Satellite Applications in Assessment of Surface Urban Heat Island: A Case Study of Islamabad and Rawalpindi, Pakistan

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Introduction
Formation of UHIs

- UHI Effect is primarily due to artificial land surface changes
- Concentration of human activities
- Surface and atmospheric temperatures are increased by anthropogenic heat discharge due to:
  
  (a) Energy consumption
  
  (b) Increased land surface coverage by artificial materials having low heat capacities and conductivities
  
  (c) Decreases in vegetation and water pervious surfaces, which reduce surface temperature through evapotranspiration
Formation of UHIs– Surfaces’ Contribution

- **Impervious Surface**
  Surface whose heat capacity is low, i.e. Concrete, Asphalt, Stone, etc.

- **Pervious Surface**
  Surface whose heat capacity is high, i.e. Water, Vegetation, etc.
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Urban Surface Energy Budget

- 30% evapotranspiration
- 55% runoff
- 10% shallow infiltration
- 5% deep infiltration
- 40% evapotranspiration
- 10% runoff
- 25% shallow infiltration
- 25% deep infiltration

Key terms:
- Sensible heat
- Anthropic heat
- Latent heat
- Short-wave radiation
- Long-wave radiation
- Thermal storage
Urban Surface Energy Budget

\[ R_n + A = G + LE + H \]  \hspace{1cm} (1)

- **Rn**: Net Radiations
- **A**: Anthropogenic Activities, like, industrialization, movement of vehicles, etc.
- **G**: Ground heat flux
- **LE**: Latent heat flux
- **H**: Sensible heat flux
### Table 1: Basic Characteristics of Surface and Atmospheric Urban Heat Islands (UHIs)

<table>
<thead>
<tr>
<th>Feature</th>
<th>Surface UHI</th>
<th>Atmospheric UHI</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Temporal Development</strong></td>
<td>• Present at all times of the day and night</td>
<td>• May be small or non-existent during the day</td>
</tr>
<tr>
<td></td>
<td>• Most intense during the day and in the summer</td>
<td>• Most intense at night or predawn and in the winter</td>
</tr>
<tr>
<td><strong>Peak Intensity (Most intense UHI conditions)</strong></td>
<td>• More spatial and temporal variation:</td>
<td>• Less variation:</td>
</tr>
<tr>
<td></td>
<td>▪ Day: 18 to 27°F (10 to 15°C)</td>
<td>▪ Day: -1.8 to 5.4°F (-1 to 3°C)</td>
</tr>
<tr>
<td></td>
<td>▪ Night: 9 to 18°F (5 to 10°C)</td>
<td>▪ Night: 12.6 to 21.6°F (7 to 12°C)</td>
</tr>
<tr>
<td><strong>Typical Identification Method</strong></td>
<td>• Indirect measurement:</td>
<td>• Direct measurement:</td>
</tr>
<tr>
<td></td>
<td>▪ Remote sensing</td>
<td>▪ Fixed weather stations</td>
</tr>
<tr>
<td><strong>Typical Depiction</strong></td>
<td>• Thermal image</td>
<td>• Mobile traverses</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Isotherm map</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Temperature graph</td>
</tr>
</tbody>
</table>
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Surface & Atmospheric UHIs

(a) Surface Temperature (Day)
(b) Air Temperature (Day)
- Urban
- Rural

Air Temperature

Heat Island intensity

\[ \Delta T_{UR} = CLUHI \]
## Factors Creating UHI

### Factors on Which Communities are Focusing

- Reduced vegetation in urban regions: Reduces the natural cooling effect from shade and evapotranspiration.
- Properties of urban materials: Contribute to absorption of solar energy, causing surfaces, and the air above them, to be warmer in urban areas than those in rural surroundings.

### Factors to be Considered in Future

- Urban geometry: The height and spacing of buildings affects the amount of radiation received and emitted by urban infrastructure.
- Anthropogenic heat emissions: Contribute additional warmth to the air.

### Additional Contributing Factors

- Weather: Certain conditions, such as clear skies and calm winds, can foster urban heat island formation.
- Geographic location: Proximity to large water bodies and mountainous terrain can influence local wind patterns and urban heat island formation.

*Although communities currently can lower anthropogenic heat emissions through energy efficiency technologies in the building and vehicle sectors*
Factors Affecting UHI

- Urban geometry
- Surface Moisture
- Vegetation Cover
- Intensity of Solar Radiations
- Sky conditions (clear / cloudy)
- Winds
- Local climate change
Why Do We Care About UHI?

