WALAILAK JOURNAL
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Intensity and Pattern of Land Surface Temperature in Hat Yai City, Thailand

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Received: 15 January 2014, Revised: 5 May 2014, Accepted: 2 June 2014

Abstract

Land Surface Temperature (LST) is an important factor in global climate. LST is governed by surface heat fluxes, which are affected by urbanization. In order to understand urban climate, LST needs to be examined. This study aimed to investigate the intensity and pattern of LST and examine the relationships between LST and the characteristics of urban land use, indices, and population density in Hat Yai City. Landsat 5TM images were used for interpretation of land use characteristics and derivation of LST, normalized difference built-up index (NDBI) and normalized vegetation index (NDVI). The characteristics of land use were classified into 4 types: commercial/high density residential, medium density residential, minimum density residential and vegetation cover/park. The average maximum and minimum LST derived from Landsat 5TM were 25.9, 33.7 and 15.8 °C, respectively. The areas with high LST were located principally in central built-up areas, slightly northwest-southeast of the study area, including the commercial center and the newly expanded residential areas. The LST pattern was well related to land use types and population density. The relationship between LST and NDVI however portrayed negative correlation, while that between LST and NDBI highlighted a positive correlation. It is concluded that NDVI and NDBI can be used to evaluate the risk of Urban Heat Island (UHI) and may help city managers better prepare for possible impacts of climate change.

Keywords: LST, NDVI, NDBI

Introduction

Rapid urbanization has led to a significant increase in the number of urban citizens worldwide. Recent research reported about 65 % of the world's population will live in urban areas by 2025 [1]. Significant growth of urban areas will also transform the natural landscape to an impervious surface that will result in the reduction of green spaces [2-4] and, consequently, an increase in surface temperature.

The results of a land surface temperature (LST) study play a significant role in both environmental management [5] and urban climate studies [6]. LST results serve as an important indicator of chemical, physical and biological processes of the eco-system [7]. LST reflects the influence of surface radiation and energy exchange [8]. It is influenced by various urban surface properties such as color, surface roughness, humidity, and chemical composition, etc [9].

Some urban discomforts such as an urban heat island (UHI) depend to a certain degree on the alteration of LST in the urban areas and the rural counterparts [10-13], where the built environments including thermodynamic capacities of materials, structural geometry, and heat generating activities cause increased heat storage and re-radiation to the atmosphere [12]. Today, UHI has become important due to the rising population in cities. In addition, the UHI has important implications for human comfort and health, urban air pollution, energy management and urban planning [14]. Higher temperatures not only affect the comfort of urban dwellers, but also increase energy consumption, ozone production, and the risk of death for humans in a heat wave. Several studies reported a number of factors that contribute to the occurrence and intensity of heat islands; these include weather, geographic location, time of day and season, land cover and city layout [15,16]. Moreover, UHI intensity tends to increase when the size of either a city or population grows [17]. However, urban green space can slow down the UHI effect. Numerous studies show that urban green space is least 2 °C cooler, compared with a town covered with concrete and asphalt surface [18].

Studies on UHI occurrence with remote sensing data have been accompanied primarily using satellite thermal images from Landsat [19,20]. Regarding UHI indices for local scale studies, the normalized vegetation index (NDVI) [21], normalized difference built-up index (NDBI) [22,23] and land surface temperature (LST) were used to monitor the UHI. These indices can be developed using remote sensing data [22], various satellite image data sources, Landsat Thematic Mapper (TM), Enhanced Thematic Mapper Plus (ETM+) and thermal infrared (TIR) data with 120 and 60 m spatial resolutions, respectively. They were utilized for local-scale studies of UHI [24,25].

