Study on Bangkok its Urban Heat Island effect and the Relationship with Electricity Consumption using Geoinformatics

Jariya Yomsatiankul[a], Sanwit Iabchoon[b] and Pariwate Varnakovida[c]

[a,b,c] *KMUTT Geospatial Engineering and InnOvation Center (KGEO), Faculty of Science, King Mongkut's University of Technology Thonburi, Bangkok 10140, Thailand*

Abstract

The research aims to study the urban heat island in Bangkok using remote sensing and Geo-information sciences, to determine the relationship between the UHI phenomenon and energy consumption and establish an electricity conservation plan. In this study, we investigated electricity consumption, solar radiation intensity, climate data, land surface temperature data, and land cover change. The quantified LST obtained from satellite imagery is used to identify areas exposed to the UHI effect. The quantified data is validated through field and observed measurements. We also illustrate LST spatial distribution and subsequent land use land cover types related to high LST. The relationship between LST, the Normalized Difference Vegetation Index, and the Normalized Difference Built Index was analyzed. LST was measured and correlated with climate data from meteorological stations. The relationship between increased LST and energy consumption was illustrated through linear regression analysis.

In the results, the energy consumption and UHI illustrate a positive relationship. Electricity consumption and LST have a high correlation of 70-90%. In the hope to mitigate the UHI effect, appropriate mitigation measures are needed to minimize its impact. Mitigation measures such as the reduction of electricity consumption by encouraging citizens to be more conscious of air conditioning use and private transportation use. Another mitigation measure is incorporating sustainable urban planning principles techniques into urban expansion such as increasing urban green spaces and the use of public transportation.

* Corresponding author.
E-mail: sanwit.iab@mail.kmutt.ac.th

Received ../../2018
Revised ../../2018
Accepted ../../2018

Keywords: Urban Heat Island, LST, Energy Consumption, Landsat, MODIS

1. Introduction

In 2014, it was estimated that 54 percent of the world's population lived in an urbanized region, by 2050 that number is projected to be 66 percent (United Nations, 2014). The environmental impacts of urbanized development have degraded local climatic factors and perpetuated unhealthy living situations (Akbari et al., 2016a). One byproduct of urbanization is the urban heat island (UHI) phenomenon. The UHI can be described as the increase in surface temperatures in urban areas in comparison to rural landscapes (Jongtanom, Kositanont & Baulert, 2011). The impacts of increased surface temperature have been attributed to the increased population size, population density, and urbanization (Xiong et al., 2012). Bangkok, Thailand has been highlighted as a metropolis at the helm of urbanization and expansion, thus, effected by UHI. Every ten years, the National Statistics Office of Thailand publishes a census report for the country. As of 2010, the census bureau has documented the current population of Bangkok at 8.305 million inhabitants. The growth in the population of Bangkok has increased by 2.4 million inhabitants in the past 20 years (National Statistics Office, 2012). As the population growth increases over time, there is also an increase in average land surface temperature. From 1994 to 2009 the average land surface temperature in Bangkok has risen by 13 °C (Srivanit, Hokao & Phonekeo, 2016, pp. 243-746).

While there have already been numerous studies in developed countries on the mitigation of UHI (Akbari et al., 2016a; Lin, Tsai, Wang & Wu, 2005; Magli, Lodi, Contini, Muscio & Tartarini, 2016, pp. 164-172; Murphy et al., 2011; Wang, Berardi & Akbari, 2016, pp. 2-19; Zhang, Estoque & Murayama, 2017, pp. 557-568). The studies describing urban morphological indicators influencing UHI in developing cities, such as Bangkok, are still not very well documented. Previous studies on UHI in Thailand have focused on recorded air surface temperature values and determining the UHI intensity by the difference in rural and urban temperature (Arifwidodo, 2015, pp. 6435-6439; Arifwidodo & Tanaka, 2015, pp. 423-428; Boonjawat, J., Niitsu, K., & Kubo, 2000, pp. 49-55; Jongtanom, Kositanont & Baulert, 2011; Srivanit & Kazunori, 2011, pp. 34-46). However, none have targeted specific indicators and (spatial) relationships through satellite imagery and indices related to high land surface temperature.

Srivanit and Kazunori (2011) and Srivanit et al. (2012) both conducted studies on the urban morphological factors influential on UHI in the Bangkok Metropolitan Area (BMA). Srivanit and Kazunori (2011) developed an analysis to find the relationship between urbanization, specifically mechanisms driving urban development and increased land surface temperature (LST). The study first focused on land use land cover, using the maximum likelihood classification (MLC) to identify building coverage, impervious surfaces, pervious surfaces, water, and vegetation. The study indicated that building coverage had the strongest relationship with the presence of UHI. The study indicated that densely packed regions have an impact on the overall retention of heat and increased surface temperature.

Wangpattarapong et al. (2008) researched the impact of climatic and economic factors on electricity consumption within Bangkok. The study employs an equation that relates electricity consumption with the variables; cooling degree-day, rainfall, income, population, the number of houses and amount of air condition units sold per month. Referred to as the residential electricity consumption model, the outcome explained that average ambient temperature influences increased energy consumption.

