposition velocities (factors leading to increased deposition velocities would lead to greater downward flux and total removal). All of these factors combine to affect total pollution removal and the standard pollution removal rate per unit tree cover.

3. Materials and methods

3.1 Nakhonratchasima City Municipality

This study focuses on a 37.78 sq.km area of NCM with GE images (Figure 1). The study area is in the administrative bound of Ni-muang sub-district, Muang district, Nakhonratchasima province in Thailand. These areas establishes in northern east region of Thailand and located in Southeast Asia of Equator from 14°56'–15°00'N to 102°01'–102°08'E. In study area, there is land use of NCM in year 2019 (Janatakat and Juntakut, 2020), includes 5 main types-based 1st level of Land Development Department (LDD) classification system: forest land (0.06 sq.km. or 0.16%), agriculture land (3.24 sq.km. or 8.58%), urban and built-up land (33.12 sq.km. or 87.67%) and, water body (1.04 sq.km. or 2.75%) and miscellaneous land (0.32 sq.km. or 0.85%).

3.2 Methods

This research aims to yearly present tree canopy cover change from 2012 to 2020 for assessing green city in NCM. Therefore, this study has visually interpreted UTC cover on Google Earth Pro version 7.3.3.7786 (64-bit) and accuracy assessment-based ground checking, estimated UTC cover and removal rate of air pollution-based i-Tree Canopy on web (<https://canopy.itreetools.org/>) and spatial analysis and making layout view in QGIS version 2.18.16 (download at <https://qgis.org/downloads/>). There are 3 main steps for this study (Figure 2) as follows:

3.2.1 Data collection

This study collected data that comprised of (1) the high-resolution GE imagery from 2007 to 2020 but was seen and available existing between 2012 and 2020 as Figure 3 and (2) GIS layer of NCM boundary from office of NCM. High-resolution GE images were selected because of freely available satellite data, providing clear view of UTC cover and various spatio-temporal images. For reason of GE-image selection, it was fixed by yearly and used

