Modelling Land Surface Temperature from Satellite Data, the case of Addis Ababa

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1. Introduction

✓ Urban expansion is the most rapid phenomena in the last few decades.

✓ Even it is projected that Urban global population will grow to 4.9 billion by 2030 (Bhatta, 2010) and is more rapid in developing countries.

✓ Urban expansion triggers multifarious environmental problems.

✓ A unique increase in temperature in urban areas i.e urban heat island (Dousset and Gourmelon, 2003) is problem of urbanization.

✓ As a response to this environmental event, proper urban greening, planning and developments are to be in place. But such like practices are very limited in developing countries.
Advancement in remote sensing in the last few decades enabled scientists to study the physical, chemical and biological processes of the earth and the interaction with the atmospheric component (Prasad et al, 2013; Neteler, 2010).

Sensors such as MODIS, AVHRR, Landsat-5 TM, Landsat-7 ETM+ and Landsat-8 are providing global thermal data.

Land surface temperature is one of the most important variables measured by using the thermal bands of these sensors.
Land Surface Temperature (LST) is the radiative land surface skin temperature which plays crucial role in the physics of land surface through the process of energy and water exchanges between land surface and atmosphere (Zhang et al, 2009; Rozenstein et al, 2014).

It is the temperature emitted by the earth features.

In areas where there is modification of vegetation cover like urban areas, there is an increase in land surface temperature than the surrounding areas (Rajeshwari and Mani, 2014; Faisal et al, 2012; Zhang et al, 2009;).

Owing to this, studies pertaining to the interaction between land cover and the state of the environment are critical to environmental monitoring, management and planning.
The objective of this study is to:

- examine the use of Landsat satellite images for land surface temperature
- investigate the relation between land surface temperature and Normalized difference vegetation index (NDVI) in Addis Ababa city.
2. Description of the Study Area

Figure 1 Map of Addis Ababa

The expansion of built up area in Addis Ababa is very rapid and the rate is unprecedented.
From 1986 to 2011, area of cultivated and grass lands are significantly reduced while the area of urban (built up) area significantly increased (see figure 1).

**Figure 2** Land use and land cover change in Addis Ababa, 1986 - 2011
3. Methods of the study

✓ Landsat 5 TM, 1985 and Landsat 8, 2015 Optical Land Imager (OLI) and Thermal Infrared Sensor (TIR) data were obtained from USGS data source

<table>
<thead>
<tr>
<th>Satellite</th>
<th>Sensor ID</th>
<th>Path/row</th>
<th>Date of acquisition</th>
<th>Spatial resolution/Grid Cell Size (m)</th>
<th>Sun Elevation</th>
<th>Cloud Cover</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landsat-5</td>
<td>TM</td>
<td>168/54</td>
<td>1985-01-02</td>
<td>30m</td>
<td>44.058</td>
<td>0.00</td>
</tr>
<tr>
<td>Landsat-8</td>
<td>OLI_TIRS</td>
<td>168/54</td>
<td>2015-01-05</td>
<td>30m</td>
<td>49.109</td>
<td>0.12</td>
</tr>
</tbody>
</table>
• Land surface temperature was derived by using Split-Window (SW) algorithm

• NDVI was derived by using 2, 3, 4 and 5 bands of Landsat images. These bands were layer stacked and NDVI was calculated.

• Parallel to this, DN were converted to spectral radiance, at stateliest temperature.

• Finally, land surface emissivity and at satellite surface temperature were used to estimate land surface temperature (figure 2).
Acquire Landsat 5 and 8, Jan 1985 and 2015

Change DN to spectral radiance

At-satellite brightness temperature

NDVI

Proportion of Vegetation

Land Surface Emissivity

Land Surface Temperature in ($^\circ$C)
1. NDVI index is required to characterize the vegetation cover of the area and further to examine the quantitative relationships between vegetation and UHI.

\[
NDVI = \frac{b_4 - b_3}{b_4 + b_3}
\]

where \(b_3\) is the reflectance value of red band

\(b_4\) is reflectance value of near-infrared band

✓ The NDVI values range from 1 to 1,
1. Convert thermal bands to spectral radiance

\[ L_{\lambda} = M_L Q_{\text{cal}} + A_L \]  

- \( L_{\lambda} \) = spectral radiance (Watts/(m² * sr * μm))
- \( M_L \) = Band-specific multiplicative rescaling factor
- \( A_L \) = Band-specific additive rescaling factor
- \( Q_{\text{cal}} \) = Quantized and calibrated standard product pixel values (DN)
2. Calculate at-satellite brightness temperature

\[ T = \frac{K_2}{\ln \left( \frac{K_1}{L_\lambda} + 1 \right)} \]  

\( T \) = At-satellite brightness temperature (°K)

\( L_\lambda \) = TOA spectral radiance (Watts/(m^2 * srad * μm))

\( K_1 \) = Band-specific thermal conversion constant

\( K_2 \) = Band-specific thermal conversion constant.

3. calculate Land Surface Emissivity (e)

\[ e = 0.004P_v + 0.986 \]  

Where \( P_v \) is Proportion of vegetation can be calculated as

\[ P_v = (NDVI - \frac{NDVI_{min}}{NDVI_{max} - NDVI_{min}})^2 \]
Land surface temperature was estimated by using the following mathematical formula:

\[\text{LST} = \frac{BT}{\Pi} + w \times \left(\frac{BT}{p}\right) \times \ln(e)\]  \hspace{1cm} \text{(6)}

\text{LST=} \text{Land surface temperature in (}^0\text{C)}

w = \text{wave length at emitted radiance (11.5um)}

p = 14380

e = \text{land surface emissivity}

Finally the relationships between NDVI and LST was calculated by taking sample pixel values from different parts of the image.
4. Result and Discussion

Significant NDVI value change is found in between 1985 and 2015

Figure 4 Estimated Normalized Difference Vegetation Index (NDVI)
Figure 6 Land Surface Emissivity

Legend
LSE-1985
Value
High : 0.988258
Low : 0.986

Legend
LSE_2015
Value
High : 0.9877
Low : 0.986
Figure 7 Land Surface Temperature

Legend
Band 10 LST_2015
<VALUE>

0 4 8 Km

Legend
Band 11 LST_2015
<VALUE>

0 4 8 Km
Figure 7 Land Surface Temperature
1985

\[ y = -22.987x + 30.24 \]
\[ R^2 = 0.5498 \]

2015

\[ y = -27.474x + 30.41 \]
\[ R^2 = 0.391 \]
5. Conclusion

• In this study, Landsat satellite images were used and the result showed that remote sensing images are pertinent for analysing urban temperature change and urban Heat Island.

• This study investigated the relationship between land use land cover, NDVI and land surface temperature (LST).

• Significant but negative correlation was found between NDVI values with Land Surface Temperature.

• This study indicates the need for urban greening and plans to increase vegetations cover to sustain the ecosystem of the city.
THANK YOU