The identification of an UHI through Landsat satellite imagery and derived land surface temperature has successfully been accomplished in numerous studies (Estoque & Murayama, 2017, pp. 18-29; Li et al., 2016, pp. 233-243; Sheng, Tang, You, Gu & Hu, 2017, pp.738-746).

The relationship between the normalized difference vegetation indexes (NDVI), the normalized difference built-up index (NDBI), and LST. The NDVI is a simple indicator that can be used to analyze remote sensing measurements and assess whether the target being observed contains live green vegetation or not (Weng, 2012, pp. 34-49). The NDBI has been used for mapping urban built-up areas using Landsat data based on blue and NIR band (Bhatti & Tripathi, 2014, pp. 445-467). Electricity consumption in relation to the urban heat island phenomenon has not been fully recognized in previous studies on UHI analysis in Bangkok. It has been well documented that an increase in energy consumption is not directly linked to an increased UHI effect. Rather the increase in UHI areas has shown to influence an increase in energy consumption (Akbari, Rosenfeld, Taha & Gartland, 2016b; Wangpattarapong, Maneewan, Ketjoy & Rakwichian, 2008).

Some studies have focused on the relationship between LST and electricity consumption using MODIS imagery (Liao, Liu, Wang & Sheng, 2017, p. 250; Peng et al., 2011). Liao et al. (2017) studied the relationship with land surface temperature and electricity consumption in 32 major cities in China. The study found that there is a positive correlation between electricity consumption and land surface temperature at night and no correlation during the daytime. Peng et al. (2011) analyzed UHI for 419 cities across the globe and determined that daytime land surface temperature has a positive correlation with urban vegetation coverage.

One major impact factor for heat retention in urban regions is the subsequently large area of impervious surfaces. Impervious built-up surfaces in urban environments absorb heat, reduce the cooling effect of the surface its evapotranspiration, and limit wind uptake and mixing of air temperatures and increase radiation emittance. All of the factors have been detected to influence the increase of urban heat islands (Kuttler, 2008).

This study proposes an approach towards identifying UHI intensity through analyzing the relationship between LST and NDVI, NDBI and electricity consumption, using Landsat and MODIS satellite-derived products. Land surface temperature will be described along with its characteristic to NDVI, NDBI and electricity consumption in two districts within the provincial boundaries of Bangkok.

2. Objectives

- Describe the relationship between energy consumption and land surface temperature using remote sensing and GIS.
- Identify urban heat island indicators using LST, NDVI, NDBI and urban morphological features (i.e. land cover type and the highest percentage of electricity consumption within Bangkok)
- Develop maps identifying urban heat islands within BMA using Pleiades 50cm resolution satellite imagery
- Briefly encourage the application of urban planning principles and conservation of electricity consumption in minimizing the urban heat island phenomenon

3. Study Area

The Bangkok province was selected as the study area to determine the relationship between LST, NDVI, NDBI and electricity consumption.

4. Data Used in the Study

The data used in the study are the Terra/Aqua MODIS products and Landsat 5, 7 and 8 satellite imagery, monthly electricity consumption, number of electricity consumers, ground level temperature data, land cover data, and incident solar radiation.

4.1 Satellite Imagery

• The Terra/Aqua MODIS MOD11A2 version 6 product provides an average LST over a period of 8-days. Pixel resolution is 1000 meter. The Data was retrieved for the years 2000, 2005, 2010 and 2015 and is used to determine LST of Bangkok area;

•The free-cloud images acquired during the dry season consist of Landsat 5 TM in 1990, 1995, 2000 and, 2005, Landsat 7 ETM+ in 2010, Landsat 8 OLI/TIRS in 2015. The Landsat 7 imagery was considered because of a high cloud coverage of the Landsat 5 imagery in 2010 in this study area. The study area is covered by two scenes per year, which are the images with row/path of 129/050 and 129/051. The spatial resolution is 30 meters on multispectral bands and 15 meters on the Panchromatic band. The cloud rate of all collected imagery is less than 10 percent.

• Pléiades-HR 1B satellite imagery in April 2015 and January 2016 for isolating micro-scale regions of UHI characteristics with spatial resolution at 50 cm.

4.2 Electricity Consumption

Statistics of Customers and Energy Sales (Kilowatt-hours (kwh)) from Metropolitan Electricity Authority by Type of Customers (residential, small general service, medium general service, large general service, and others), Bangkok: 2005 – 2014;

4.3 Solar Incident Radiation

Monthly average of incident solar radiation data (MJ/m^2) in 2002 – 2014 supplied by the Department of Alternative Energy Development and Efficiency.

4.4 Weather Data

Daily air temperature data collected by the weather stations in Bangkok area. This data provided by the Thai Meteorological Department in 1982 – 2012.

5. Methodology

This study investigates the relationship between the UHI phenomenon and electricity consumption in Bangkok by analyzing various physical parameters, in order to support policy-making concerning energy consumption, which in turn is able to respond to potential UHI phenomena in large urban communities. (Figure 1)

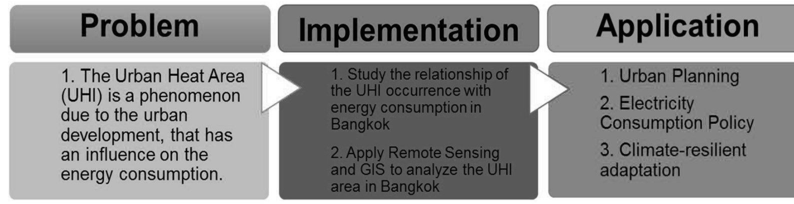


Figure 1. Research framework.