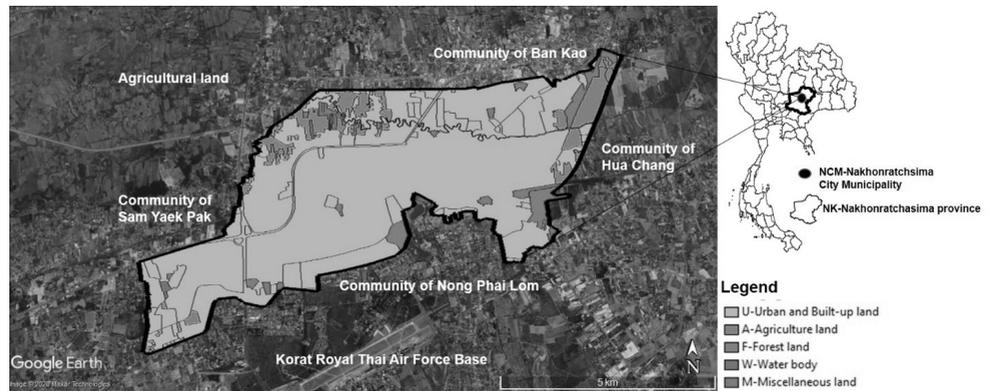


Figure 1. Study area and land use in year 2019

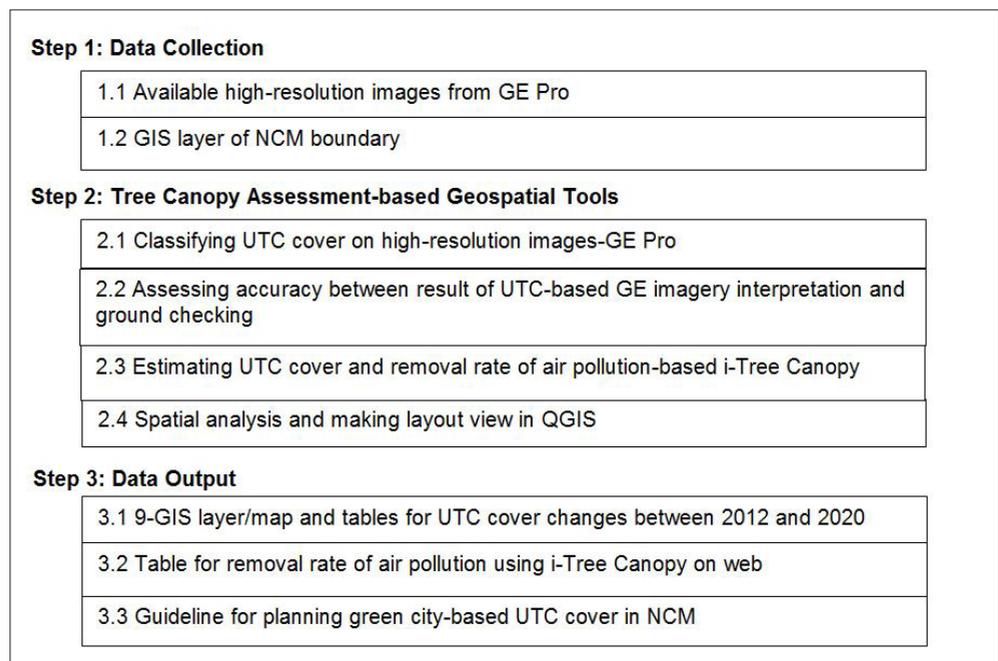


Figure 2. Steps for studying Spatial and temporal changing for UTC cover in NCM

winter seasonal period of Thailand (from mid-October to mid-February) but maybe used summer season (from mid-February to mid-May) replace as a), b) and e). On the other words, this study tried to select without cloud cover or free of distractions in GE imagery.

3.2.2 Tree Canopy Assessment-based Geospatial Tools

1) Classifying tree canopy on high-resolution GE images

This study used method of visual interpretation-based report of Jensen (2007) for classifying UTC cover on high-resolution

GE imagery in GE Pro. There are 8 components of visually interpreting fundamental include x,y location, size, shape, shadow, tone/color, texture, pattern, height/depth/volume/slope/aspect, and site/situation/association.

2) Assessing accuracy-based ground checking

Accuracy assessment-based field checking with random sampling and simple description statistics (> 80% with 95% confidence level) as Figure 4. In investigation of true ground, this study is able to check result of UTC cover's interpretation on GE images in present time (on January 9, 2020)

