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Urban heat island monitoring and analysis by using integration of satellite data and knowledge based method

Teerawong Laosuwan [1]*, Satith Sangpradit [2]

[1] *Department of Physics, Faculty of Science, Mahasarakham University, Khamriang Sub-District, Kantarawichai District Mahasarakham 44150, Thailand*

[2] *Department of Geoinformatics, Faculty of Informatics, Mahasarakham University, Khamriang Sub-District, Kantarawichai District Mahasarakham 44150, Thailand*

Abstract

In this study, the effect of urban heat island was analyzed by using the Landsat-5 TM data and knowledge based method based on a case study conducted for the years 2006 and 2009 in Kantarawichai District, Mahasarakham, Thailand. In order to investigate urban heat island (UHI) in the study area, two algorithms were developed, and Surface Radiance Temperature (SRT), Normalized Difference Vegetation Index (NDVI) and Normalized Difference Build-up Index (NDBI) were analyzed. The research employed high-quality solar radiation data acquired from solar-radiation measurement station at Mahasarakham University. The results pointed out that the Landsat-5 TM and knowledge based method are appropriate approaches for illustrating Land use and Land cover changes.

Keywords: Urban heat island, Satellite data, Knowledge based method

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* Corresponding author. *E-mail address:* teerawong@msu.ac.th

1. Introduction

The increase of global warming is believed to be resulted by Land use and Land Cover changes (Landsberg, 1981). One of the most general consequences of land use change and global warming is the urban heat island (UHI) (Streutker, 2002) which is one of the straight representations of environmental issues (Lu et al., 2009). UHI is a metropolitan area that is importantly warmer than its neighboring rural areas. The higher urbanization leads to added distinct UHI with enormous temperature differences between urban and rural areas. The idea of UHI was firstly described by Howard in 1833, and since then this research theme has received increasing attentions (Detwiller, 1970; Fukui, 1970; Katsoulis, 1985; Wang, et al., 1990; Kim, 1992; Lee, 1993; Johnson, et al., 1994; Tso, 1996; Camilloni and Barros, 1997; Chen et al., 2009). The study on the UHI incident by satellite image derived by Land Surface Temperature (LST) measurements have been carried out by some researchers, mainly by using NOAA AVHRR data (Streutker, 2002, 2003) for urban temperature mapping in local scale. Recently, Landsat Thermatic Mapper sensor (TMs) and Enhanced Thermatic Mapper sensor Plus (ETMs+), Thermal Infrared sensor (TIR) data with resolutions (60 meter and 120 meter), particularly, have been utilized for local scale mapping studies of UHI (Weng, 2001; Chen et al., 2002). Research on LST illustrated that the dividing sensible and latent heat fluxes and thus surface radiant temperature response was resulted by varying surface soil water content and vegetation cover (Owen, et al., 1998). This finding encourages research on the association among LST and vegetation abundance (Gallo et al., 1998a, 1998b, Hawkins et al., 2004). The UHI intensity is related to patterns of Land Use / Land Cover Changes (LULCC), such as the composition of vegetation, water and built-up areas and change detection. The result of rural variability has been used for the calculation of UHI outcome (Tian and Xiangjun, 1998). The qualitative research on the connection between LULC pattern and LST will help us in LC planning. It is known that various vegetation indices obtained from remote sensing data can be used in the measurement of vegetation cover qualitatively and quantitatively (Purevdorj, et al., 1998; Chen, et al., 2002). The relations with various vegetation indices and percent vegetation cover have been created by using regression analysis (Wang et al., 2004), e.g. Normalized Difference Vegetation Index (NDVI), Difference Vegetation Index (DVI) and Perpendicular Vegetation Index (PVI).

The NDVI is used for estimation of vegetation production and precipitation in semiarid areas (Streutker, 2002; Chen et al., 2004), while the Normalized Difference Water Index (NDWI) can be used for the determination of Vegetation Water Content (VWC) under the physical principles (Gao, 1996). Although NDVI has limited capability for estimating VWC Ceccato, et al., 2002), it is ideal to integrate NDVI and NDWI to represent the state of vegetation. Zha et al. (2003) has developed the Normalized Difference Built-up Index (NDBI) to classify urban and built-up areas. The utilization of NDVI, NDWI and NDBI could represent Land Cover types quantitatively so that the relationships between different indices, such as NDVI, NDWI, NDBI, and temperature can be established in UHI studies. The objective of this study was to integrate of satellite data and knowledge based methods. In addition, the NDVI and NDBI was extracted LULC information from Landsat-5 TM images of two time periods (2006 and 2009) by using supervised classification of UHI, based on high-quality data from SMS.

