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Air Temperature Estimation from Satellite Remote Sensing to Detect the Effect of Urbanization in Jakarta, Indonesia

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Abstract
This study demonstrated the application of Landsat imaging for estimating land surface temperature (LST; T_s) and air temperature (T_a) in Jakarta, Indonesia, using the observed relationship between T_s and T_a. The use of satellite remote-sensing data can help overcome the spatial problem of estimating T_a, particularly in areas with low station density, using satellite-based T_s estimation and ground-based relationships between T_s and T_a. T_s values were obtained from Landsat images taken in 1989 and 2006. The Landsat images were compared with ground-based measurements obtained in 2012. The results showed a strong correlation between Landsat T_s and ground-based T_s measurements ($R^2 = 0.79$) which indicated the reliability of this approach to represent actual T_s values. To understand the relationship between T_a and T_s using satellite imagery in both years, a statistical approach was applied. The range of the determination coefficient (R^2) between T_a and T_s in ground-based measurements was $R^2 = 0.77$ in Landsat. This result demonstrating the usefulness of T_s as an indicator of T_a estimation in Jakarta by using image satellite.

Keywords: air temperature; land surface temperature; satellite image; statistical approach; urban area

INTRODUCTION

Urbanization has various impacts on the environment. The population of Jakarta, the capital of Indonesia, was approximately 12 million in 2000, whereas it was only 5 million in the 1970s. In 2010, 43% of the Asia-Pacific population lived in urban areas of Jakarta (UN-ESCAPE, 2011). With the rapid increase in population, urban areas have also expanded rapidly within the past several decades. Present-day Jakarta and the extended zone surrounding it (Jakarta, Bogor, Tangerang, and Bekasi) cover a total of 7500 km^2 (Goldblum and Wong, 2000).

Numerous studies have indicated that urban expansion has caused localized increases in the air temperature (T_a) as shown by both long-term analysis of ground-based measurements (Goldblum and Wong, 2000; Kataoka et al, 2000) and analysis of satellite data (Jiang, and Tian, 2007; Rizwan, Leung, and Liu, 2008; Tursilowati et al., 2012). Heat islands degrade residential environments and increase the risk of heat-related illnesses and dengue; thus, temperature monitoring is an important issue. However, monitoring heat-island temperatures has proven to be difficult, requiring a dense network of observation sites to record T_a in various locales. As such, several studies have investigated the use of the land surface temperature (LST; T_s) readings derived from satellite data as an indicator of heat islands.

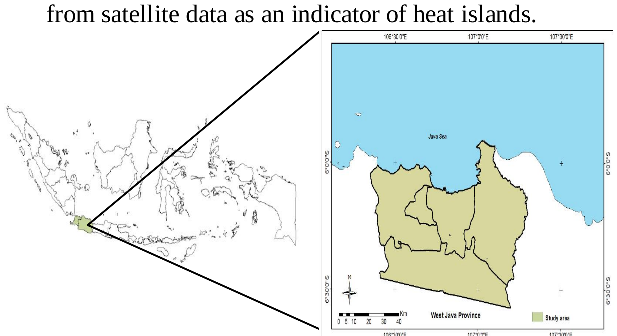

Figure 1. Study area in Jakarta, Indonesia, urban area

Thermal infra-red remote sensing data was commonly known as a source to determine the T_s from space. T_s originates from the balance between absorbed solar radiation and losses through sensible heat and latent heat fluxes as well as radiant emissions which governed by moisture content, surface type, wind velocity and emissivity. It was assumed that variability of the T_s affects T_a particularly in clear-sky days (Voogt and Oke, 2003). The objective of our study is to demonstrate the feasibility of Landsat T_S product as a source for calculating spatial distribution of T_a to detect urbanization effect in Jakarta city.

