International Workshop

TOWARDS SCENARIOS FOR URBAN ADAPTATION PLANNING
Assessing seawater intrusion under climate and land cover changes in Dar es Salaam, Tanzania

Investigating the Relationship between Land Cover and Vulnerability to Climate Change in Dar es Salaam

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Activity 2.1

- Activity aim: develop methodologies for monitoring changes in peri-urban settlements using remote sensing
Goals of the study

- Methodology for Land Cover (LC) monitoring
- Analysis of Land Cover Change (LCC) and urban dynamics
- Investigation of the relationships between urban sprawl and population growth, as a first step towards the development of future urban expansion scenarios.
Land Cover Change and Vulnerability to CC

Non Climatic Factors
(Land Cover / Urban Sprawl)

- Land Cover affects urban climate (heat island) which in turn combines with CC effects
- Urban Sprawl increases the number of households relying on boreholes for access to water. Consequently, groundwater exploitation also increases leading to an acceleration of seawater intrusion process
- Land Cover Change decreases natural resources available to household, thus reducing options for livelihoods.
- Migration to less dense areas represents a form of maladaptation option as it fosters Urban Sprawl
- Measures for reducing the need to migrate and the demand for further land-take should be considered as a proactive adaptation option by local institution

Climate Change and Variability

- Exposure
- Households’ Sensitivity
- Environmental Sensitivity
- Autonomous Adaptive Capacity

Non Climatic Drivers
(Population growth and distribution, Migration, Land tenure)

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Scheme of Migration within Dar es Salaam Region

- Environmental disasters
- Search for job opportunities
- Family reasons
- Search for farmland
- Expulsion because of urban renewal
- Search for larger houses
  - Business reasons
  - Search for job opportunities

Adapted from Norero, 2012
Land Cover Classification Methodology: Workflow

- **Landsat images**
- **Preprocessing**
  - Georeferencing
  - Cloud masking
  - Atmospheric correction
  - Image mosaicking
- **Processing**
  - Maximum Likelihood classification
  - Vegetation indices
  - Knowledge-Based classification
- **Land Cover Classification**
Land Cover Classification Methodology: 
Landsat Data

• **Available for free** at the USGS Landsat archive (http://landsat.usgs.gov/):
  – Images have **6 multispectral bands** with a **spatial resolution of 30m**
  – About 60 images acquired from 1984 to 2011 were downloaded

• **Imagery issues**:
  – Landsat 7 images acquired after 2003 have SLC-off gaps
  – Cloud cover is often present in most of Landsat images

• **New satellite (Landsat 8) already in orbit** (public release of data beginning in late May 2013)
Land Cover Classification Methodology: Preprocessing

• Main steps
  – Convert **DN to reflectance**, applying atmospheric correction (DOS1 image based model)
  – Image **georeferencing**
  – Create **clouds mask** and shadows mask
  – Apply clouds and shadows masks
  – Combine multiple images in a **mosaic** in order to obtain a cloud-free image
Land Cover Classification Methodology: Processing

- Definition of the **training areas** identifying the classes

- Classification using the **Maximum Likelihood** (ML) algorithm

- Calculation of **vegetation indices** (NDVI)

- Refinement of ML classification using **Knowledge-base classification** with ancillary data and vegetation indices
Land Cover Classification

- Spatial resolution: 30m
- Identified LC classes:
  - “Continuously Built-up”, a densely developed class
  - “Discontinuously Built-up”, an urbanized class with low-density development
  - “Soil”, bare soil or sparse vegetation
  - “Full Vegetation”, very green and abundant vegetation (mainly trees)
  - “Mostly Vegetation”, a less green class of vegetation (typically grass and brush)
  - “Water”
Land Cover Classification: Validation Methodology

- **Accuracy assessment**: comparison of LC classification to ground truth data
- **Photo interpretation** of reference images (high resolution)
- Calculation of fuzzy **error matrices**
- **Field survey** for the validation of the photo interpretation
Land Cover Classification:
Semi-Automatic classification plugin for QGIS

- **Free open source** (based on SEXTANTE, Orfeo Toolbox and SAGA)
- Allows for the training area collection through the **region growing**
- Allows for the LC classification using **several algorithms**
Land Cover Classification: Results

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Land Cover Change

- **Increase of built-up LC classes**

<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuously Built-up</td>
<td>8,415</td>
<td>14,808</td>
<td>+76</td>
</tr>
<tr>
<td>Discontinuously Built-up</td>
<td>8,098</td>
<td>23,678</td>
<td>+192</td>
</tr>
</tbody>
</table>

- **LCC from 2002 to 2011**

<table>
<thead>
<tr>
<th>Land Cover Change Class</th>
<th>Area [ha]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuously Built-up in 2002</td>
<td>6,402</td>
</tr>
<tr>
<td>Discontinuously Built-up converted to Continuously Built-up (2002-2011)</td>
<td>2,856</td>
</tr>
<tr>
<td>Non-urban converted to Continuously Built-up (2002-2011)</td>
<td>5,550</td>
</tr>
<tr>
<td>Non-urban converted to Discontinuously Built-up (2002-2011)</td>
<td>15,580</td>
</tr>
</tbody>
</table>

- **Urban Sprawl Indicator**

  \[ \text{Urban Sprawl Indicator} = \frac{\text{Discontinuously Built – up area}}{\text{Total Urban area}} \times 100 \]

<table>
<thead>
<tr>
<th>Year</th>
<th>2002</th>
<th>2004</th>
<th>2007</th>
<th>2009</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban Sprawl Indicator [%]</td>
<td>49.0</td>
<td>47.7</td>
<td>54.5</td>
<td>58.3</td>
<td>61.5</td>
</tr>
</tbody>
</table>
Land Cover Classification: Limits