2. The study areas and data usage

2.1. The study areas

The study areas consist of Kantarawichai district, Mahasarakham province, and northeast of Thailand (Figure 1).

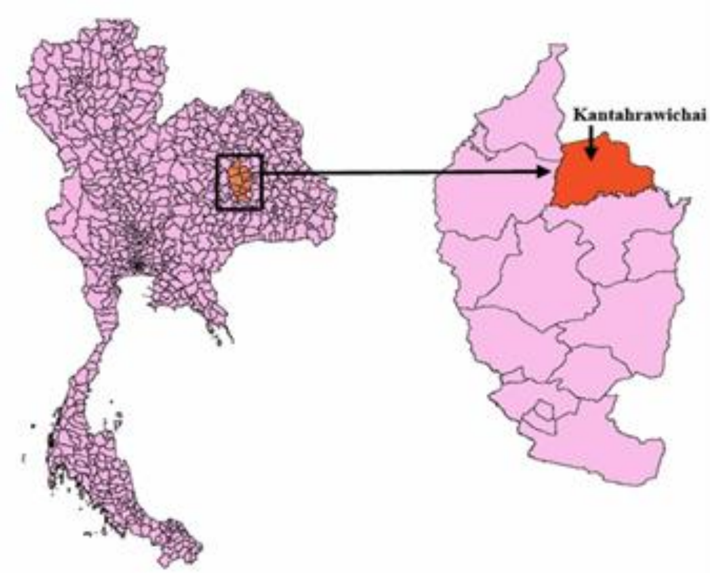


Figure 1. The Study area

2.2. Data usage

2.2.1. Satellite data and related data

- Landsat 5 –TM dataset acquired in 2006 and 2009 (from "Geo-Informatics and Space Technology Development Agency" - GISTDA).
- L7018 Series of topographic map at scale 1:50000 (from "Royal Thai Survey Department" - RTSD).
- LULC mapping in 2006 – 2009 (from "Land Development Department" - LDD).
- GIS database i.e. topography, administrative boundary in Amphoe and Tumbon (from "Land Development Department" - LDD).

2.2.2. Land Surface Temperature (LST)

LST data was acquired from Solar-radiation Measurement Station (SMS) located in Mahasarakham University, Mahasarakham Province, Thailand (Figure 2). The data from SMS has been verified in accordance with the International Daylight Measurement Program (IDMP) by the Commission International de l' Eclairage (CIE) (Pattanasethanon et al., 2007). The data on Global Horizontal Irradiance (GHI) and Diffuse Horizontal Irradiance (DHI) was taken in W/m^2 units; therefor it is necessary to be convereted into "mW/cm^{-2} sr^{-1} μm^{-1}" units.

Figure 2. Solar-radiation measurement station (SMS)

3. Methodology

Three broad sets of activities have been done as follows (Figure 3): 1) LULC Supervise classification, 2) knowledge-based detection method (LST, NDVI and NDBI), and 3) UHI and comparison result in 2006 and 2009.

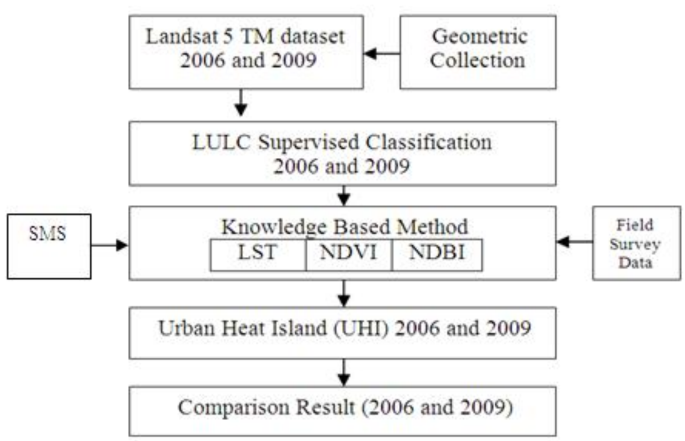


Figure 3. Flowchart of the study

3.1. LULC supervised classification

The spectral property of the training sets along with previous knowledge, as well as the data from field studies and higher resolution images were combined to perform a supervised classification. In this research dataset from Landsat 5- TM was interpreted straight to LULC in 5 classes as follows; (F) Forest, (W) Water body, (U) Urban, (P) Paddy field, and (C) Crop field. Figure 4 illustrates sample training area of water and sample training area of forest.