- Increased energy consumption
- Elevated emissions of air pollutants and greenhouse gases
- Compromised human health and comfort
- Impaired water quality

As shown in this example from New Orleans, electrical load can increase steadily once temperatures begin to exceed about 68 to 77°F (20 to 25°C). Other areas of the country show similar demand curves as temperature increases.
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Mitigation of Urban Heat Island Effect

- Greening the city (streets and roof top)
- Change construction materials
- Porous Pavings
- Reduce anthropogenic heat sources
A Case Study of Islamabad and Rawalpindi
Objective

- Mapping of Urban Sprawl during study period, i.e. 2000 to 2010
- Quantification of rural area replaced by urbanization during study period
- Quantification of the increase in magnitude of LST due to urbanization
Study Area
Data Used

- SPOT 5
- MODIS LST Product MOD11_L2
- Boundary Layers
MODIS LST product (MOD11_L2) is generated using the MODIS sensor radiance data product (MOD021KM), the geo-location product (MOD03), the atmospheric temperature and water profile product (MOD07_L2), the cloud mask product (MOD35_L2), the quarterly land cover (MOD12Q1), and snow product.

This product is the result of generalized split-window LST algorithm (Wan and Dozier 1996), having 1 km spatial resolution.
Methodology

SPOT 5 with 2.5 m & 5 m Spatial Resolution

Urban Sprawl

Buffer (1 km around Urban Sprawl) to extract Rural Sprawl

MODIS MOD11_L2 LST Product

Geo-reference

Subset Study Area

Masking – Urban & Rural Areas from LST

Averaging – no. of measurements

Subtract Rural LST from Urban

Analyze Results
Factors Affecting LST

- Wind Speed
- Atmospheric Temperature
- Cloud Cover
- Atmospheric Aerosol
- Water Vapor Content

How we will then account that whether the change (increase / decrease) in LST is due to Urbanization or the mentioned environmental variables???
**Solution 1:** The Product (MOD11_L2) is considering some of the variables.

**Solution 2:** Differencing Process.
## Results

<table>
<thead>
<tr>
<th>Sr. No</th>
<th>Land use Classes</th>
<th>Urban Land 2000</th>
<th>Urban Land 2010</th>
<th>Converted other land into Urban from 2000 to 2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Urban Land</td>
<td>346.17</td>
<td>483.4</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>Barren Land</td>
<td>-</td>
<td>-</td>
<td>20.58</td>
</tr>
<tr>
<td>3</td>
<td>Agricultural Land</td>
<td>-</td>
<td>-</td>
<td>27.49</td>
</tr>
<tr>
<td>4</td>
<td>Natural Vegetation</td>
<td>-</td>
<td>-</td>
<td>15.05</td>
</tr>
<tr>
<td>5</td>
<td>Water Body</td>
<td>-</td>
<td>-</td>
<td>0.07</td>
</tr>
<tr>
<td>6</td>
<td>Rocky Area</td>
<td>-</td>
<td>-</td>
<td>48.09</td>
</tr>
<tr>
<td>7</td>
<td>Other Settlements</td>
<td>-</td>
<td>-</td>
<td>25.95</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td>-</td>
<td>-</td>
<td><strong>137.23</strong></td>
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</table>
Results

Rural Temperature Histogram

Normalized Distribution

Temperature (degree C)

Interval 1
Interval 2
### Mean UHI magnitude for Summer and Winter

<table>
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<tr>
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<th>Interval 1 (°C)</th>
<th>Interval 2 (°C)</th>
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<td>April - June</td>
<td>0.508 ± 0.331 (34)</td>
<td>0.755 ± 0.113 (47)</td>
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<td>October - December</td>
<td>0.175 ± 0.059 (49)</td>
<td>0.206 ± 0.052 (33)</td>
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The numbers in parentheses are the total number of measurements in each season.

Analysis reveals the increase of $0.193 \pm 0.044^\circ C$ and $0.349 \pm 0.030^\circ C$ during summer and winter respectively with mean increase in urban area from 346 km² to 483 km².
Results

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- Small standard deviations, for those years in which urbanization is not increasing, reveal that LST is not significantly influenced by environmental variables.
### Mean UHI magnitude for Summer and Winter

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Warm, sunny and dry weather in summer cause relatively greater evapo-transpiration rates along rural areas and producing a prominent bias with urban temperature.

The results are consistent with theory (Oke 1982).
Conclusion

- Urban heat islands occur due to the ways cities are built, as well as an area’s climatic conditions.
- The effects are wide ranging, from higher energy costs to impacts on the quality of life.
- UHI has distinct seasonal behavior, usually greatest in the summer, weakest in the winter.
- UHI not only affects temperature, it affects cloudiness, precipitation and air quality. It also impacts global warming.
- Reducing heat island effects requires substantial changes to urban surfaces, including the amount and type of tree cover, roofing, and paved surfaces.
Questions and Discussion
Thank You