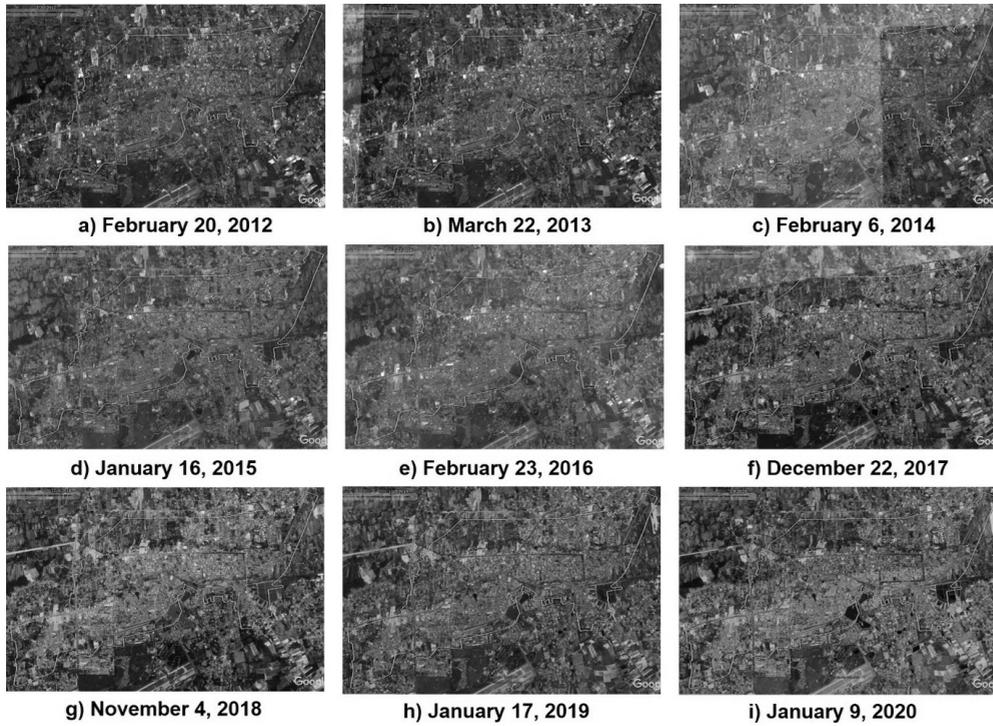


Figure 3. Collection of Google Earth images between 2010 and 2020 for this study

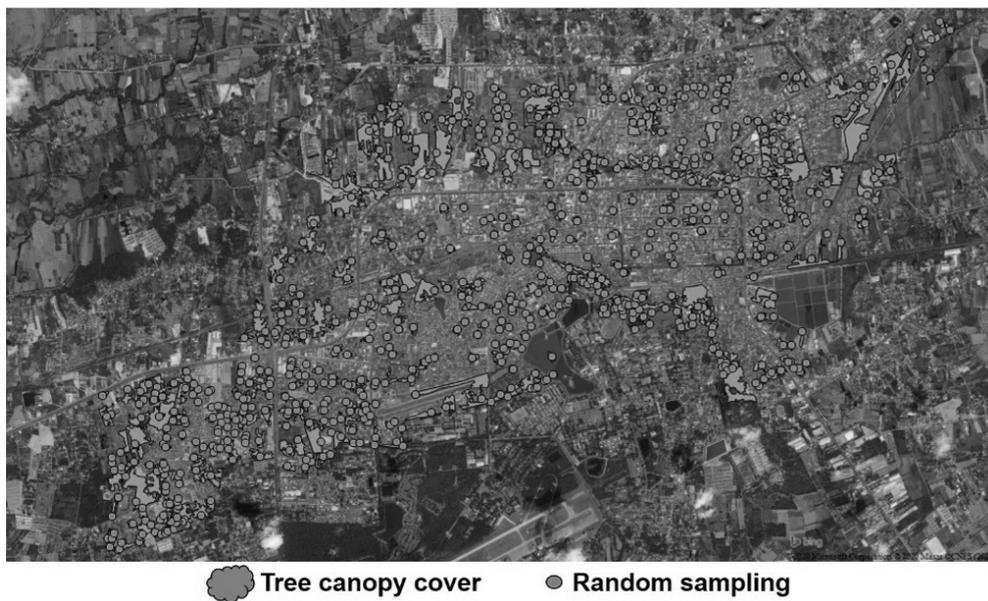


Figure 4. Processing of random sampling points using QGIS

only. However, such obtained result of ground checking would be used for helping interpretation of other annual GE images because we cannot back to the past to check field. In addition, the equation for the approximate sample size (N) used two papers that focused on accuracy assessment of land use/land cover map i.e., Fitzpatrick-Lins (1981) and Snedecor & Cochran (1967). This equation was taken as:

$$N = \frac{z^2(p)(q)}{E^2} \quad (\text{Eq.1})$$

Where p is the expected percent accuracy (85%) and q is 100- p (15%). The value for Z = 2 is generalized from the standard normal deviate of 1.96 for the 95% two-sided confidence level. At the same time, E is the allowable error of 4% (2 standard deviations of 2%), the number of sample points necessary for a 95% two-sided confidence probability would be explored as:

$$N = \frac{4(85 \times 15)}{4^2} = 319 \quad (\text{Eq.2})$$

Therefore, this study used 319 random sampling points for spatial processing on UTC cover map and then was surveyed in field. Fitzpatrick-Lins (1981) gave reason for mapping at least 85% accuracy-based the land-use classification system while allowable error of 2% standard deviation were selected for very little ground survey-based sampling method. These statistics can help for minimal costs because if there are a large sample, the possibility of confidence interval will be higher.