Many researchers studied the intensity of UHI using calculations and investigated the relationship between LST and indices such as NDVI and NDBI; for example, Srivanit *et al*. [26] studied the impact of urbanization on the thermal environment in Metropolitan Bangkok by using a derivation of LST and NDVI. They found that UHI is related to patterns of land use/cover changes (LUCC) e.g., the composition of vegetation, water and built-up areas [26]. In the metropolis of Tianan, Sun *et al*. [27] investigated the relationship between urban greenery and the thermal environment. They studied the average surface temperature (ST) to calculate surface urban heat island intensity (SUHI). The result of regression analysis showed an obvious relationship between NDVI and UHI [27]. Liu and Zhang [28] studied the spatial pattern of LST in Hong Kong, they retrieved data that characterized LST on their local urban heat island. The result showed that the green land can weaken the effect on UHI [28].

Hat Yai City is the center of commercial activity and tourism in Southern Thailand. Many tourists travel in this area. Furthermore, the increasing built-up area tends to raise the urban temperature, but there seems to have been no investigation on LST in this area before. This study attempts to derive intensity and the spatial pattern of LST and the relationships between the intensity of LST and the urban surface characteristics and indices. The results can be used as a scientific basis for decision making for mitigating climate change and environmentally friendly urban planning.

Study area

Hat Yai City and its vicinities are located at 7°1′N 100°28′E, near the Thai-Malaysian border. It has a population of 203,035 in the city and about 800,000 in the greater Hat Yai area. Hat Yai is the largest city in Songkhla Province, and is the largest metropolitan and economic center of the lower part of southern Thailand. The city has a tropical climate, which is hot and humid, with 2 seasons, wet and dry. The wet season, which is influenced by monsoon and rain storms, starts from May and lasts until December; the dry season is from January to April (**Figure 1**).

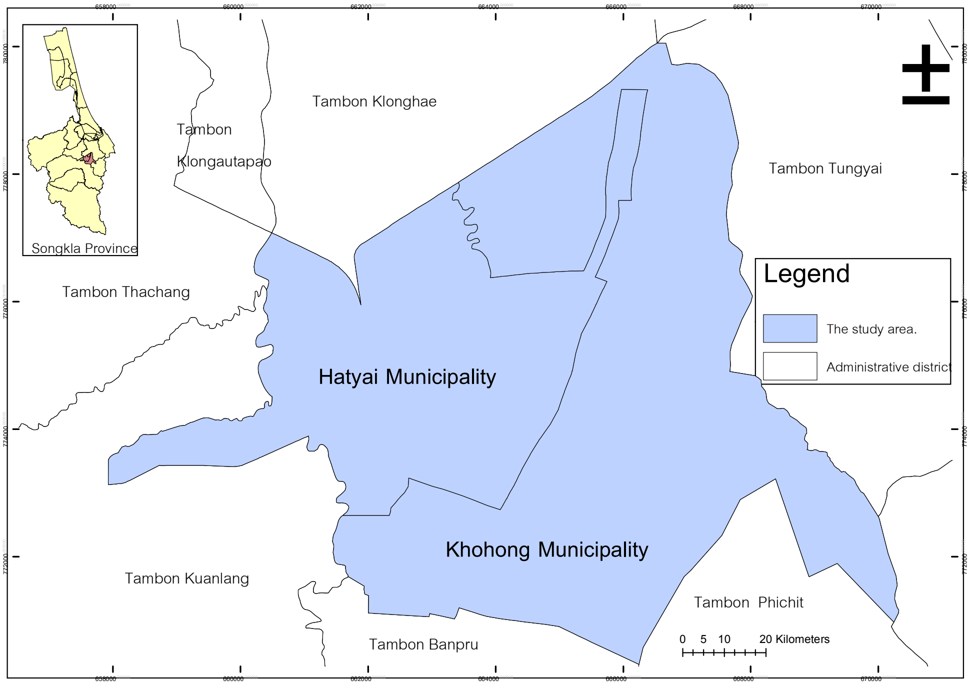

Figure 1 Study area.