The implementation can briefly be described by starting from data gathering of spatial (satellite imagery, topographic data) and non-spatial data (electricity consumption, solar incident radiation, and weather data) from various sources. These data were pre-processed, including geometric and atmospheric corrections of satellite imagery. Then the data was converted from digital numbers (DN) to spectral radiance and to LST for thermal bands of Landsat 5, 7 and 8. This conversion was conducted according to the equations provided in Landsat 7 Data Users Handbook. For MODIS imagery, LST was derived from the MODIS LST product by applying the simple linear equation $y = a * x + b$, where a is the scale factor that equals to 0.02 and b is the added offset that equals to 0 according to the MODIS LST Products Users' Guide. Then, LST obtained from this conversion in degrees Kelvin was converted to degrees Celsius. Next, Bang Khun Thian and Pathumwan districts were selected as study areas. The UHI data analysis was conducted using very-high resolution Pleiades satellite imagery for selected districts. In this analysis the built-up area expansion was calculated, followed by data analysis of various parameters using Landsat TM, ETM and Terra/Aqua MODIS satellite imagery. Several different relationships were calculated: between LST and land cover; between average, minimum and maximum air temperature obtained from weather stations; between LST and NDVI; and between LST, NDBI, and NDVI. The factors of the relationship between electricity consumption and urban heat island were also analyzed. As a final step, maps were created of LST, electricity consumption and the UHI of Bangkok, using GIS. The final result could be used as information to propose an UHI mitigation plan to the urban planners and decision makers. The methodology flowchart is shown below in Figure 2.

6. Results and Discussion

6.1 Analysis of Temperature Severity Index and Trend of Change

The results from the data analysis showed several different temperature scenarios' related to the trend of change in temperature in the study area. Cool days and nights are likely to decrease. Days and nights with temperatures higher than average are likely to increase in which the average, maximum and minimum temperatures tend to increase too. The difference between the maximum and minimum temperatures is likely to decrease. During the year of the El Nino phenomenon, it was found that all areas had higher temperatures and drought. During the year of El Nino, there was more rainfall and lower temperatures.

6.2 Comparison of the average annual LST of Bangkok during day and night time

Average annual land surface temperature data was analyzed using MODIS satellite image for the years 2000, 2005, 2010, and – 2015. The LST expansion in 2015 was higher than the previous year in the city center during the day and night. It is obvious that the temperature increases each year. This is consistent with the daily temperature data that was analyzed in Section 6.1 as Bangkok has land surface temperatures between 23-37˚C