3) Estimating UTC cover and removal rate of air pollution using i-Tree Canopy on web

UTC cover and removal rate of air pollution (CO, NO₂, O₃, PM10, PM_{2.5} and SO₂) were estimated by i-Tree Canopy on web (<https://canopy.itreetools.org/>). In this study, the visual interpretation of UTC cover on high-resolution GE images were in form of vector layers that were exported .kmz file and then were converted in form of ESRI shapefile (.shp) to be imported and calculated for area of UTC cover and removal value of air pollution in i-Tree Canopy on web. In addition, Nowak et al. (2006) mentioned to calculation of CO, NO₂, O₃, PM10, PM_{2.5} and SO₂ as follows:

- NO₂, O₃, and SO₂ used a modified hybrid of big-leaf and multilayer canopy deposition models-based papers of Baldocchi et al. (1987) and Baldocchi (1988).

- CO and particulate matters (PM10 and PM_{2.5}) were removed by vegetation (canopy resistance) that are not directly related to photosynthesis and transpiration.

Canopy resistance of CO used paper of Bidwell and Fraser (1972) while canopy resistance of particulate matters used papers of Lovett (1994) and Zinke (1967).

4) Spatial analysis and making layout view in QGIS

This study used research tools (i.e., random points inside polygons (fixed)), geoprocessing tools (i.e., vector overlay), data management tools (i.e., merge vector layer), and making layout view for UTC cover mapping.

3.2.3 Data output

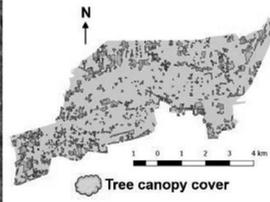
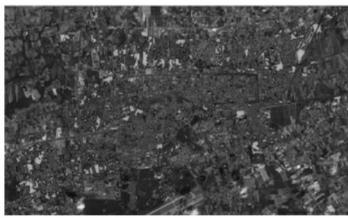
Output of green city's assessment is analyzed by change of UTC cover during 9 years (2012-2020). This output will be explored by 9-GIS layer/map and tables for UTC cover changes between 2012 and 2020, able for tree benefit such as air pollution from i-Tree Canopy and guideline for planning green city-based UTC cover in NCM.

4. Results and discussions

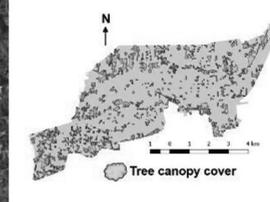
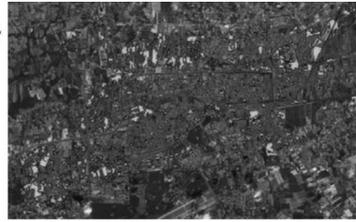
4.1 UTC cover changes in NCM between 2012 and 2020

This study analysis accuracy of UTC cover map in year 2020 (this was used to be the UTC cover-base map for supporting visual interpretation on GE images in the past period) that this sample provided a reliable estimate of the map accuracy as a whole. The accuracy result was the ratio of 308 points correct to a total of 319 points, or 96.5517%, having a one-tailed 95% lower confidence limit of 91%. This means that there is 95% confidence that the accuracy of the map was at least 91% or better and a mistaken threshold value is 20 points for the criterion of 85% accuracy (Fitzpatrick-Lins, 1981). For this accuracy result of this study has fallibility at 11 points that correspond to the criterion of 85% accuracy.