Air Temperature (T_a) trends from the 1950s to 2010 in Jakarta

Meteorological records

The daily average T_a time series was provided by the National Climatic Data Center (NCDC). Two stations were selected for the comparison of urban (Jakarta) and suburban (Bogor) areas. T_a, the near-surface air temperature, was measured 1.5–2 m above the ground, coinciding with weather station readings. Halim Perdanakusuma Airport or Jakarta Airport (the urban site) is located at S6°15'0", E106°54'0"; Atang Sanjaya (the suburban site) is located at S6°54'0", E106°32'60"

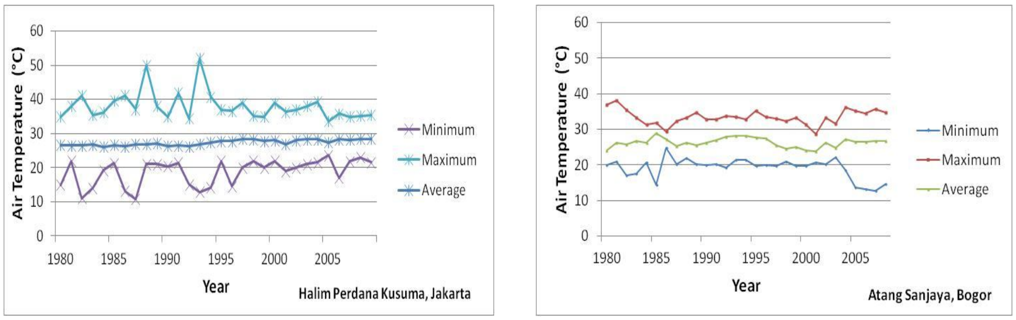

Figure 2. Time series of annual averaged daily minimum, maximum, and average temperature in (a) Jakarta (the urban area near Halim Perdanakusuma Airport) and (b) Bogor (the suburban area of Atang Sanjaya).

Figure 2 shows the time series of 1-year averaged daily minimum, maximum, and average T_a in Jakarta (at Halim Perdanakusuma Airport) and Bogor (Atang Sanjaya) during 1980–2010. The trend shows that the average and minimum T_a during the 1980s to 2000s increased in Jakarta, while the maximum T_a decreased. In comparison, the Bogor station showed a decreasing average, minimum, and maximum T_a over the same period. Table 1 shows the 10-year average daily T_a obtained from the Jakarta and Bogor stations. The daily average T_a increased over the 10-year period in Jakarta, and remained unchanged over the same time period for Bogor.

Table 1. Characteristics of air temperature (T_a) at selected stations

Year	Avarage	
	Jakarta	Bogor
1980-1990	26.65	26.29
1991-2000	27.72	26.73
2001-2010	28.02	26.55

METHOD

Land Surface Temperature (LST) Retrieval Method

Changes in the urban thermal environment resulting from urbanization should influence the LST, which is governed by land surface–atmosphere interactions and energy fluctuations between the atmosphere and the ground (Benali *et al*, 2012; Jim and Dickinson, 2010; Mildrexler, Zhao, and Running, 2005). LST can be used for remote-sensing thermal radiance measurements (Mildrexler, Zhao, and Running, 2005). To determine the LST trends in Jakarta, daily Landsat time-series data were used. Ground-based measurements of LST were also obtained for comparison.

Landsat thermal data using the thermal infrared (TIR) band can be used to determine the surface temperature (T_s) because the daytime satellite provides LST values that are much closer to the maximum daily temperature of the land surface, where the diurnal highest thermal response reflection occurs with respect to vegetation and dry surfaces ((Mildrexler, Zhao, and Running, 2005; Coops, Duro, Wulder, and Han, 2007). In this research, Landsat TM series data, acquired in May 1989 and July 2006, were used to investigate the urban thermal environment. This time series was chosen due to the absence of clouds over Jakarta. The procedure used to retrieve T_s was based on the Landsat 7 Science Data Users Handbook (Landsat User Handbook, 2011).