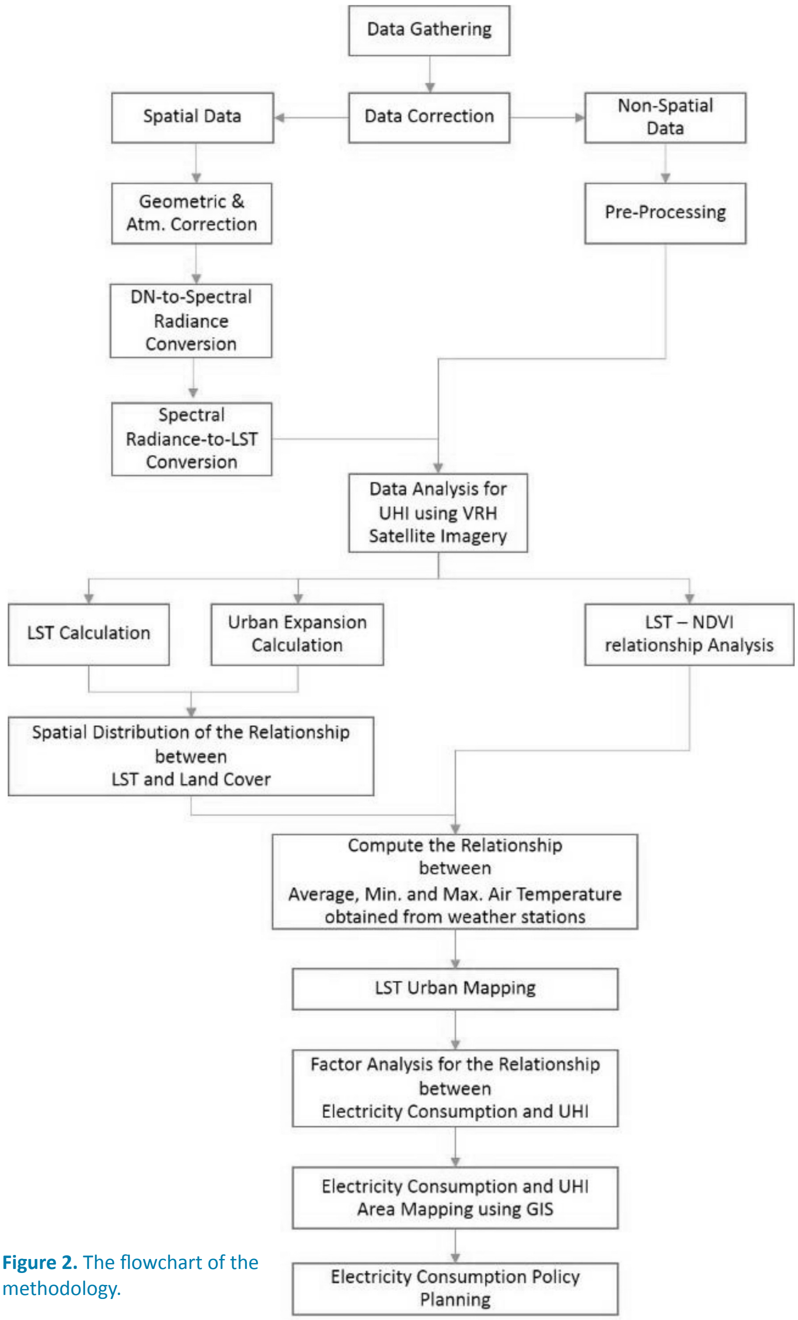


Figure 2. The flowchart of the methodology.

and 21-28˚C for daytime and nighttime, respectively. The maximum temperature measured in the city center during the day is in the year 2000 and during the night in the year 2010. The high-temperature areas are Klong Toey, Klongsan, Phayathai, Din Daeng, Dusit, Pathumwan and Bangkok Yai, and this has expanded to the neighboring areas, such as Chatuchak, Chomthong, Thonburi, Bangkok Noi, Bang Kholaem, Bang Sue, Bangrak, Pom Prap Sattru Phai, Phra Khanong, Phranakhon Ratchathewi, Huay Kwang, Yannawa, Ratburana, Ladprao, Wang Thonglang, Wattana and Sathorn. The dense urban areas have an average temperature which is different from the lowest temperature outside Bangkok area (8-12˚C during day time). The average temperature during the night in dense urban areas is different from the lowest temperature outside Bangkok (3-4˚C) (Figure 3 and 4).

6.3 The Analysis of the Relationship between LST, NDVI and NDBI

The results of the comparison for LST, NDVI and NDBI in 1990, 1995, 2000, 2005, 2010 and 2015 are described as shown in Table 1 and 2. In Table 1 and 2 the relationship levels were set using the R^2 range values where 0.90-1.00, 0.70-0.89, 0.50-0.69, 0.30-0.49 and 0.00-0.30 are very high, high, moderate, low and very low level, respectively. The comparison between LST and NDVI showed that these two parameters have a low-level relationship in 1995, while in 1990, 2000, 2005, 2010 and 2015, the relationship is even lower. For the case of LST and NDBI, their relationship is of a very high level in 1990, high in 1995, 2005, 2010 and 2015, and moderate in 2000. From this it can be concluded that LST data has a low to very low correlation with the NDVI, but has a very high correlation with the NDBI since the urban areas have land use for residential buildings, commercial buildings, industrial buildings, industrial plants, roads, covered surfaces such as concrete, metallic roof, which will result in high temperatures.