Materials

Landsat 5 TM has 6 spectral bands with a resolution of 30 m, and one thermal infrared band with a resolution of 120 m (**Table 1**) [20]. Bands 1 - 5 and 7 were used for land use classification, NDVI and NDBI, while band 6 was used for LST extraction.

Table 1 Spectral bands of Landsat 5TM Sensor.

Band	Spectral range	Wavelength (µm)
1	Visible	0.49
2	Visible	0.56
3	Visible	0.66
4	Near Infrared	0.83
5	Mid-Infrared	1.65
6	Thermal Infrared	11.475
7	Mid-Infrared	2.22

Methods

The studies of LST, land use, NDVI and NDBI have been applied using Landsat 5 TM data. Several remote sensing data processing methods were utilized in order to carry out this study: image classification and temperature retrieval. The methodology is described in **Figure 2**.

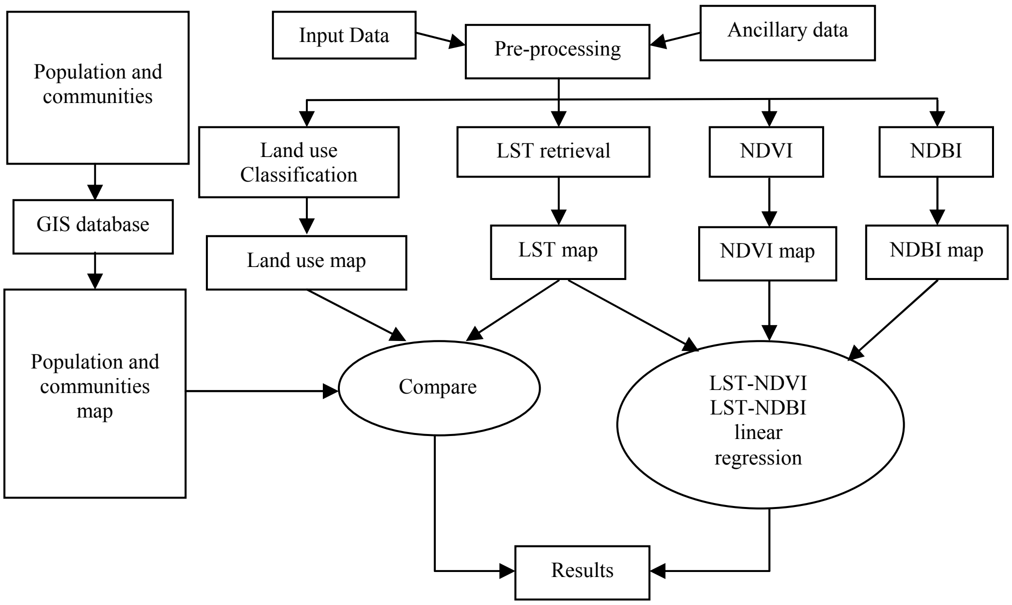

Figure 2 Methodology workflow.

Image pre-processing

Landsat 5 Thematic Mapper (TM) images of Hat Yai City, acquired on March 5, 2010, was geo-referenced to a common UTM coordinate system based on a rectified high resolution aerial photograph and 1:50,000 scale topographic maps. Using the radiometric correction method of Schroeder *et al*. [29], images of the original digital numbers of bands 1 to 5 and 7 were converted to at-satellite radiance, at-satellite reflectance, and then to surface reflectance.

Image classification

The study of land use was preceded by the interpretation of Landsat 5 TM resolution 30×30 m images acquired in 2010. According to the study, the land use in the study area could be classified into 4 types: (1) commercial/high density residential, (2) medium density residential, (3) minimum density residential and (4) vegetation covered/park.

Derivation of land Surface temperature (LST)

The Landsat Thematic Mapper (TM) sensors acquired temperature data and stored this information as a digital number (DN) with a range between 0 and 255. The thermal infrared band (10.4 - 12.5 μm) data were utilized for retrieving LST; the procedures can be simplified into three steps as follows:

Step 1: Generation of the digital number (DN) to TOA (Top of atmospheric) radiance

Landsat TM thermal infrared band data were used to derive the LST using Eq. (1) [30];

$$L_\lambda = \frac{L_{max} - L_{min}\,(DN - QCAL_{min}) + L_{min}}{QCAL_{max} - QCAL_{min}} \tag{1}$$

where L_λ is the TOA radiance at the sensor's aperture in W/(m^2sr μm), $QCAL_{max}$ (255) and $QCAL_{min}$ (0) are the highest and the lowest points of the range of rescaled radiance in DN, L_{min} and L_{max} are the TOA radiances that were scaled to $QCAL_{min}$ and $QCAL_{max}$ in W/(m^2srμm).

Step 2: Conversion of TOA radiance to temperature in Kelvin

Then the effective at-satellite temperature of the viewed Earth-atmosphere system under the assumption of a uniform emissivity could be obtained from the above spectral radiance with Eq. (2) [31];

$$T = \frac{K_2}{\ln(K_1/L_\lambda + 1)} \tag{2}$$

where T is the effective at-satellite brightness temperature in Kelvin; K_1 = 607.76 (W/m^2srμm) and K_2 = 1,260.56 (Kelvin) were calibration constants; and L_λ is the TOA radiances in W/m^2srμm.

Step 3: Conversion of Kelvin to Celsius

$$T_C = T_K - 273.15 \tag{3}$$

where T_C is the temperature in Celsius; T_K is the temperature in Kelvin.

Derivation of NDVI and NDBI from Landsat 5TM

The normalized difference vegetation index (NDVI) was used to identify vegetation in the study area. The NDVI is a measure of the amount of vegetation at the surface [4,32]. The value of NDVI varied between −1 and +1. NDVI that were obtained as Eq. (4) [27].

$$NDVI = NIR - R / NIR + R \tag{4}$$

where R = red color bands; NIR = Near Infrared Reflectance.

The normalized difference built-up index (NDBI) was used to identify built-up areas. The NDBI is sensitive to the built-up area and it was determined as Eq. (5) [28].

$$NDBI = MIR - NIR / MIR + NIR \tag{5}$$

where NIR = Near Infrared Reflectance; MIR = Mid Infrared Reflectance.

GIS database of population and number of communities

The population and number of communities data in 2013 was obtained from Hat Yai Municipality and Khohong Municipality. After that, the data file was converted to a GIS data layer by ArcGIS 9.3.

Results and discussion

Intensity and pattern of LST

The LSTs investigated using Landsat 5 TM thermal images, acquired on March 5, 2010, are shown in **Figure 3** with an average temperature of 25.9 °C ± SD 1.95, a maximum temperature of 33.7 °C and a minimum temperature of 15.8 °C. The LST intensity was estimated as the difference between urban areas' temperature and that of surrounding areas. The pattern of LST was well distributed in accordance with the built-up areas in the middle, slightly in the northwest-southeast direction of the study area. These included commercial centers and newly expanding high density residential areas (**Figure 3**).