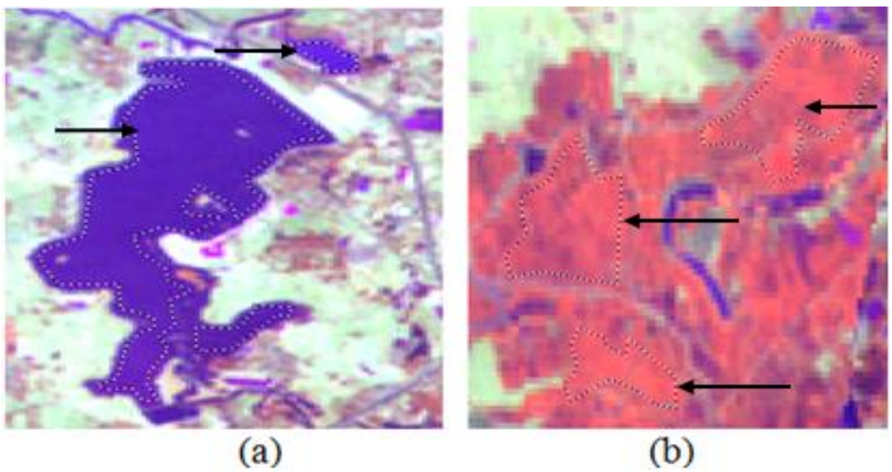


Figure 4. illustrate (a) sample training area of water and (b) sample training area of forest

3.2. Application of knowledge based method

3.2.1. Land Surface Temperature (LST)

LST is an important factor for the determination of several biophysical parameters and processes. It enables monitoring of surface energy fluxes, particularly evapotranspiration (Stisen et al., 2008; Tang et al., 2010) e.g. LST controlled through the surface energy balance, atmospheric state, thermal properties of the surface, and subsurface mediums, are important factors controlling most physical, chemical, and biological processes of the Earth (Becker and Li, 1990). The radiation that reaches the earth's surface can be represented in a number of different ways. Global Horizontal Irradiance (GHI) is the total amount of shortwave radiation received from above by a horizontal surface. Diffuse Horizontal Irradiance (DHI) is the amount of radiation received per unit area by a surface that does not arrive on a direct path from the sun, but has been scattered by molecules and particles in the atmosphere and comes equally from all directions. In this work, retrieval of brightness temperature from the Landsat-5 TM data (digital number: DN) of band 6 are converted to radiation luminance (RTM6, mW $cm^{-2}sr^{-1}$) by using the below formula (Zhao and Chen, 2005).

$$R_{TM6} = (R_{max} - R_{min}) / 255 * DN + R_{min} \quad (1)$$

$$R_{TM} = m * DN + d \quad (2)$$

3.2.2. Normalized Difference Vegetation Index (NDVI)

The Normalized Difference Vegetation Index (NDVI) is a simple graphical indicator that can be used to analyze remote sensing measurements, typically but not necessarily from a space platform, and assess whether the target being observed contains live green vegetation or not. In this study, NDVI was computed for each pixel using the following equation:

$$NDVI = (Band\ 4 - Band\ 3) / (Band\ 3 + Band\ 4) \quad (3)$$

where Band 3 = Red = 0.63- 0.69 μm, Band 4 = Near-Infrared – 0.76-0.90 μm.

3.2.3. Normalized Difference Built-up Index (NDBI)

The original NDBI approach developed by (Zha et al., 2003) was implemented as three arithmetic manipulations of Landsat-5 TM bands 3–5, followed by recoding. This study used Landsat-5 TM (RGB 4 5 3) based on the below equation:

$$NDBI = (Band\ 4 - Band\ 3) / (Band\ 3 + Band\ 4) \quad (4)$$

where Band 3 = Red = 0.63- 0.69 μm, Band 4 = Near-Infrared = 0.76-0.90 μm.

4. Result

4.1. LULC classification

The LULC classification by using supervised classification on 5 classes in 2006 was shown in Figure 5 and 2009 was shown in Figure 6.

4.2. Knowledge Based Method Result

4.2.1. Calculate result of LST

The calculate result of LST from GHI and DHI on 2006 and 2009 are shown in Table 1. The average result of MAX, MIN, MEAN and STD from each year calculated by coefficient correlations method is shown in Table 2 and Table 3.

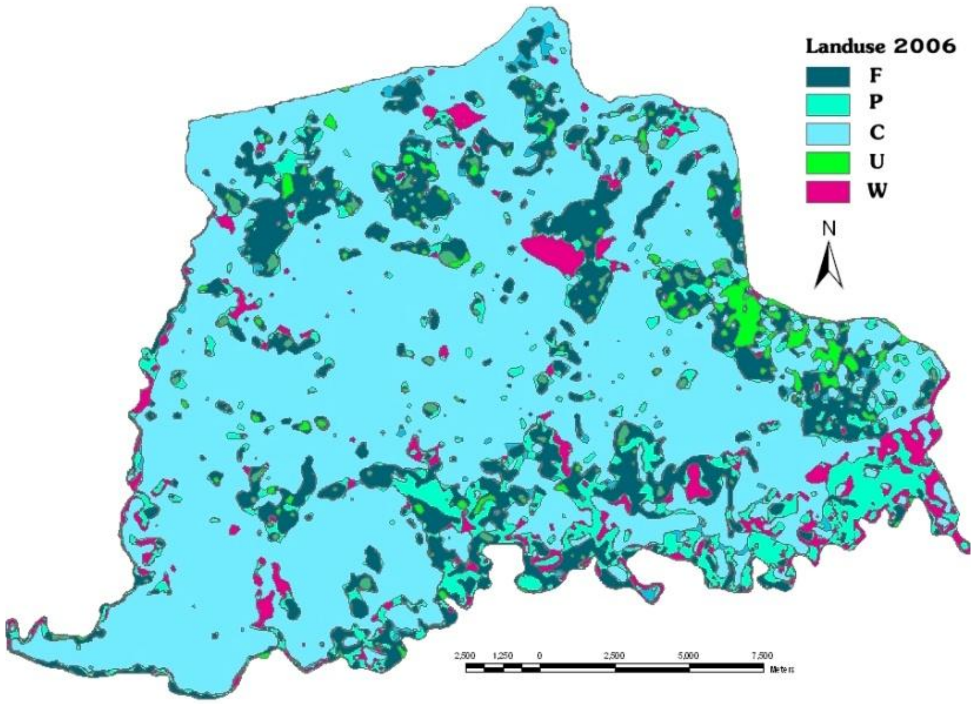


Figure 5. LULC classifications on 2006

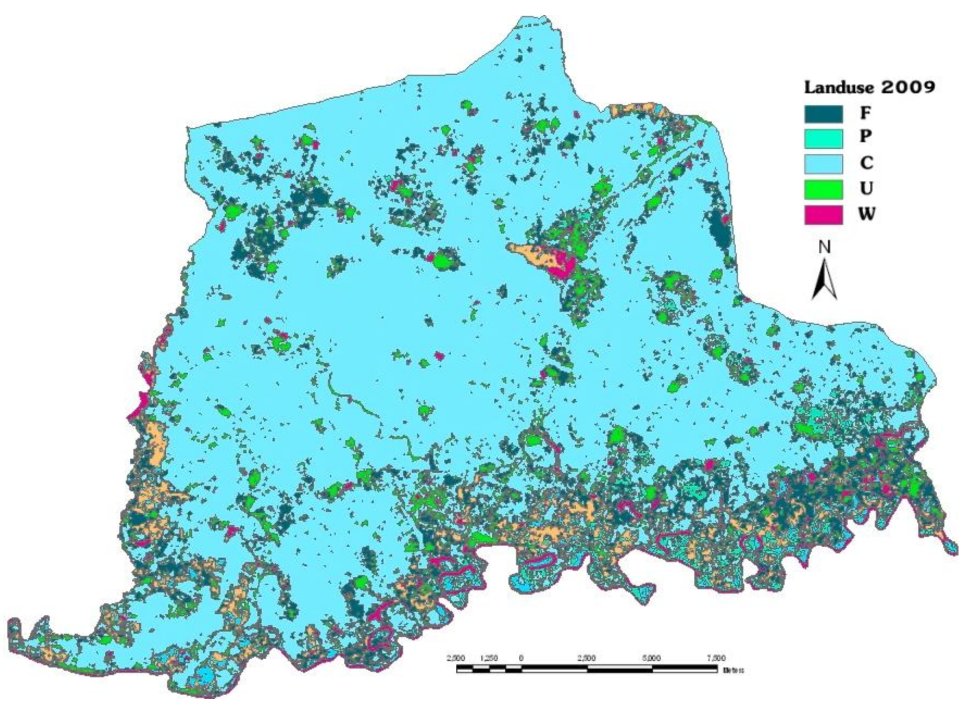


Figure 6. LULC classifications on 2009

Table 1. GHI and DHI (average annual in yearly)