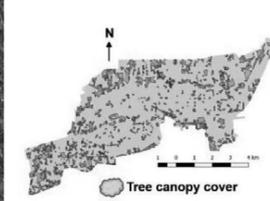
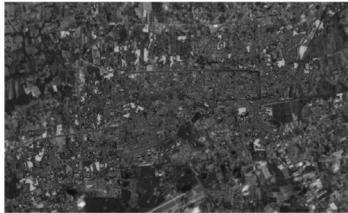
Change in tree cover during the varying periods of analysis ranged from dramatic reduction in percent tree cover of 17.2873% in year 2013 and 0.056% in year 2015 to an increase in percent tree cover of 0.3122% in year 2016 and 0.0488% in year 2017 (as shown [Figure 5.](#) and [Table 2.](#)). For 2018-2020, there are gradually decreased to be 0.0688% in year 2018, 0.0612% in year 2019 and 0.0691% in year 2020. Furthermore, there is big change of reduction in UTC between 2012 and 2013 (17%) because there was immediate land use change in urban and built-up area from 2012 to 2013 that was found that had higher rate 30% or the highest land use in NCM from report of Jantakat & Juntakat (2020). Conversely, UTC in 2016 and 2017 are increasing because the office of NCM had renovated landscape in public parks (e.g. Suranaree monument, Phumrak park etc.) with bringing big trees from other places to planting in such public parks. However, other years are decreasing because some trees did not survive.



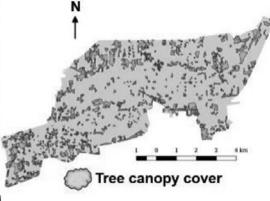
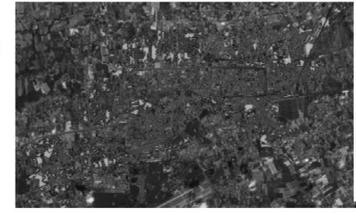
a) February 2, 2012



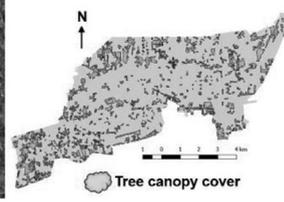
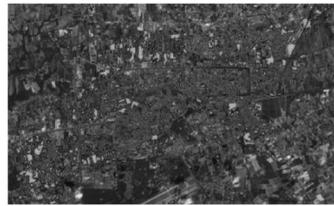
b) March 22, 2013



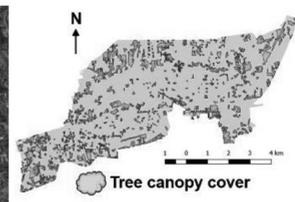
c) February 6, 2014



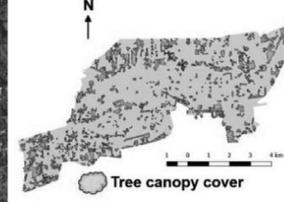
d) January 16, 2015



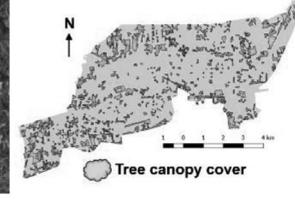
e) February 23, 2016



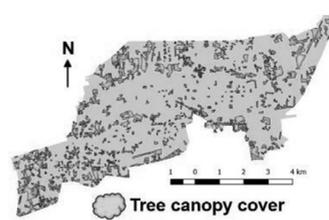
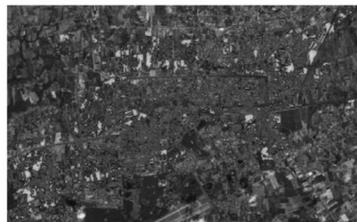
f) December 22, 2017



g) November 4, 2018



h) January 17, 2019



i) January 9, 2020

Figure 5. UTC change in NCM-based annually GE images from 2012 to 2020

Table 2. UTC change in NCM-based annually GE images from 2012 to 2020

GE images	Area (sq.m.)	% of NCM	UTC change (sq.m.)	% of UTC change
1. February 20, 2012	12,966,202.744	34.3203	0	0
2. March 22, 2013	6,435,044.4586	17.0329	-6,531,158.2853	-17.2873
3. February 6, 2014	6,435,044.4586	17.0329	0	0
4. January 16, 2015	6,413,839.2654	16.9768	-21,205.1932	-0.0561
5. February 23, 2016	6,531,797.4424	17.2890	+117,958.1770	+0.3122
6. December 22, 2017	6,550,227.9442	17.3378	+18,430.5018	+0.0488
7. November 4, 2018	6,524,234.6249	17.2690	-25,993.3193	-0.0688
8. January 17, 2019	6,501,101.9342	17.2078	-23,132.6907	-0.0612
9. January 9, 2020	6,474,997.5931	17.1387	-26,104.3412	-0.0691