• Sources of classification errors:
  – The **high cloud cover**, and the need to mosaic different images adds spectral variability to Land Cover classes
  – **Spectral similarity** between soil and white roofs
  – In low density built-up the pixel is mixed (because of **spatial resolution**) causing spectral confusion with soils, especially during the dry season

• **Fuzzy accuracy for the 2011 classification:**
  – Overall Accuracy = 72.0%
  – User’s and Producer’s accuracies

<table>
<thead>
<tr>
<th>Class</th>
<th>User’s accuracy [%]</th>
<th>Producer’s accuracy [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuous Urban</td>
<td>98.0</td>
<td>93.1</td>
</tr>
<tr>
<td>Discontinuous Urban</td>
<td>97.5</td>
<td>70.8</td>
</tr>
</tbody>
</table>
Land Cover Classification: Advantages

- **Affordable methodology** for LC monitoring:
  - Free images
  - Low computer requirements
  - Free open source alternative for processing

- **Assessment of LCC** over the years:
  - Monitoring urban sprawl
  - Institutions can integrate LCC assessment in planning processes
Population Estimation Workflow

1. Households Survey Data
2. Average Household Size
3. Land Cover Classification
4. Average Household Density per Land Cover Class
5. Household Estimation
6. Population Estimation
Household data

- 2011 Household Survey, under Activity 1.1 of the project
- 5860 households interviewed and georeferenced with GPS
- 20 households counted between each interviewed household
- The distance between two interviewed households varies with household density
Household Estimation

- Assumption: the household density around a given interviewed household is inversely proportional to the distance between that interviewed household and the next one in the sample.

- It is then possible to calculate the average household density per LC class ($\bar{\rho}_i$) in relation to the distance (GIS spatial analysis).

- Estimation of households in Dar es Salaam =

  \[
  \text{Average Household Density} \times \text{LC Class Area}
  \]

<table>
<thead>
<tr>
<th>Land Cover Class</th>
<th>Household Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuously Built-up</td>
<td>$\bar{\rho}<em>{\text{Continuously Built-up}} \times \text{Area}</em>{\text{Continuously Built-up}}$</td>
</tr>
<tr>
<td>Discontinuously Built-up</td>
<td>$\bar{\rho}<em>{\text{Discontinuously Built-up}} \times \text{Area}</em>{\text{Discontinuously Built-up}}$</td>
</tr>
<tr>
<td>Soil</td>
<td>$\bar{\rho}<em>{\text{Soil}} \times \text{Area}</em>{\text{Discontinuously Built-up}}$</td>
</tr>
<tr>
<td>Full Vegetation</td>
<td></td>
</tr>
<tr>
<td>Mostly Vegetation</td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td></td>
</tr>
</tbody>
</table>
Household Estimation: Results

- Assumption: average household densities did not change over the years considered
- Household estimation in Dar es Salaam for 2002 and following years

<table>
<thead>
<tr>
<th>Land Cover Class</th>
<th>Area [ha]</th>
<th>Average Household Density [household/ha]</th>
<th>Estimated Households</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuously Built-up</td>
<td>8,365.5</td>
<td>31.11</td>
<td>260,251</td>
</tr>
<tr>
<td>Discontinuously Built-up</td>
<td>8,032.0</td>
<td>17.56</td>
<td>141,043</td>
</tr>
<tr>
<td>Soil</td>
<td>8,032.0</td>
<td>13.78</td>
<td>110,682</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>511,975</strong></td>
<td></td>
<td><strong>±15%</strong></td>
</tr>
</tbody>
</table>

- Comparison between estimates and census data: ±15%
Population Estimation

• Estimation of population in Dar es Salaam = Estimated Households x Average Household Size

• Average Household Size (National Bureau of Statistics, 2013)
  – Dar es Salaam 2002 = 4.2
  – Dar es Salaam 2012 = 4.0

• Average Household Size calculated per year

<table>
<thead>
<tr>
<th>Year</th>
<th>Average Household Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002</td>
<td>4.20</td>
</tr>
<tr>
<td>2004</td>
<td>4.16</td>
</tr>
<tr>
<td>2007</td>
<td>4.10</td>
</tr>
<tr>
<td>2009</td>
<td>4.06</td>
</tr>
<tr>
<td>2011</td>
<td>4.02</td>
</tr>
</tbody>
</table>
Population Estimation: Results

- Population estimates in Dar es Salaam from 2002 to 2011
- Comparison between estimates and census: margin of error ±15%
- Comparison between estimates and projections
Population Estimation: Results at Municipal Level

- Comparison between estimate and census: margin of error ±25%
Limits of This Method

- **Margin of error ±15%** at city level and ±25% at municipal level

- **Spatial resolution and accuracy of LC classifications**
  - LC classifications do not distinguish land uses, which can have different population densities

- The relationship between LC and population depends on the specific development of the city

- Influenced by variations over time of:
  - Average Household Density
  - Average Household Size
Advantages of This Method

• **Rapid and affordable** demographic estimation

• Valuable *alternative to traditional census*, which has low frequency given the growth rate of Dar es Salaam

• Valuable *alternative to projections*, especially when growth is rapid or unexpected, or when census data is outdated
Conclusions

Affordable methodology of LC monitoring through remote sensing

Analysis of Land Cover Change (LCC) and urban dynamics

Investigation of the relationships between urban sprawl and population growth

Future Urban Sprawl Scenarios
Conclusions

- Urban Sprawl “happens when population growth and the physical expansion of a city are misaligned” (UN-Habitat, 2010, p.10)

- Other drivers also cause urban sprawl in Dar es Salaam, and this affects the reliability of the population estimation method
Thank you

References: