ANALYSIS OF RELATIONSHIP BETWEEN URBAN THERMAL DISTRIBUTION & MORPHOLOGICAL ASPECTS IN COLOMBO CITY USING THERMAL REMOTE SENSING

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***ABSTRACT*:** The overheating of urban areas can be widely seen in megacities of the developing world due to rapid urbanization processes. This phenomenon is also called as “Urban Heat Island Affect”, which can be defined as the excess warmth in urban areas compared to surrounding rural areas. The situation creates negative consequences for people’s health and well-being, and also affects standard of living. Further, it also contributes for creation of thermally uncomfortable microclimates & energy demand in urban environments.

Urban Morphology has an important role in creating Urban Heat Island phenomenon. High proportion of impervious surfaces, less proportion of greenery cover, urban geometries that trap heat, high solar absorptive surface materials and high levels of air pollution are some of the urban morphological aspects which trigger the thermal discomfort condition in urban areas.

The city of Colombo, the main commercial & administrative hub of Sri Lanka, is also suffering from increased thermal stress which associates with rapid urbanization processes. Hence the aim of this study is to analyze the relationship between the urban surface temperature and the urban morphological aspects in Colombo city using Thermal Remote Sensing.

When investigating distribution of surface temperature, it is essential to have adequate area wide temperature information. The conventional ways of collecting in situ point based temperature information are insufficient for perform more detailed spatial analysis, since such information only reflect thermal condition of that particular point. Besides, it is more time consuming & tedious to collect temperature information from adequate number of points. The recent development in high resolution satellite technology & image processing technology enables extraction of urban thermal information comprehensively & more cost effective manner.

KEYWORDS: Thermal Remote Sensing, Urban Morphology

1.0 Introduction

Heat stress in urban areas increases the demand for energy, creates thermal discomfort &decline the urban quality of life. This severe thermal environment creates a well-known phenomenon called Urban Heat Island (UHI) effect, which can be described as the excess warmth in urban atmosphere & ground surface compared to the surrounding rural setting.The Atmospheric UHI is usually detected by ground-based air temperature measurements taken from standard meteorological stations, whereas surface UHI is observed from thermal remote sensors which record the upwelling thermal radiance emitted by the surface area that lies within the instantaneous field of view (IFOV) of the sensor (M. Stathopoulou, C. Cartalis and A. Andritsos, 2005).

Lack of vegetation, wide spread impermeable surfaces, increased thermal diffusivity of urban materials, low solar reflectance of urban materials, urban geometries that trap heat, urban geometries that slow wind speeds, increased levels of air pollution&increased energy use(Gartland L, 2008) can be considered as the factors which contribute for overheating of urban areas. Hence the spatial arrangement of different morphological aspects contributes overheat of urban areas in different proportions.

The knowledge of surface temperature is important to a range of issues and themes in earth sciences central to urban climatology, global environmental change, and human-environment interactions.Urban thermal environment is closely associates with local climatic condition. The unprecedented climatic changes in which the Colombo has experienced in recently can be the consequences of severe thermal environment.

There are various satellites which provides thermal information about earth surface. They are Geostationary Operational Environmental Satellite (GOES), NOAA-Advanced Very High Resolution Radiometer (AVHRR), Terra and Aqua - Moderate Resolution Imaging Spectroradiometer (MODIS), Terra-Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) &Landsat-7 Enhanced Thematic Mapper (ETM+).

The present study employs Landsat-7 ETM+ images acquired on 14th of March 2001, to obtain thermal distribution information related to an urban setting.The surface temperature information acquired through remote sensing technique was linked to different morphological aspects of Colombo city for investigate the relationship between temperature behavior and urban structures.

1.1 Objectives

- Analyze the distribution of surface temperature using Landsat-7 ETM+ over heterogeneous urban area.
- Analyze the relationship ofurban morphological aspects with surface temperature.

1.2 Justification

Many studies have estimated therelative warmth of cities by measuring the airtemperature, using terrestrial and airborne sensor.Some studies used measurements of temperatureusing temperature sensors mounted on vehicles, alongvarious routes. This method can beboth expensive and time consuming and sometimes the results may be low in spatial resolution.

Hence Thermal Remote Sensing can be considered as better method to obtain quantitative information about surface temperature covering substantial areas with high spatial & temporal resolution.