Remark: - Minus (-) is reducing and addition (+) is increasing

- The big change of reduction in UTC between 2012 and 2013 (17%) because there was immediate land use change in urban and built-up area from 2012 to 2013 that was found that had higher rate 30% or the highest land use in NCM from report of Jantakat & Juntakut (2020).
- UTC in 2016 and 2017 are increasing because the office of NCM had renovated landscape in public parks (e.g. Suranaree monument, Phumrak park etc.) with bringing big trees from other places to planting in such public parks. However, other years are decreasing because some trees did not survive.

4.2 Comparison between UTC areas in NCM-based GE images and removal rate of air pollution

Pollution removal values for each pollutant (CO, NO₂, O₃, PM₁₀, PM_{2.5} and SO₂) has varied among the periods (2012-2020) as shown in Table 3. NCM's UTC cover has the highest total removal value of CO (17.0 x 10⁻⁷ % per year) in year 2017; of NO₂ (74.0 x 10⁻⁷ % per year) in year 2013, 2014 and 2017; of O₃ (711.0 x 10⁻⁷ % per year) in year 2015; of PM₁₀ (240.0 x 10⁻⁷ % per year) in year 2013 and 2014; of PM_{2.5} (38.0 x 10⁻⁷ % per year) in year 2017; of SO₂ (48.0 x 10⁻⁷ % per year) in year 2013 and 2014. These results are found that rate of NCM-UTC cover in year 2013 (17.0329% of NCM), 2014 (17.0329% of NCM), and 2017 (17.3378% of NCM) is closely each other and this covering rate could remove almost all air pollutants except removal of O₃ in year 2015. Noteworthy, the largest UTC cover was seen in year 2012 (about 34.3203% of NCM) but removal rate of air pollution was not high as well. This result is related to the statement of Nowak et al. (2006), Nowak et al. (2012) and Nowak et al. (2013a) that should consider other including factors such as pollution concentrate, length of in-leaf season, amount of precipitation, and other meteorological variables (see details in 2.2 using i-Tree Canopy above). In addition, this study is found that selection of date and month in Thai season has influence on the results of pollution removal values.

5. Conclusion

UTC cover map in year 2020 is accurately assessed as 96.5517% that is used to be the base map for GE image-based visual interpretation. For this accuracy result of this study has fallibility at 11 points that correspond to the criterion of 85% accuracy. Change in tree cover during the varying periods were found that there is big change of reduction in UTC between 2012 and 2013 (17%) because there was immediate land use change in urban and built-up area from 2012 to 2013 that was found that had higher rate 30% or the highest land use in NCM from report of Jantakat & Juntakut (2020). There was still slightly reduced 0.0561% in year 2015 to an increase in percent tree cover of 0.3122% in year 2016 and 0.0488% in year 2017. UTC in 2016 and 2017 are increasing because the office of NCM had renovated landscape in public parks (e.g. Suranaree monument, Phumrak park etc.) with bringing big trees from other places to planting in such public parks. However, other years are decreasing because some trees did not survive. Later, change of UTC cover between 2018 and 2020 has been gradually decreased to be 0.0688% in year 2018, 0.0612% in year 2019 and 0.0691% in year 2020.

Table 3. Comparison between UTC areas in NCM-based GE images and removal rate of air pollution