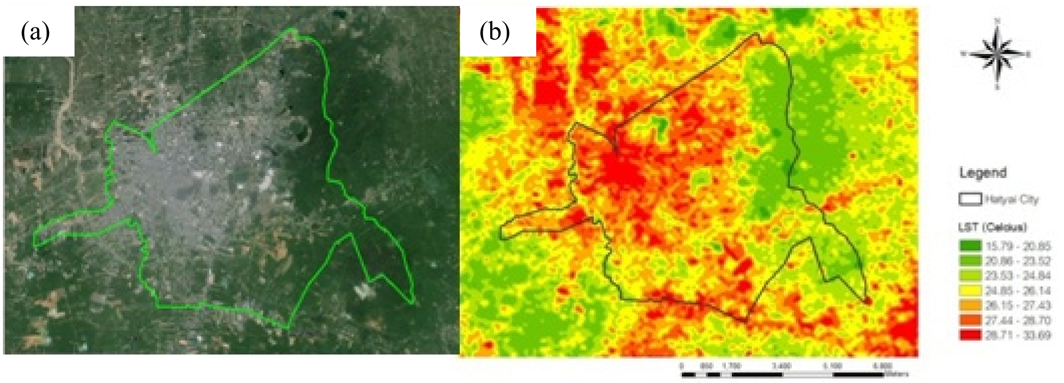

Figure 3 Spatial distribution pattern of (a) land use types from Google Maps and (b) LST intensity in Hat Yai city from the Landsat 5 TM images.

The relationship between LST and land uses

Differences in LST reflected the impact of land use on the thermal environment [26]. In this study, LST distribution corresponded relatively well to different land use types, which can be seen by comparing land use with temperature maps (**Figure 3b**) and **Table 2**.

Table 2 LST of different land use types.

Land use types	Max (°C)	Min (°C)	Mean (°C)
Commercial/high density residential	33.7	26.6	29.1
Medium density residential	30.0	24.4	27.6
Minimum density residential	29.1	19.0	26.0
Vegetation covered/park	26.6	15.8	24.6

The results of LST analysis, as shown in **Table 2**, indicated that the LST varies with land use types. The results of the commercial/high density residential areas analysis exhibited the highest land surface temperature, followed by the medium density residential, minimum density residential and vegetation covered/park area. It was clear that impervious surface areas were warmer than vegetation covered areas.

The urban heat island intensity of commercial/high density residential area increased by 1.4 to 4.5 °C, compared to the vegetation covered/park area. Because Hat Yai city is the commercial center of the South, there are an increasing number of immigrant laborers and immigrants from nearby southern provinces; these numbers include immigration caused by unstable political situations [33]. Urban fringe development rapidly expanded in the northwest with dense low-cost residential housing. Moreover, the areas with high density population and covered with impervious surface contributed to the urban heat island intensity.

The relationship between LST and population

Apart from the main campus area of Prince of Songkla University on the eastern part of the city, a large part of which is still covered by plants, the LST distribution (**Figure 4b**) tends to follow the population density (**Figure 4a**).

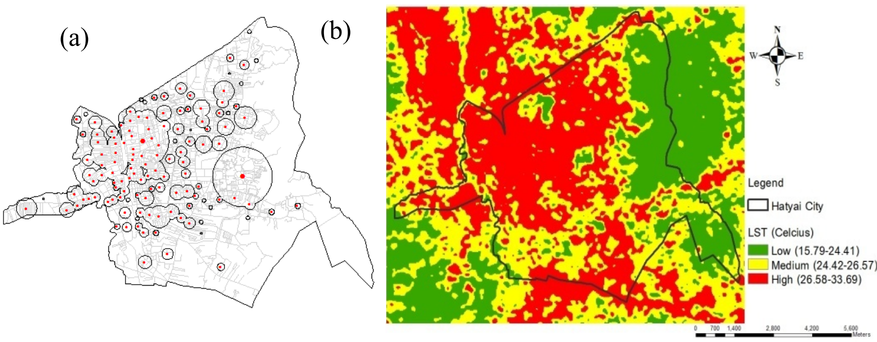

Figure 4 The densely populated zone compared the LST pattern.

Figure 5 shows the relationship between communities and LST distribution and that more than 88.5 % of the 139 communities in Hat Yai face high temperatures (**Table 3** and **Figure 5**).

Table 3 Number and percentages of communities compared with LST.