Year	GHI (mW / cm^{-2} sr^{-1} µm^{-1})	DHI (mW / cm^{-2} sr^{-1} µm^{-1})
2006	0.7767486	0.27778590
2009	0.8641163	0.03629537

Table 2. MAX, MIN, MEAN and STD (2006)

2006	MIN	MAX	MEAN	STD
NDBI	-0.84615400	0.49425300	0.0196565	0.1190310
NDVI	-0.45454500	0.69512200	0.3290480	0.1307610
SRT (GHI)	112.479134	114.409615	2.2239470	15.693694
SRT(DHI)	38.4823190	38.7289960	0.7588080	5.3546650

Table 3. MAX, MIN, MEAN and STD (2009)

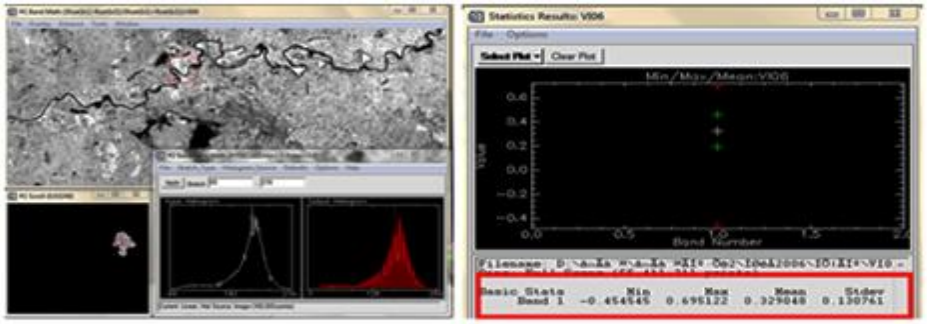
2009	MIN	MAX	MEAN	STD
NDBI	-0.80952400	0.57466100	0.209066	0.1546700
NDVI	-0.50000000	0.63964000	0.167996	0.1240230
SRT(GHI)	103.041656	108.078979	2.072586	14.692989
SRT(DHI)	4.33420900	4.34002500	0.084632	0.5999670

4.2.2. Calculate result of NDVI

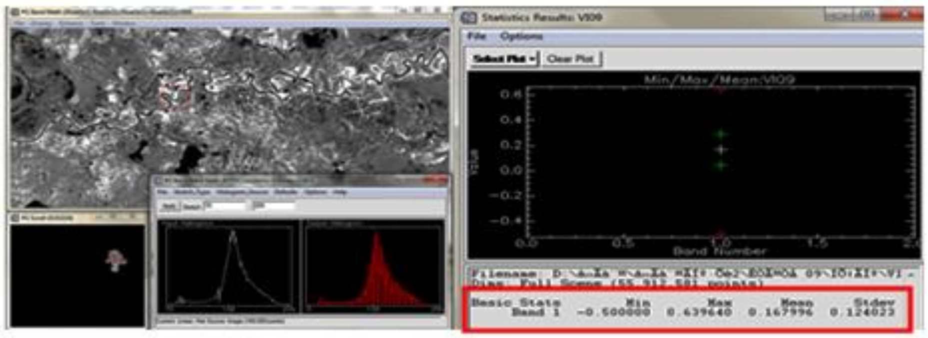
We used ENVI 4.xx software for calculation result of NDVI. The result shown in Figure 7 (a) is NDVI on 2006 (in the red box was shown; MIN, MAX, MEAN and STD), and Figure 7 (b) shows NDVI on 2009 (in the red box was shown; MIN, MAX, MEAN and STD).

4.2.3. Calculating the result of NDBI

By using ENVI 4.xx software for calculations, the result of NDBI was obtained and is shown in Figure 8 (a) NDBI on 2006 (in the red box was shown; MIN, MAX, MEAN and STD), and Figure 8 (b) shows NDBI on 2009 (in the red box was shown; MIN, MAX, MEAN and STD).