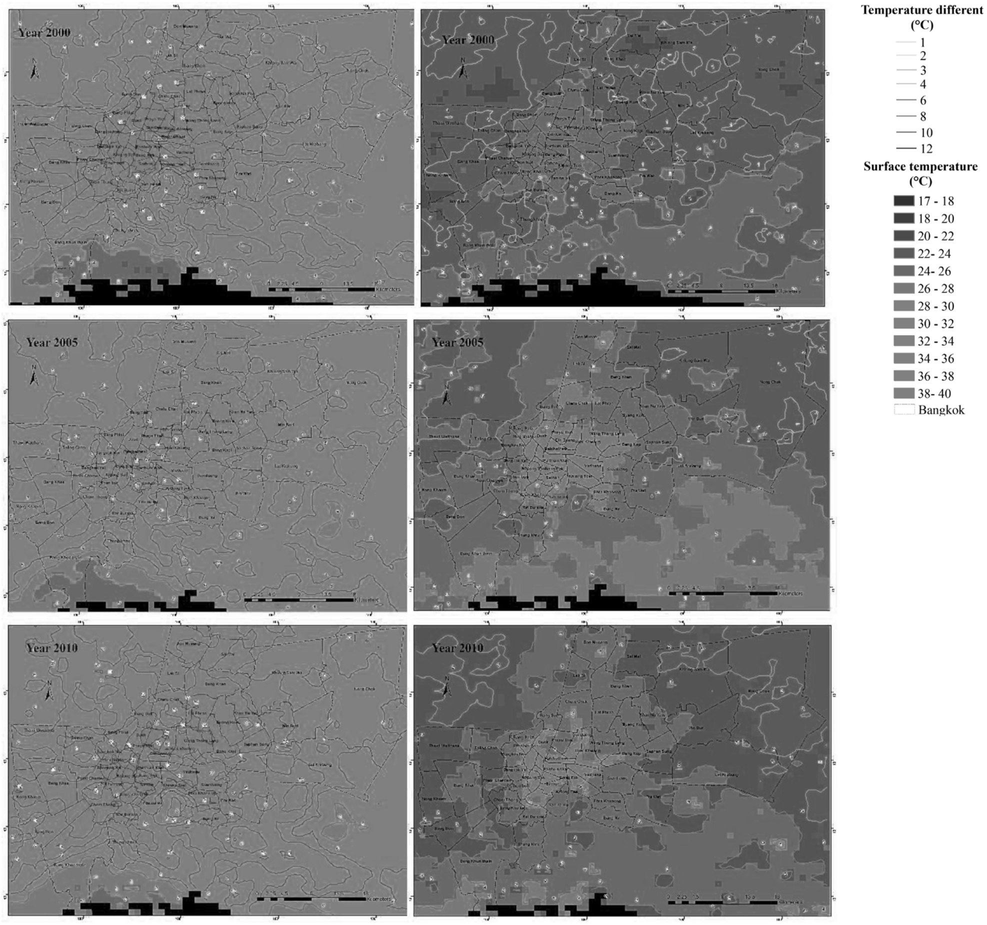
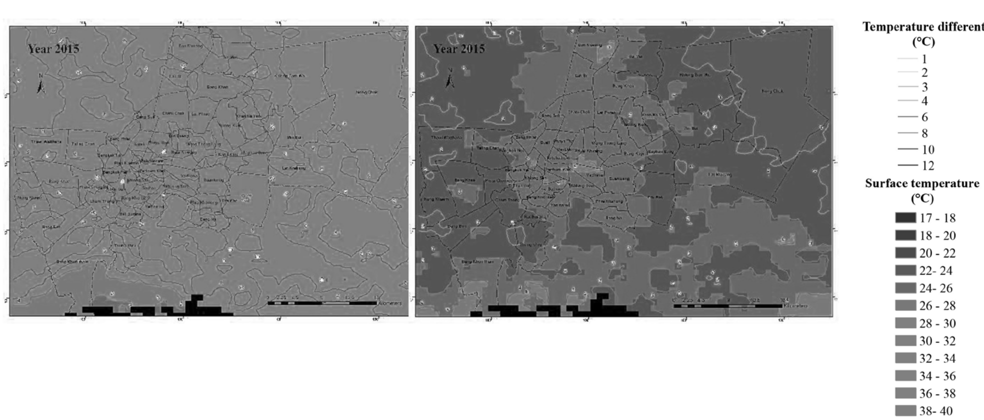


Figure 3 The difference of LST in daytime (left) and nighttime (right) within Bangkok area. (2000, 2005,and 2010)



igure 4 The difference of LST
daytime (left) and nighttime
ight) within Bangkok area
2015).

Table 1. Relationship between LST, NDVI and NDBI in Electricity Distribution Area (EDA) of Bangkok in 1990, 1995, and 2000.

	1990			1995			2000		
EDA	LST	NDVI	NDBI	LST	NDVI	NDBI	LST	NDVI	NDBI
Khlong Toey	26.87	0.23	0	28.23	0.09	-0.01	25.55	0.16	0.04
Thonbury	24.56	0.46	-0.16	26.65	0.31	-0.14	23.86	0.35	-0.07
Bangkapi	25.45	0.37	-0.09	27.45	0.25	-0.08	25.91	0.29	0
Bang Khun Thian	24.06	0.47	-0.17	26.63	0.32	-0.15	23.98	0.35	-0.08
Bang Khen	25.1	0.38	-0.17	27.15	0.25	-0.06	25.73	0.33	-0.04
Prawet	24.28	0.4	-0.19	26.69	0.25	-0.1	25.54	0.32	-0.05
Minbury	23.37	0.3	-0.29	25.85	0.29	-0.08	24.58	0.46	-0.13
Yannawa	26.38	0.24	-0.03	28.06	0.09	-0.01	25.57	0.16	0.05
Rachaburana	23.26	0.31	-0.22	25.46	0.12	-0.2	23.02	0.19	-0.18
Lad Krabang	23.22	0.31	-0.28	25.89	0.28	-0.09	24.67	0.44	-0.11
Lad Phrao	25.1	0.39	-0.15	27.03	0.25	-0.09	26.15	0.31	-0.01
Wat Liap	26.94	0.17	0.03	28.48	0.03	0.03	25.39	0.11	0.08
Sam Sen	26.37	0.29	-0.02	28.09	0.16	-0.03	25.61	0.21	0.04
R square		0.28	0.94		0.38	0.74		0.04	0.57

Table 2. Relationship between LST, NDVI and NDBI in Electricity Distribution Area (EDA) of Bangkok in 2005, 2010, and 2015.