2.0 Case Study Area

Colombo Municipal Council area, which is the main commercial & administrative capital of Sri Lanka is selected as the case study area.As a city located at lower altitudes, the effect of heat island has a significant effect, than a city located at higher altitudes. But as a coastal city, the windy condition mitigates the overheating phenomenon of city of Colombo to some extent.

Figure 1.0: Location of Colombo City

The uncomfortable thermal environment in the Colombo city would be worse without the sea breeze. The inter-monsoon periodbetween March and May is the most uncomfortable; temperatures are at their peak.

December and January are the least uncomfortable months. Being close to the equator, the solar elevation isvery high throughout the year.

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Min Temp	22	22	23	24	25	25	25	25	25	24	23	23
Max Temp	30	31	31	31	31	30	29	29	30	29	30	30
Avg Temp	26	26.5	27	28	28	28	27	27	28	27	27	26.5
Avg Rainfall	88	96	118	260	353	212	140	124	153	354	324	175
Relative Humidity	75	76	78	81	82	82	81	80	80	83	82	78

Table 1.0 Annual temperature of City of Colombo

Figure 2.0 shows the distribution of air temperature from 1901 to 2001 in city of Colombo. The average air temperature of thecity for last 100 years (1901 to 2001) is 27.25^{0}C.But since 1960’s most of the years indicate a trend of increasing temperature, showing positive deviation and it is considerably high in after 1990’s.

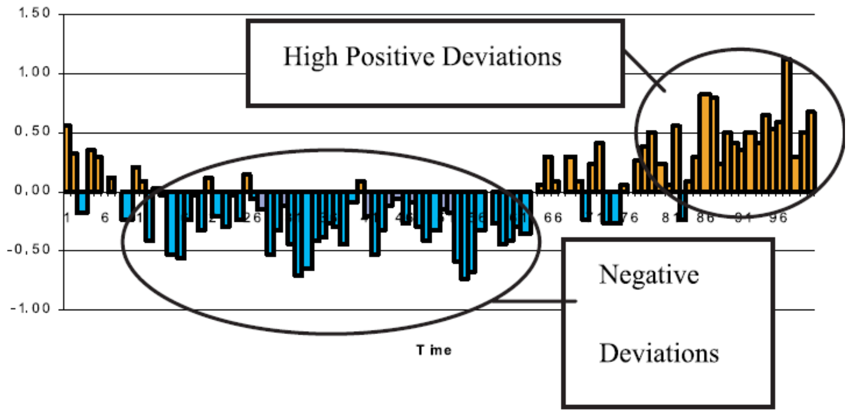

Figure 2.0: Distribution of air temperature from 1901 to 2001 in the city of Colombo