The satellite image, *DN*, must first be converted to a spectral radiance value, *L*, as follows:

$$L = (LMAX - LMIN)/255 \times DN + LMIN, \qquad (1)$$

where *DN* is the digital number reading, and *LMAX*, *LMIN* are derived from the gain status indicated by the satellite image header file. The spectral radiance value is then converted into a brightness temperature for the satellite sensor (T_b) using Eq. (2):

$$T_b = \frac{K_2}{\ln(\frac{K_1}{L} + 1)} \qquad (2)$$

where T_b is the effective satellite temperature in absolute temperature, K_1 and K_2 are calibration constants for the Landsat TM/ETM+ system, and L is the spectral radiance in W m^{-2} sr^{-1}µm. K_1 was set to 607.76, and K_2 was set to 1260.56 (Landsat User Handbook, 2011). The brightness temperature was determined by applying blackbody principles. Surface emissivity was considered in the estimation of T_s for the targets (Sobrino, Jimenez-Munoz, and Leonardo, 2003; Voogt and Oke, 2003; Tursilowati et al., 2012).

$$T_s = \frac{T_b}{1 + (\lambda \times T_b / \rho) ln\varepsilon} \tag{3}$$

where T_s indicates the LST in absolute temperature, λ is the wavelength of the radiance emitted (λ = 11.5 µm), ρ = (h × c) / σ = 1.438 ×10^{-2} (m K) , h is Planck`s constant (6.626 × 10^{-34} Js), c is the velocity of light (2.998 × 10^{8} m/s), σ is the Boltzmann constant (1.38 ×10^{-23} J/K), and ε is the composite emissivity. In this study, ε = 0.97 was used for the soil and vegetation (Sobrino, Jimenez-Munoz, and Leonardo, 2003).

Variations in LST Data

Figures 3(a) and (b) show the spatial distribution of the LST in the Jakarta urban area, derived from Landsat TM data obtained on 3 May 1989 and from TM data on 5 July 2006. A comparison with ground-based measurements was used to validate the estimated T_s values. The observation was carried out during 18–26 September 2012 at the same local standard time (10:00) at 35 sample points and with one point for the ground control measurement, located in the central urban site.

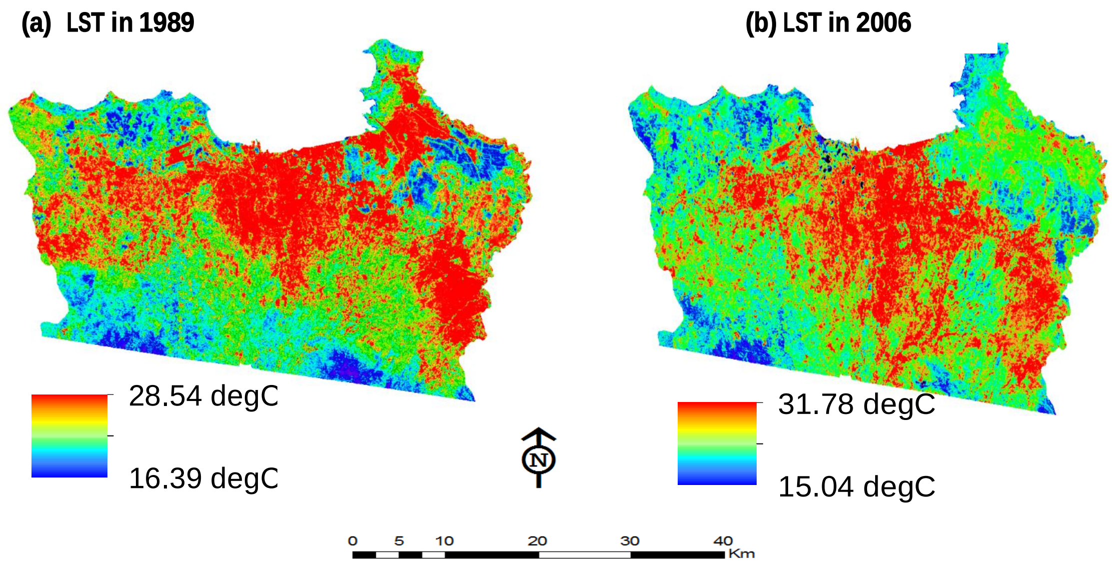

Figure 3. Spatial distribution of surface temperature (T_s) a Jakarta urban area in (a) 1989 and (b) 2006