	2005			2010			2015		
EDA	LST	NDVI	NDBI	LST	NDVI	NDBI	LST	NDVI	NDBI
Khlong Toey	29.42	0.13	-0.06	32.41	0.18	-0.03	26.59	0.23	0.02
Thonbury	28.05	0.26	-0.11	31.65	0.33	-0.11	26.63	0.4	-0.05
Bangkapi	29.73	0.19	-0.06	32.2	0.25	-0.05	26.44	0.34	-0.01
Bang Khun Thian	27.85	0.26	-0.12	31.71	0.33	-0.11	26.44	0.4	-0.05
Bang Khen	29.58	0.21	-0.07	32.55	0.26	-0.06	26.84	0.37	-0.03
Prawet	29.4	0.21	-0.08	30.62	0.27	-0.08	25.97	0.37	-0.05
Minbury	28.17	0.26	-0.11	29.77	0.29	-0.08	25.16	0.49	-0.11
Yannawa	29.43	0.13	-0.04	32.6	0.18	-0.01	26.82	0.22	0.05
Rachaburana	26.48	0.15	-0.23	28.22	0.21	-0.18	24.86	0.23	-0.12
Lad Krabang	28.86	0.23	-0.09	29.64	0.28	-0.09	25.18	0.46	-0.1
Lad Phrao	29.91	0.2	-0.05	32.84	0.24	-0.04	26.88	0.33	0
Wat Liap	29.47	0.11	-0.02	33.16	0.15	0.01	27.12	0.2	0.07
Sam Sen	29.85	0.16	-0.04	33.39	0.21	-0.02	27.12	0.27	0.04
R square		0.09	0.89		0.11	0.71		0.19	0.80

6.4 Analysis Results for Land Cover Classification and its Relationship with LST in 2015.

The analysis for land cover classification was conducted using Landsat satellite images of 1990, 1995, 2000, 2005, 2010 and 2015. Results show an increase of the built up area during all these years as well as a consequential decrease in green areas and water bodies, as shown in Figure 5. Densely built areas with and high agglomerations of big buildings or open spaces have a higher LST than the other areas. From the analysis, the appearance of the LST with various land covers are described. The roofs with dark color tones have higher temperatures than light-colored roofs. The LST of the areas with water bodies or green areas located in between the buildings is lower compared to areas without water bodies or green areas. In the area where the commercial buildings which are well distributed or having space between building blocks, LST is not high because there is space for air circulation which helps to cool down the air flow between the buildings. Figure 6, 7, 8, and 9 illustrate the land use and land cover using very high resolution satellite images of Pléiades in true color for different building types in comparison with MODIS LST images.

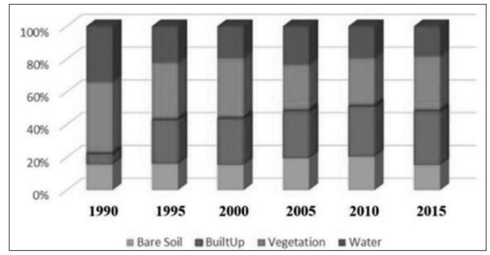


Figure 5. Comparison of land cover ratio in Bangkok Area in 1990 – 2015

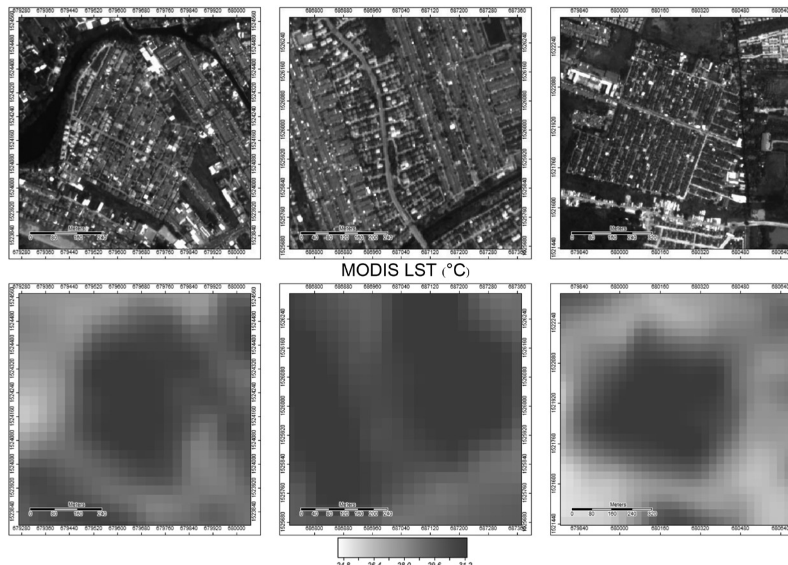


Figure 6. LST in single houses areas Pléiades True Color.

6.5 The Analysis Results of Relationship between LST and Electricity Consumption.

Table 3 shows the electricity distribution amount is related to LST in the range from moderate to very high level. In 2013, the relationship is of a very high level, which is opposite to 2011, when it was of a low level. The reason for this year is the El Nino year where many parts of the city were flooded due to more rainfall. Klong Toey Electricity Distribution Area (EDA) -covering the areas of Khlong Toey, Pathumwan, Bangrak and parts of Sathon and Yannawa districts- is the area with highest electricity consumption in every year. The second highest is Samsen EDA, which covers Dusit, Phayathai, Din Daeng, Huay Kwang and parts of Bang Sue and Ratchathewi districts.