Land surface temperature	No. of communities	Percentages (%)
High	123	88.5
Medium	11	7.9
Low	5	3.6

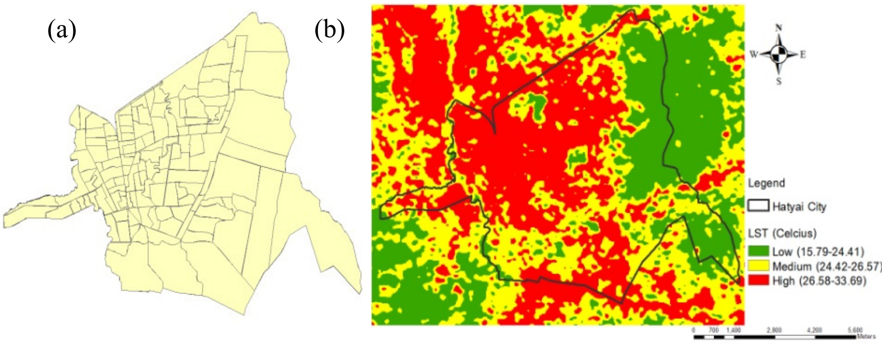

Figure 5 The zone of communities (a) compared the LST pattern (b).

Correlation between LST and indices (NDVI and NDBI)

NDVI was used as an indicator of vegetation abundance and was then used to estimate LST [34]. Previous studies showed that urban green spaces play an important role in increasing the moisture content in the air and reducing the urban air temperature [35]. The study of relationships between temperature and vegetation were frequently investigated using the NDVI [27]. The results showed that the value of NDVI was located between −0.71 and 0.79. The high value of NDVI was distributed in the east, north, and northeast, where mostly rubber plantations and Hat Yai city park areas are located. The low value of NDVI was mainly located in urban and dense residential areas with less vegetation coverage (**Figure 6**).

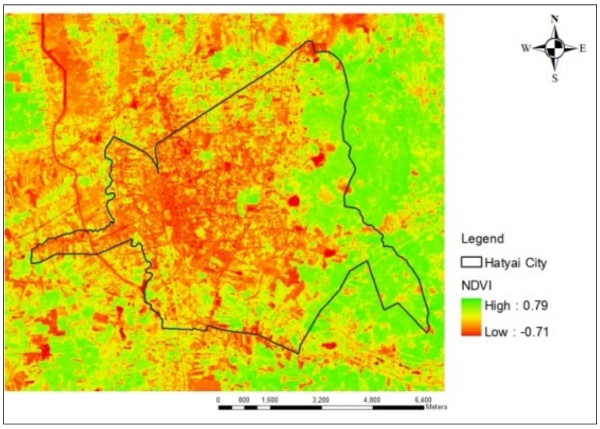

Figure 6 NDVI map of Hat Yai city.

Regarding the relationship between NDVI and LST, scatter plots are shown in **Figure 7**. The regression models yielded meaningful explanations in which NDVI was negatively correlated with surface temperature (**Figure 6**). The results indicated that the vegetation covered areas can weaken the effect of LST.

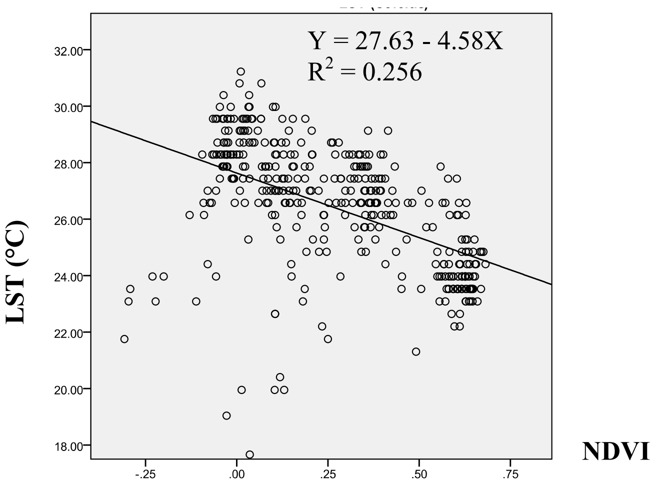

Figure 7 A regression model of LST and NDVI of Hat Yai city.