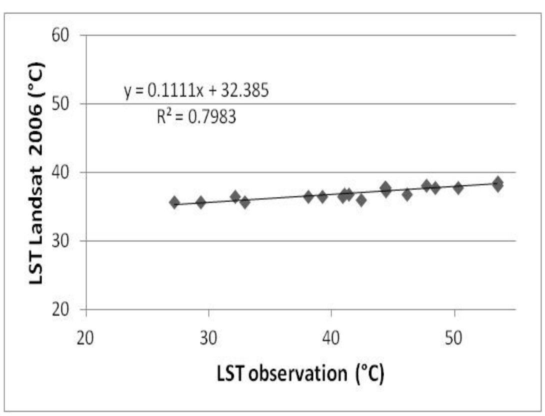

Figure 4. Relationship between land-surface temperatures (LSTs) derived from satellite data and from ground-based measurements

Strong correlation was observed between the estimated LST using Landsat data and ground measurements. The determination coefficient (R^2) was 0.79 ; thus, the LST estimated by Landsat data provided a good representation of the actual LST in Jakarta (Mao, Qin, and Gong, 2005; Tursilowati et al., 2012). The LST was corrected based on regression relationships between the LST estimated by Landsat data and ground-based observations. The corrected LST distributions are shown in Fig 3. The comparison of results for 1989 and 2006 shows that the high-LST area had clearly expanded beyond the city center, as indicated by the 2006 data.

RESULT AND DISCUSSION

Observed Relationship between Air Temperature (T_a) and Land Surface Temperature (LST)

To confirm the relationship between near-surface T_a and LST, ground-based measurements were carried out in Jakarta from 18 to 26 September 2012 at the same local standard time as that satellite images (10:00-12.00).

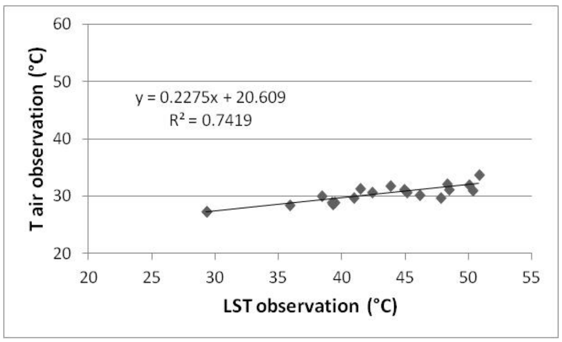

Figure 5. Relationship between LST and air temperature (T_a) in ground-based observations

Figure 5 shows a scatter plot of the relationship between ground-based measurements of T_a and LST. The regression relationship was obtained by comparing T_a and LST. The determination coefficient (R^2) was 0.74, and also confirm the use of LST as an indicator of T_a.

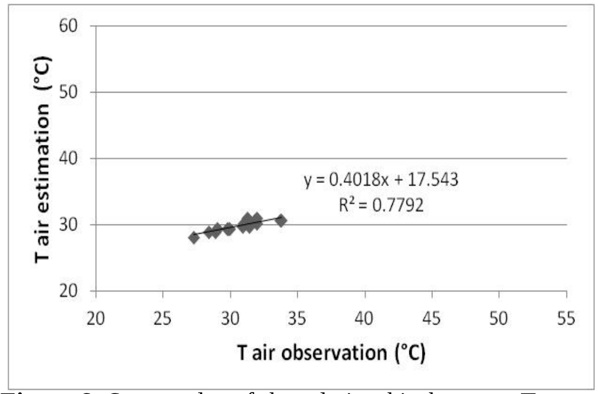

Figure 6. Scatter plot of the relationship between T_a derived from satellite data and from ground-based measurements.