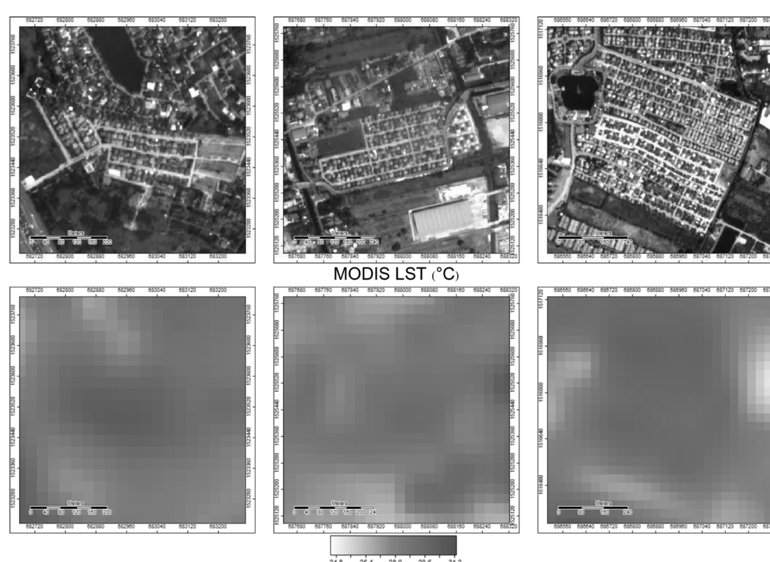


Figure 7. LST in Industrial Factories areas.

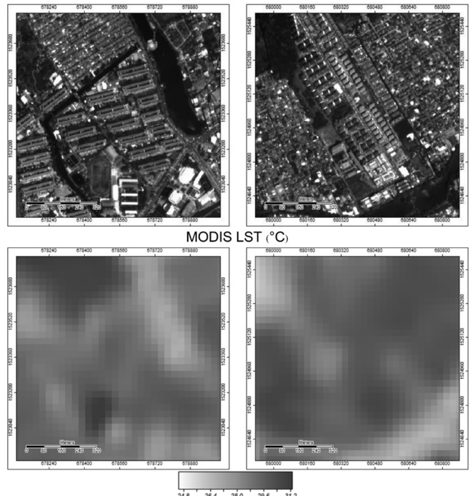


Figure 8. LST in Apartments areas

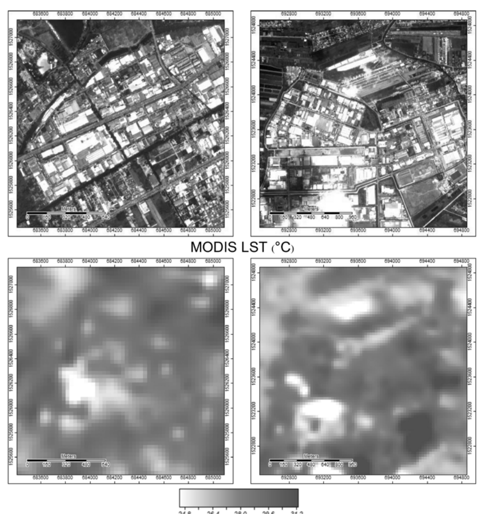


Figure 9. LST in Industrial Factories areas

Table 3. Relationship between LST and electricity distribution among EDA in Bangkok Area.

EDA	2010	2011	2012	2013	2014	2015
Khlong Toey	0.01	0.14	0.74	0.87	0.80	0.74
Thonburi	0.80	0.12	0.71	0.99	0.77	0.74
Bangkapi	0.80	0.70	0.77	0.91	0.86	0.59
Bang Khun Thian	0.41	0.08	0.80	0.99	0.88	0.80
Bang Khen	0.71	0.13	0.12	0.82	0.78	0.79
Pravet	0.51	0.27	0.82	0.87	0.82	0.68
Minburi	0.61	0.26	0.92	0.81	0.86	0.71
Yannawa	0.83	0.31	0.79	0.97	0.93	0.70
Ratburana	0.02	0.46	0.91	0.67	0.85	0.88
Ladkrabang	0.59	0.64	0.96	0.89	0.67	0.92
Ladprao	0.72	0.76	0.79	0.97	0.88	0.83
Wat Liab	0.66	0.61	0.54	0.95	0.85	0.86

6.6 Heat island and Energy Consumption Mapping in Bangkok

Heat island and energy consumption mapping for Bangkok area is based on a correlation analysis between LST and electricity consumption (unit: Million kWh), where the amount of electricity consumed for each area is not available for the same period. The heat island intensity level is divided into 3 zones: zone 1 is the highest intensity zone while zones 2 and 3 are moderate and low zones, respectively, as shown in Figure 10. The area with highest heat amount is located in city center with highest electricity consumption, and the heat expands to the surrounding area. Urban expansion is characterized by vertical and horizontal directions, especially in the central urban areas with densely populated areas and economic activity. In this area, the expansion of the built up area is extended in vertical direction, while in the outer suburbs areas expansion is influenced by real estate investment, consequentially expanding horizontally. If the area expansion is still in the way without effective control, there will be loss of agricultural and forestry land, when the area changes to residential, commercial, industrial or economic activity areas. In turn, this results in higher temperatures with more natural disasters.