Source: Manawadu, L., Liyanage, N., 2008

3.0 Methodology

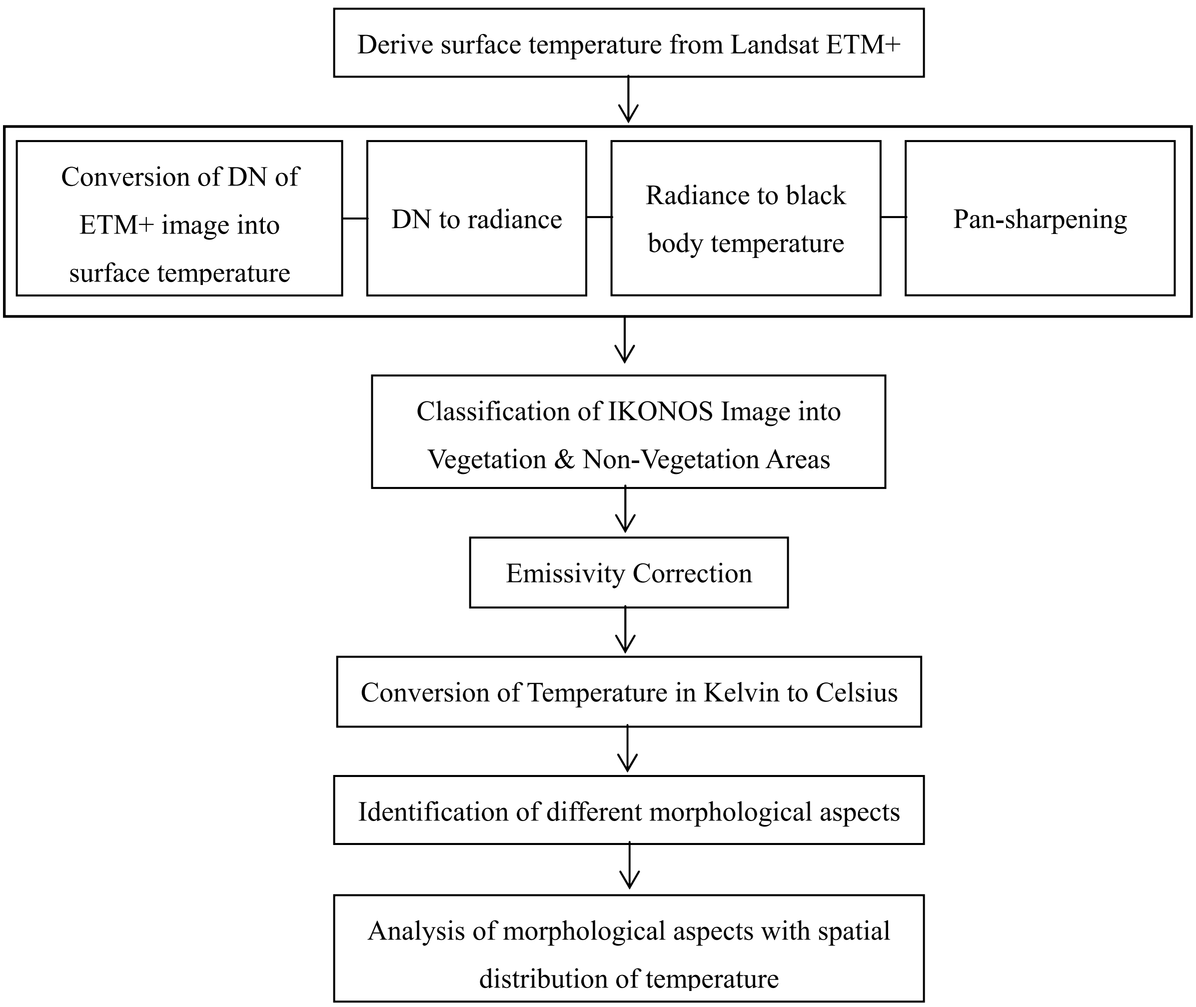

Figure 3.0: Methodology

3.1 Conversion of Digital Number (DN) to Spectral Radiance

$$Li = \frac{(Lmax - Lmin)\ DNi}{Range\ of\ DN\ Values} + Lmin$$

L_i = Radiance of pixel I / Wm-2 sr-1

L_{max} = Highest radiance measured by the detector/ Wm-2 sr-1

L_{min} = Lowest radiance measured by the detector/ Wm-2 sr-1

DN_i = DN value of pixel i

3.2 Conversion of the Spectral Radiance to Black Body Temperature

$$\mathrm{T} = \frac{K_2}{\ln\left[{}^{\mathrm{K}_1}/_{\mathrm{L}_\lambda} + 1\right]}$$

T = Temperature in K

K_1 = calibration constant 1 in W m-2 sr-1 (666.09);

K_2 = calibration constant 2 in K (1282.7);

L_λ = spectral radiance in W m-2 sr-1.

3.3 Emissivity Correction

The ETM+ image was classified into 3 main land cover classes & the corrections for emissivity differences was carried out according to the land cover type. The emissivity corrected surface temperature can be computed as follows:

$$\mathrm{T_s} = \frac{\mathrm{T}}{1 + \frac{\lambda \mathrm{T}}{\alpha} \ln\varepsilon}$$

λ = the wavelength of emitted radiance;

α = hc/K (1.438×10^{-2} m K)

h = Planck's constant ($6{:}26 \times 10^{-34}$ J s)

c = velocity of light (2.998×10^{8} m s^{-1})

K =Bolzmann's constant ($1{:}38 \times 10^{-23}$ J K^{-1})

The following surface emissivity values (ε) were used for the correction.