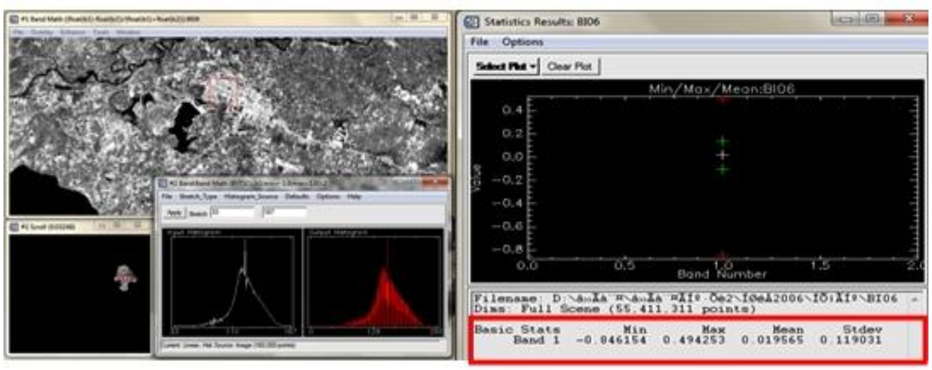


(a)

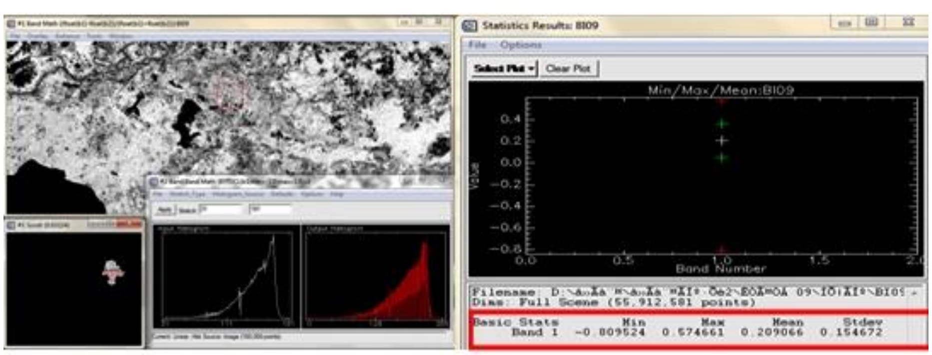


(b)

Figure 7. illustrate NDVI (a) in 2006, (b) 2009



(a)



(b)

Figure 8. illustrate NDBI (a) in 2006, (b) 2009

The study for 2006 showed that the relationship between LST and NDVI has an average value of -0.133749929 mW/cm^2, and LST with NDBI have average value of -0.56429509 mW/cm^2. Calculation for defining the relation of NDVI with NDBI showed an average value of 0.873654799 mW/cm^2. The study for 2009 showed that the relationship between LST and NDVI has an average value of -0.060820953 mW/cm^2, LST and NDBI indicated an average value of -0.544705705 mW/cm^2, and the calculation of the relation between NDVI with NDBI showed an average value of 0.873654799 mW/cm^2. Calculating the relation between NDVI with NDBI showed an average value equal to 0.86657639 mW/cm^2. In this case, it was found that LULC was changed (2006 and 2009). In addition, LULC change showed the increase in the NDVI and the decrease of the NDVI.

5. Conclusion

Landsat- 5TM data were found to have great potentials for analysis and monitoring of UHI phenomenon. Based on this study, a formula has been used to determine the LST for LULC changes in growing communities with UHI conditions. The calculation of LST (2006and 2009) showed that changes to the distribution of radiation increases, at the year 2006with an average Global Horizontal Irradiance (GHI) is 0.00063785 mW/cm^2 It can be compared with the year 2009which showed the distributions of radiation increases with the average value of 0.00124935mW/cm^2. The Diffuse Horizontal Irradiance (DHI) was shown to be 0.000663722 mW/cm^2, in average. It can be compared to the results related to the year 2009 which showed the distributions of radiation increases equal averagely to 0.00077502 mW/cm^2. When comparing the relationship of LST and NDBI during the period from year 2006 and 2009 in the study area, it was found a higher value for NDBI. Comparison between GHI and DHI illustrates the higher values of LST, because it has a higher temperature when the NDBI value is in highest level. Moreover, it was found that when the LST and NDBI are in highest level, the NDVI value was reduced. The LST value is higher because of additional construction and growth of the human community.

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