7. Conclusion

The analysis of the UHI phenomenon and energy consumption of large urban areas such Bangkok can be implemented by applying geographic information systems and remote sensing technology. Especially, the use of various satellite imagery in different spatial resolutions can be helpful to analyze the land surface temperature and land cover types, in case weather stations are not available to completely cover all of the study area. By comparing the temperature data obtained from the weather stations and derived from satellite imagery, the data is correlated. The analysis of the relationship between the heat island phenomenon and the

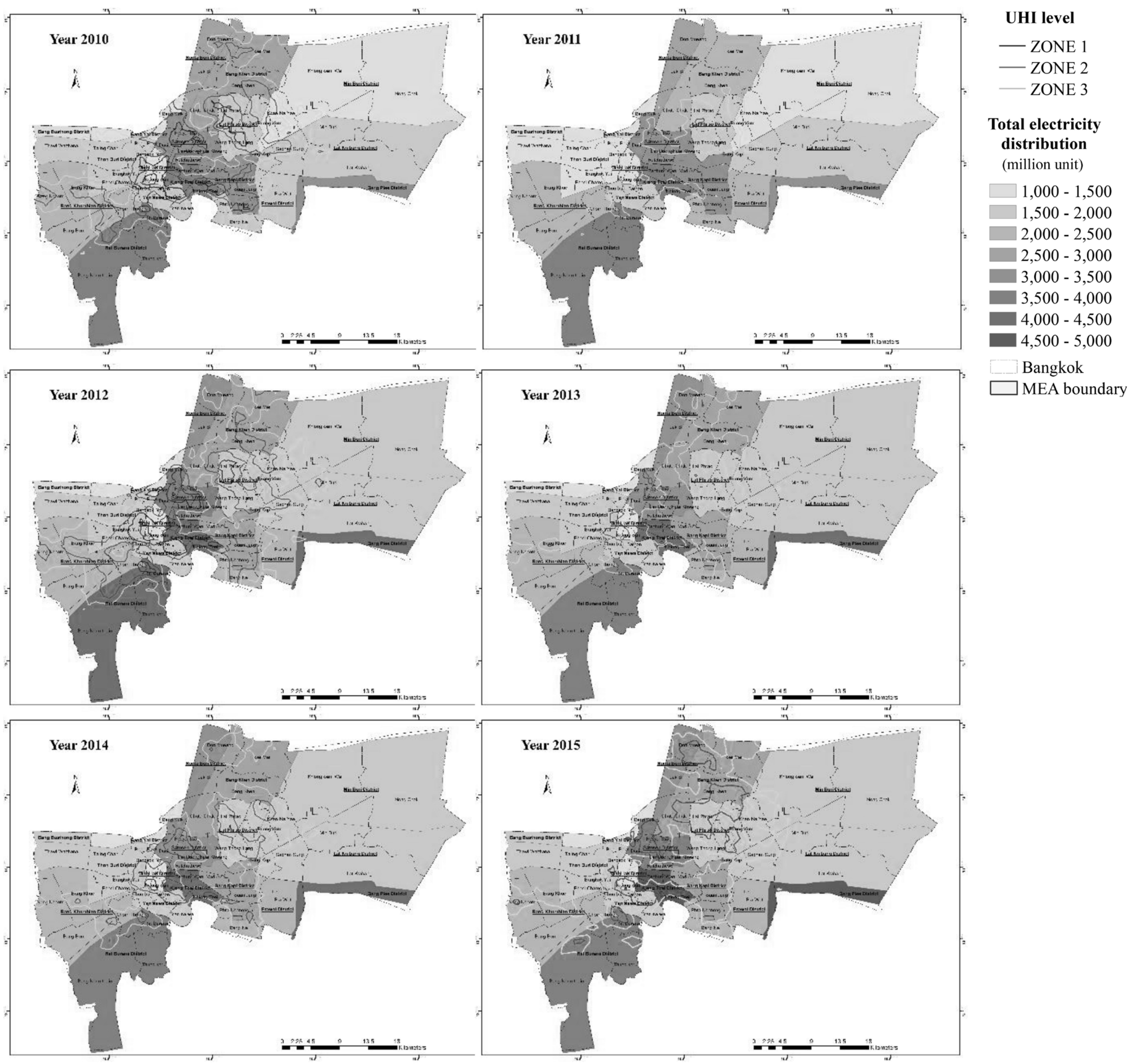


Figure 10. Bangkok heat island map of 2010-2015.

energy consumption in Bangkok was conducted and the data are highly correlated. In Bangkok, as well as in Thailand, there are many government agencies, various academic and research institutions, private sectors and other organizations who are concerned with energy conservation and natural resources preservation. There are many strategies and measures operational in society. In order to achieve these successfully, they need to start with simple energy conservation in real practice, in which all people are aware of their responsibilities and social participation.

9. Acknowledgement

We are grateful to the National Science and Technology Development Agency for funding support during the realization of this project. We wish to thank Metropolitan Electricity Authority, Thai Meteorological Department and Department of Public Works and Town & Country Planning for their data support. We would also like to show our gratitude to the Landsat-5, 7 and 8 image courtesy of the U.S. Geological Survey and The MODIS MOD11A2 data products that were retrieved from the online Data Pool, courtesy of the NASA Land Processes Distributed Active Archive Center (LP DAAC), USGS/Earth Resources Observation and Science (EROS) Center, Sioux Falls, South Dakota, https://lpdaac.usgs.gov/data_access/data_pool". We are also immensely grateful to Dr. Vivarad Phonekeo for his comments on an earlier version of the manuscript, although any errors are our own and should not tarnish the reputations of these esteemed persons.

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