Non-Vegetation (Soil, asphalt, sand, mixed pixel) – 0.96

Vegetation – 0.97

3.4 Data & Information Used

Input Data	Date of published	Data sources	Spatial Resolution	Remarks
Landsat–7 ETM+ Thermal Infrared image	14th of March 2001	US Geological Survey (USGS) Earth Resource Observation Systems Data Center	60m	The spectral region of the Thermal IR imageis about 10.40-12.50 µm
Landsat–7 ETM+ Panchromatic image	14th of March 2001	US Geological Survey (USGS) Earth Resource Observation Systems Data Center	15m	
IKONOS Image	2001		1m	Used as a ground truth data
Detailed Landuse vector data	2005	Survey Department of Sri Lanka	1:10000	For comparison of land use data with changing pattern of green space system
Field observations	2009 – 2010	Through field visits	-	Several field visits were done for ground verifications.

Table 2.0

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4.0 Results

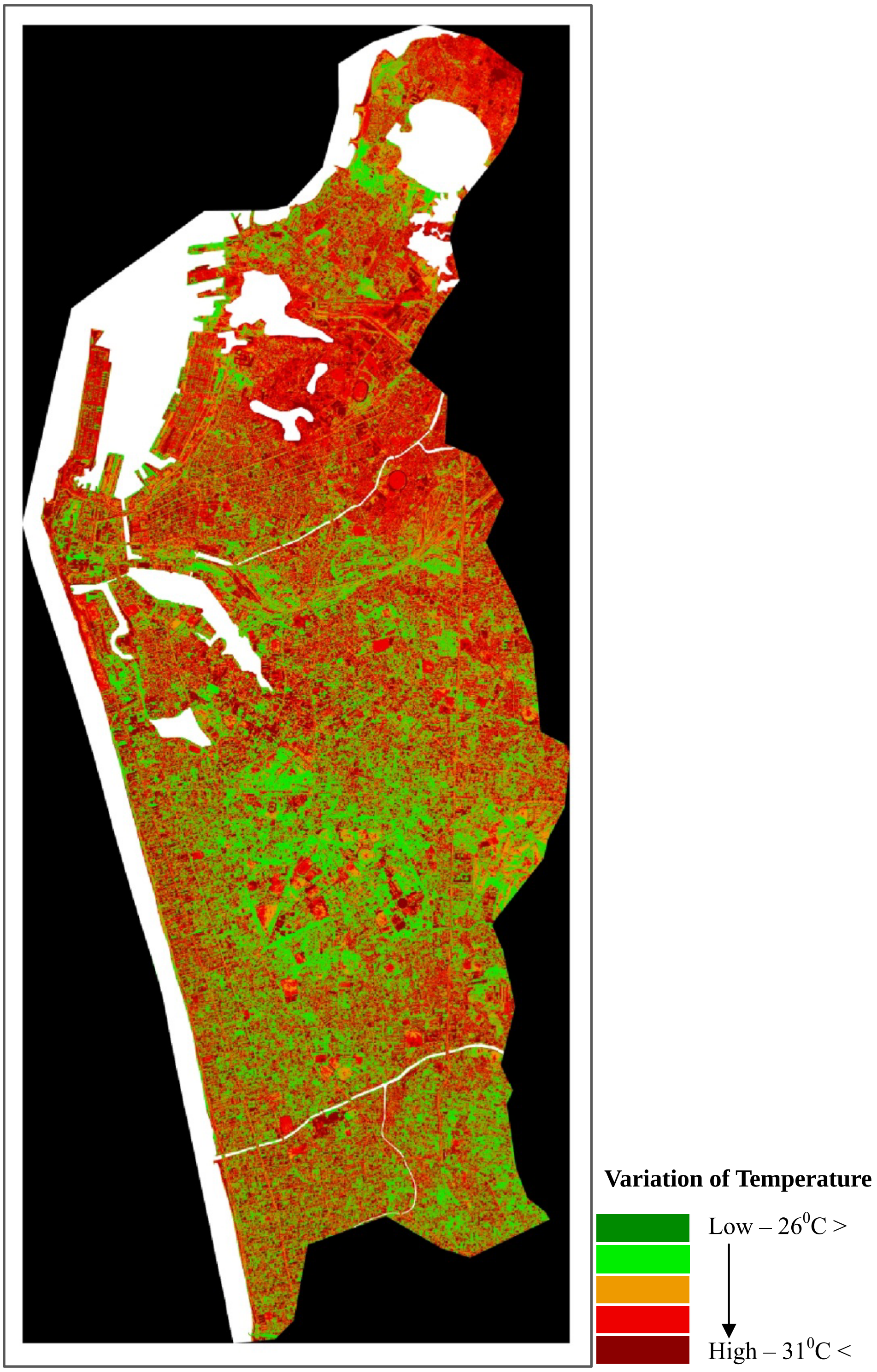

Figure 4.0: Spatial distribution of surface temperature of over Colombo City.