On the other hand, using the value of NDBI located between 0 and 255, the high value of NDBI was distributed in the central areas of city center which is dominated by buildings and hardened surfaces, high building density, and was low along the east and northeast outskirts (**Figure 8**).

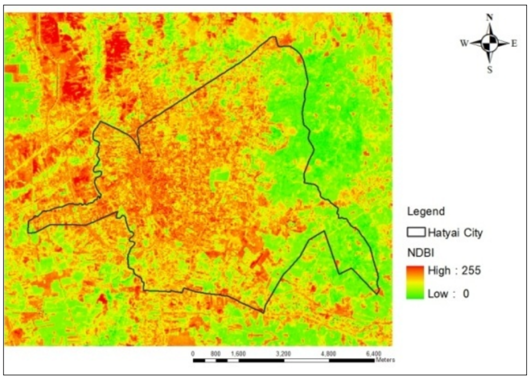

Figure 8 NDBI Map of Hat Yai city.

In addition, to explore the relationship between NDBI and LST further, scatter plots were drawn in **Figure 9**. The regression models yielded meaningful explanations in which NDBI was positively correlated with temperature (**Figure 9**). The results indicated that the building cover area can strengthen the effect of LST [27,28].

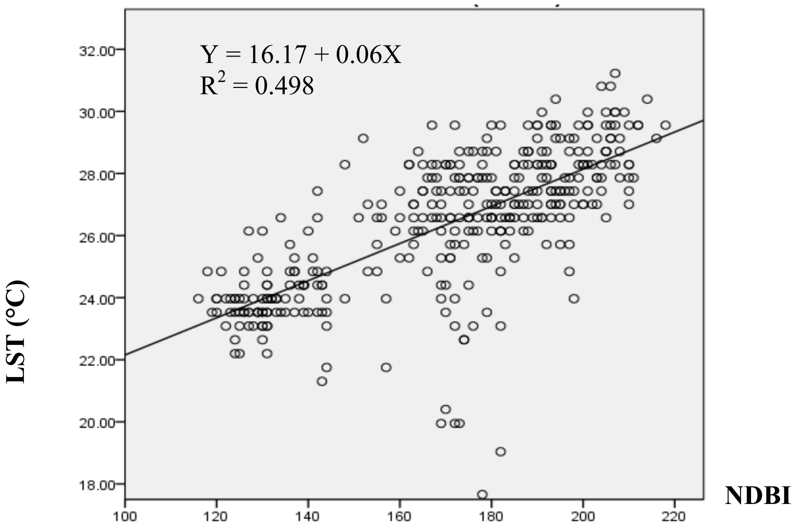

Figure 9 A regression model of LST and NDBI of Hat Yai city.

Conclusions

This study investigated the LST pattern which corresponded relatively well to the land cover types. The areas with impervious surfaces, high population density and human activities revealed high land surface temperature intensity. Higher temperatures are common in areas under development or recently developed. The higher LST was distributed around the city in the densely built-up areas. On the other hand, the low value of NDVI was mainly located in urban and high density residential areas with less vegetation coverage. Generally, the urban areas exhibited smaller NDVI values than non-urban areas, which declined in NDVI with an increased level of urban development, and with a consistent decrease in the mean NDVI as the mean of NDBI and LST increases. The factors affecting the land surface temperature intensity were rather diversified and complicated depending on meteorological conditions, time, geographical features, city size, and land use. Additionally, the presence of green spaces made important contributions to the regulation of city climate, and green spaces increased humidity in the air and decreased the temperature, thus improving the air quality. Also correlation studies showed that the LST is negatively correlated with NDVI. This finding assists in monitoring and mitigating the urban climate.

Finally, the application of remote sensing and GIS technology is an effective approach to monitoring and analyzing land use characteristics and LST. LST, NDBI and NDVI indices can be used to predict spatial characteristics of the UHI and could be applied further to the establishment of environmentally friendly urban planning.

Acknowledgements

The authors would like to thank Hatyai University and Prince of Songkla University for financial support.

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