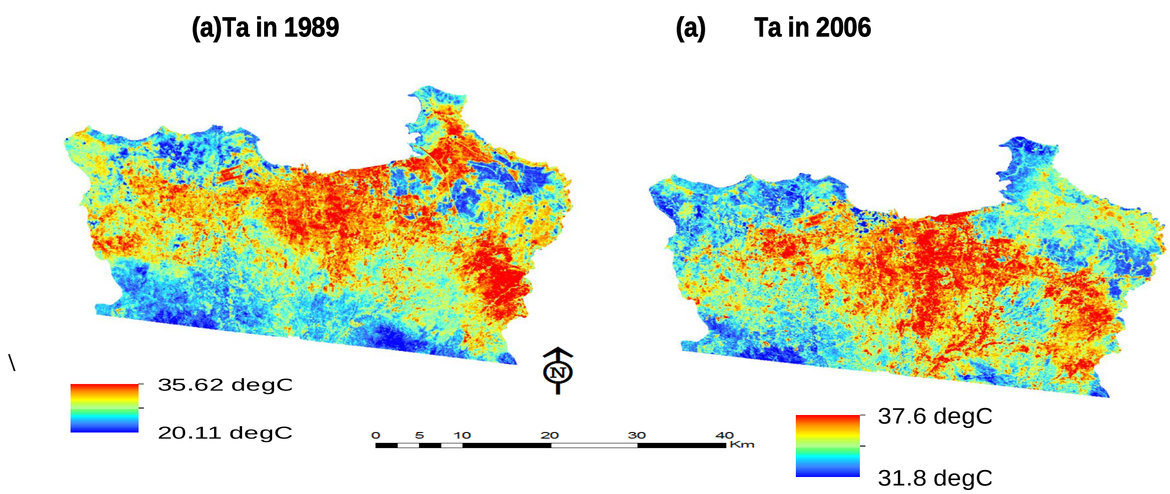

Figure 7. Spatial distribution of air temperature (T_a) a Jakarta urban area in (a) 1989 and (b) 2006.

Figure 6 shows the relationship between T_a in ground-based measurements and that estimated by satellite-derived LST in 2006 to each corresponding pixel. The values show the deviations after being reduced from their initial values. A high R^2 coefficient (R^2 = 0.77) was determined in regression between T_a observation - T_a estimation 2006. To understand the T_a spatial distribution in 1989, the equation was applied on 1989`s satellite. Figure 7 shows the T_a spatial distribution in both years. On 1989 satellite, the minimum is 20.11 °C, maximum is 35.62 °C, and standard deviation is 5.93 °C. On 2006 satellite, the minimum is 31.8 °C, maximum is 37.6 °C, and standard deviation is 6.35 °C.

Table 2. Minimum, maximum, and average of T_a and T_s in satellite data

Satellite data	Air temperature (°C)			Surface temperature (°C)		
	Minimum	Maximum	Avarage	Minimum	Maximum	Avarage
1989	20.11	35.62	27.86	16.39	28.54	22.46
2006	31.8	37.6	34.7	15.04	31.78	23.41

Nearly, all T_s were lower temperature in each data than the T_a. Differences between T_s and T_a tended to be larger in lower temperature. The large difference of average air temperature also detected in each data satellite, it can be caused of air temperature is created in near surface of the earth and get large influence from surrounding area.

Table 3. Comparison of air temperature (°C) between field measurement and Landsat 2006

Location		Observation (°C)	2006 (°C)	Difference
S	E			
6°23'45.8"	106°51'07.5"	23.5	32.82	9.32
6°10'04.5"	106°49'34.9"	33.9	31.55	-2.35
6°10'46.5"	106°49'31.8"	29.6	31.12	1.52
6°10'44.2"	106°49'23.3"	31.9	30.70	-1.20
6°13'12.0"	106°49'59.5"	32.8	31.55	-2.98
6°11'50.9"	106°50'12.9"	31.4	31.97	0.57
6°12'06.3"	106°49'56.7"	35.7	31.55	-4.15

Table 3 is the comparison of air temperature between field measurement and Landsat 2006 in some corresponding pixels. 2006 data was chosen because those data is relatively close to the observation time. Positive or negative deviation between the ground-based measurements and estimated values did not appear to have a significant effect on changes in the difference range. The difference between them varied locally by (-2) – 9°C around noon. Our study is emphasizing on the effectivity of Landsat Ts to estimate T_a and neglected the land use or topographic aspects.

CONCLUSIONS

In this study, the application of Landsat imagery for estimating LST and T_a in Jakarta, Indonesia, using the observed relationship between T_s and T_a, was investigated. The results showed a strong correlation between Landsat T_s and ground-based T_s measurements in both years indicating that the Landsat T_s value provides a reliable representation of the actual LST. The range of determination coefficient (R^2) between T_a and LST in ground-based measurements was 0.74. Therefore, LST can be used as an indicator of T_a.