Figure 4.0 shows the spatial distribution of surfacetemperature of over Colombo City. The ocean, water bodies, clouds & shadows cast by clouds were masked to prevent errors in the image analysis process. They are representing in white color. The red color areas in the image show the regions which have high temperature. The green areas show the regions which have low temperature. The below figures show the distribution of surface temperature with respect to different morphological aspects.

4.1 Open spaces

Figure 4.11: Raw Image – Open Spaces

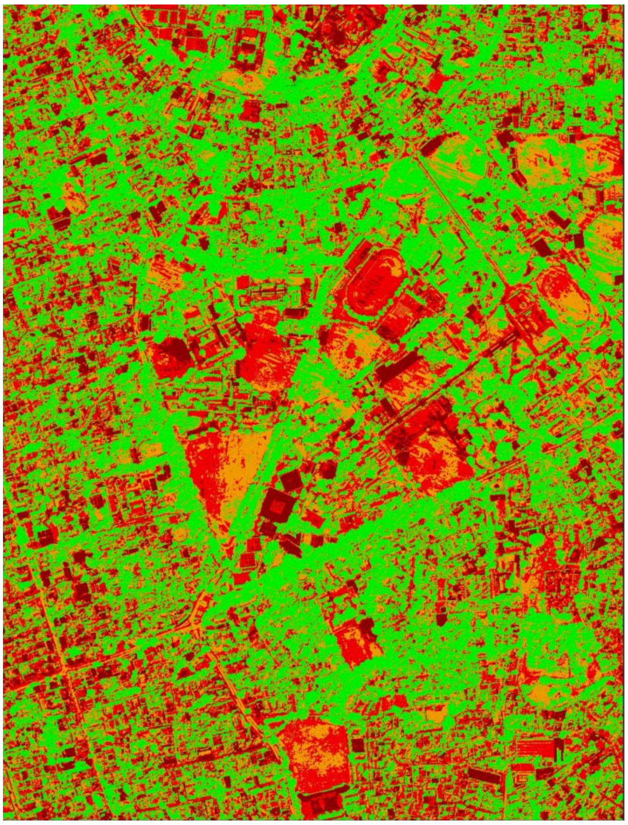

Figure 4.12: Thermal Image – Open Spaces

4.2 High Dense Built Up

Figure 4.21: Raw Image – High Dense Built-Up

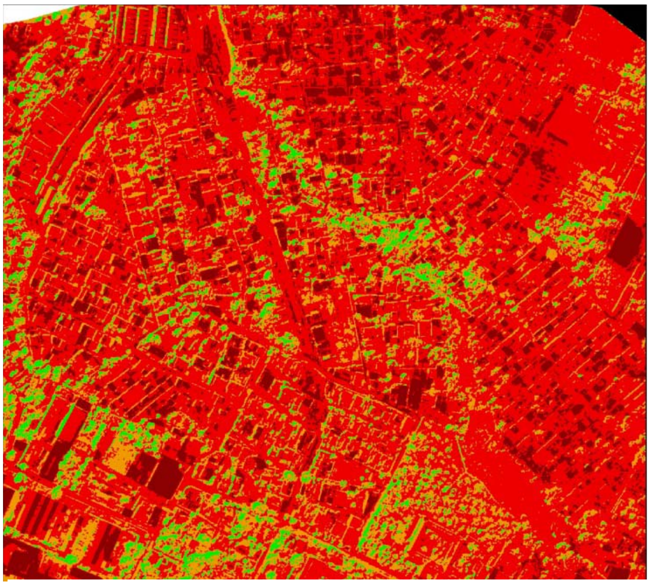

Figure 4.22: Thermal Image – High Dense Built Up

4.3 Industrial Zones

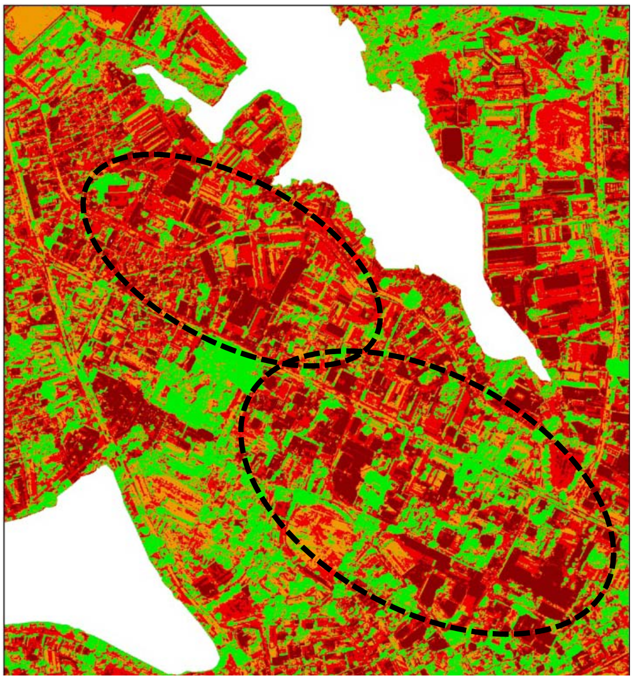

Figure 4.31: Raw Image – Industrial Zones **Figure 4.32: Thermal Image – Industrial Zones**

4.4 Inland Wetland

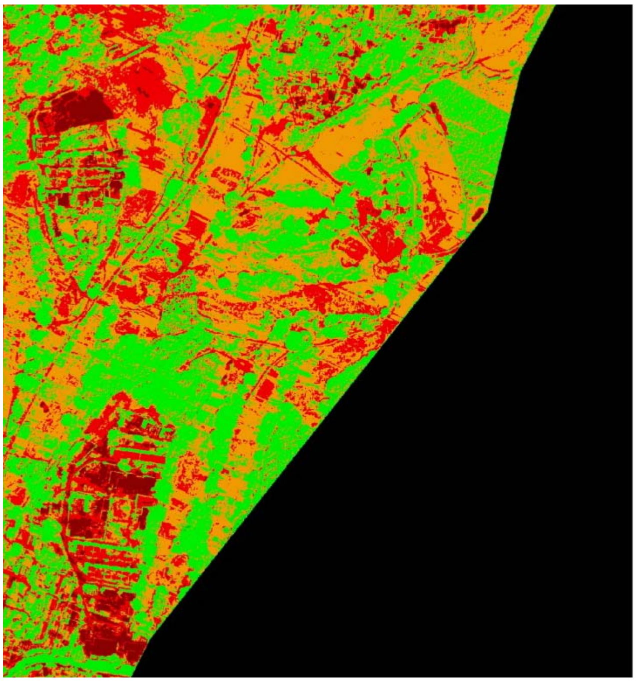

Figure 4.41: Raw Image – Inland Wetland **Figure 4.42: Thermal Image – Inland Wetland**

The Table 3.0 shows some of the significant morphological elements in the urban setting & their temperature variations.

Morphological Aspect	**Temperature (^{0}C)**
Water Body	26 - 28
Vegetation	26 - 28
Buildings with concrete roof tops	31 <
Buildings with asphalt roof tops	28 - 31
Buildings with tile roof tops	26 - 29
Shadows cast by buildings & trees	28 >
Paved Roads	28 - 29
Bare Soil	29 <
Play grounds with grass	28 - 29

Table 3.0

5.0 Conclusion

The analysis of urban thermal temperature distribution with different urban morphological aspects can be used as a reference for urban planning & reduction of heat island effect. The thermal remote sensing technique which applied here was very useful in understanding the spatial distribution of surface temperature in a particular urban setting, rather than depending on measured data by the meteorological department on very few locations. A limitation there in the research is although the method has employed two emissivity values for vegetation & non-vegetation surfaces, the applied emissivity values differ greatly within that two classified categories.

6.0 References

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- Roth, M., T.R. Oke and W.J. Emery, 1989. Satellite-Derived Urban Heat Islands from 3 Coastal Cities and the Utilization of Such Data in Urban Climatology. International Journal of Remote Sensing, 10 (11): pp. 1699-1720.