GE images	UTC cover (sq.m.), (% of NCM)	Removal Rate of Air Pollution (lbs/year), % of NCM					
		CO	NO ₂	O ₃	PM10	PM _{2.5}	SO ₂
1. February 20, 2012	12,966,202.744, 34.3203	1.3035, 9.0x10 ⁻⁷	5.3185, 38.0x10 ⁻⁷	49.3695, 354.0x10 ⁻⁷	16.8045, 120.0x10 ⁻⁷	2.7805, 20.0x10 ⁻⁷	3.4995, 25.0x10 ⁻⁷
2. March 22, 2013	6,435,044.4586, 17.0329	1.1035, 16.0x10 ⁻⁷	5.1185, 74.0x10 ⁻⁷	49.1695, 710.0x10 ⁻⁷	16.6045, 240.0x10 ⁻⁷	2.5805, 37.0x10 ⁻⁷	3.2995, 48.0x10 ⁻⁷
3. February 6, 2014	6,435,044.4586, 17.0329	1.1035, 16.0x10 ⁻⁷	5.1185, 74.0x10 ⁻⁷	49.1695, 710.0x10 ⁻⁷	16.6045, 240.0x10 ⁻⁷	2.5805, 37.0x10 ⁻⁷	3.2995, 48.0x10 ⁻⁷
4. January 16, 2015	6,413,839.2654, 16.9768	1.0043, 15.0x10 ⁻⁷	5.0193, 73.0x10 ⁻⁷	49.0703, 711.0x10 ⁻⁷	16.5053, 239.0x10 ⁻⁷	2.4813, 36.0x10 ⁻⁷	3.2003, 46.0x10 ⁻⁷
5. February 23, 2016	6,531,797.4424, 17.2890	1.1032, 16.0x10 ⁻⁷	5.1182, 73.0x10 ⁻⁷	49.1692, 699.0x10 ⁻⁷	16.6042, 236.0x10 ⁻⁷	2.5802, 37.0x10 ⁻⁷	3.2992, 47.0x10 ⁻⁷
6. December 22, 2017	6,550,227.9442, 17.3378	1.2039, 17.0x10 ⁻⁷	5.2189, 74.0x10 ⁻⁷	49.2699, 699.0x10 ⁻⁷	16.7049, 237.0x10 ⁻⁷	2.6809, 38.0x10 ⁻⁷	3.3999, 48.0x10 ⁻⁷
7. November 4, 2018	6,524,234.6249, 17.2690	1.1029, 16.0x10 ⁻⁷	5.1179, 73.0x10 ⁻⁷	49.1689, 700.0x10 ⁻⁷	16.6039, 236.0x10 ⁻⁷	2.5799, 37.0x10 ⁻⁷	3.2989, 47.0x10 ⁻⁷
8. January 17, 2019	6,501,101.9342, 17.2078	1.0023, 14.0x10 ⁻⁷	5.0173, 72.0x10 ⁻⁷	49.0683, 701.0x10 ⁻⁷	16.5033, 236.0x10 ⁻⁷	2.4793, 35.0x10 ⁻⁷	3.1983, 46.0x10 ⁻⁷
9. January 9, 2020	6,474,997.5931, 17.1387	0.9020, 13.0x10 ⁻⁷	4.9170, 71.0x10 ⁻⁷	48.9680, 703.0x10 ⁻⁷	16.4030, 235.0x10 ⁻⁷	2.3790, 34.0x10 ⁻⁷	3.0980, 44.0x10 ⁻⁷

Remark: CO is Carbon Monoxide, NO₂ is Nitrogen Dioxide, O₃ is Ozone, PM10 is Particulate Matter greater than 2.5 microns and less than 10, PM_{2.5} is Particulate Matter less than 2.5 microns, and SO₂ is Sulfur Dioxide

NCM's UTC cover has the highest total removal value of CO (17.0 x 10⁻⁷ % per year) in year 2017; of NO₂ (74.0 x 10⁻⁷ % per year) in year 2013, 2014 and 2017; of O₃ (711.0 x 10⁻⁷ % per year) in year 2015; of PM10 (240.0 x 10⁻⁷ % per year) in year 2013 and 2014; of PM_{2.5} (38.0 x 10⁻⁷ % per year) in year 2017; of SO₂ (48.0 x 10⁻⁷ % per year) in year 2013 and 2014. Moreover, assessment of such pollutant removal should not only be considered by tree cover but also the concerned factors (i.e., pollution concentrate, length of in-leaf season, amount of precipitation, and other meteorological variables).

The mentioned results above, they will be used for spatial information for planning green city in area of NCM and guiding other green cities. Moreover, this study suggests for next work as: (1) study relationship between tree cover and land use/land cover and (2) study other related factors for UTC cover change.

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