Although the T_a estimated from satellites tended to be higher than ground-based measurements, the use of satellite remote-sensing data can be used to overcome the spatial problem of estimating T_a, particularly in areas with low station density, using satellite-based LST estimations and the ground-based relationship between LST and T_a. To reduce the biases in satellite-estimated T_a in future work, retrieval methods based on the land surface heat budget may be effective (e.g. Kato, S., and Yamaguchi).

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REFERENCES

UN-ESCAPE. 2011. Statistical Yearbook for Asia and The Pacific. pp. 7–8.

National Aeronautics and Space Administration. 2011. Landsat 7 Science Data Users Handbook. p. 120.

Benali, A., Carvalho, A.C., Nunes, J.P., Carvalhais, N., and Santos, A. Estimating air surface temperature in Portugal using MODIS LST data. Remote Sensing of Environment, 124 (2012), pp. 108–121.

Coops, C.N., Duro, C.D., Wulder, A.M., and Han, T. Estimating afternoon MODIS land surface temperatures (LST) based on morning MODIS overpass, location, and elevation information for Canada. International Journal of Remote Sensing, 28 (2007), pp. 2391–2396.

Goldblum, C., and Wong, T.. Growth, crisis and spatial change: a study of haphazard urbanization in Jakarta, Indonesia. Land Use Policy, 17 (2000), pp. 29–37.

Hung, T., Uchihama, D., Ochi, S., and Yasuoka, Y. Assessment with satellite data of the urban heat island effects in Asian mega cities. International Journal of Applied Earth Observation and Geoinformation, 8 (2006), pp. 34–48.

Jiang, J. and Tian, G. Analysis of the impact of land use/land cover change on land surface temperature with remote sensing. Procedia Environmental Sciences, 2 (2010), pp. 571–575.

Jim, M., and Dickinson, E.R. Land surface skin temperature climatology: benefitting from the strengths of satellite observations. Environmental Research Letters, 5 (2010) 044004 (13 pp).

Kataoka, K., Matsumoto, F., Ichinose, T., and Taniguchi, M. Urban warming trends in several large Asian cities over the last 100 years. Science of the Total Environment, 407 (2009), pp. 3112– 3119.

Kato, S., and Yamaguchi, Y. Analysis of urban heat-island effects using ASTER and ETM+ data: separation of anthropogenic heat discharge and natural heat radiation from sensible heat flux. Remote Sensing of Environment, 99 (2005), pp. 44–45.

Mao, K., Qin, Z., and Gong, P. A practical split-window algorithm for retrieving land-surface temperature from MODIS data. International Journal of Remote Sensing, Vol. 26 (2005) No. 15, pp. 3181–3204.

Landsat 7 Science DataUsers Handbook. 2011. National Aeronautics and Space Administration. Pp 53 – 120.

Mildrexler, J.D., Zhao, M., and Running, W.S. A global comparison between station air temperatures and MODIS land surface temperatures reveals the cooling role of forests. Journal of Geophysical Research, 116 (2011) GO3025.

Rizwan, A. Memon, D., Leung Y.C., and Liu, C. A review on the generation, determination and mitigation of urban heat island. Journal of Environmental Sciences, 20 (2008), pp. 120–128.

Sobrino, A.J., Jimenez-Munoz, C.J., and Leonardo, P. Surface temperature and water vapour retrieval from MODIS data. International Journal of Remote Sensing, Vol. 24 (2003), No. 24, 5161-5182.

Tursilowati, Laras., Tetuko, Josaphat., Kuze, Hiroaki., and Adiningsih, S. E. Relationship between Urban Heat Island Phenomenon and Land Use/Land Cover Changes in Jakarta – Indonesia. Journal of Emerging Trends in Engineering and Applied Sciences, 3 (4): 645 – 653.

Voogt, J.A, and Oke, T.R. Thermal remote sensing of urban climates. Remote Sensing of Environment, 86 (2003) 370–384.

Wubet, Tsehaye, Michael. Estimation of absolute surface temperature by satellite remote sensing. Thesis of International Institute for Geo-information and Earth Observation, Enschede, The Netherland. 2003