Land Use/Cover Changes & Modeling Urban Expansion of Nairobi City
Urban land use/cover types and distribution necessary for monitoring growth and evaluation of urban policies and development strategies.

Because of rapid urban growth, models are needed to provide understanding of the consequences of planning policies.
African Cities

✓ Experiencing most rapid spatial expansion of all regions (Cohen, 2004).
✓ Urban growth sprawl coupled with explosive population growth
✓ Inadequate infrastructure and basic amenities
✓ Consequences – unsuitable land uses, traffic congestion, environmental and social effects
Objectives

✓ To analyze the dynamics of land use/cover changes

✓ To model the urban growth and simulate urban expansion using Cellular Automata and GIS
Administrative Area: 713 km$^2$
Average Altitude: 1700m asl
Population: 3.5 Million
Soils
Vegetation
Population
Analysis of Land Use/cover changes

✓ Use of multi-temporal Landsat images
  ✓ (resampling)

✓ Change detection to map spatial dynamics of land use/cover.

✓ Physical and socio-economic data for factors influencing land use/cover changes.

Landsat Data:

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Resolution</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landsat MSS</td>
<td>79/120</td>
<td>Feb./1976</td>
</tr>
<tr>
<td>Landsat TM</td>
<td>30/120</td>
<td>Oct./1988</td>
</tr>
<tr>
<td>Landsat ETM+</td>
<td>15/30/60</td>
<td>Feb./2000</td>
</tr>
</tbody>
</table>
# Statistics in Land Use/Cover Changes

<table>
<thead>
<tr>
<th>Year</th>
<th>1976</th>
<th></th>
<th>1988</th>
<th></th>
<th>2000</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Area (km²)</td>
<td>%</td>
<td>Area (Km²)</td>
<td>%</td>
<td>Area (Km²)</td>
<td>%</td>
</tr>
<tr>
<td>Urban</td>
<td>13.99</td>
<td>1.9</td>
<td>41.18</td>
<td>5.8</td>
<td>61.23</td>
<td>8.6</td>
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<tr>
<td>Agriculture</td>
<td>49.83</td>
<td>6.9</td>
<td>57.83</td>
<td>8.1</td>
<td>87.78</td>
<td>12.3</td>
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<tr>
<td>Forests</td>
<td>100.15</td>
<td>14.0</td>
<td>29.09</td>
<td>4.1</td>
<td>23.56</td>
<td>3.3</td>
</tr>
<tr>
<td>Bushlands</td>
<td>154.48</td>
<td>22.3</td>
<td>101.49</td>
<td>14.2</td>
<td>95.98</td>
<td>13.5</td>
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<tr>
<td>Mixed rangelands</td>
<td>357.32</td>
<td>50.1</td>
<td>340.62</td>
<td>47.7</td>
<td>237.63</td>
<td>33.3</td>
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<tr>
<td>Shrub/Brush range</td>
<td>25.22</td>
<td>3.5</td>
<td>64.19</td>
<td>8.9</td>
<td>170.78</td>
<td>23.9</td>
</tr>
<tr>
<td>Open/Transitional</td>
<td>6.92</td>
<td>0.9</td>
<td>77.96</td>
<td>10.9</td>
<td>32.72</td>
<td>4.6</td>
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<tr>
<td>Water</td>
<td>0.50</td>
<td>0.1</td>
<td>1.09</td>
<td>0.2</td>
<td>3.77</td>
<td>0.5</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>713.41</strong></td>
<td><strong>100.0</strong></td>
<td><strong>713.44</strong></td>
<td><strong>100.0</strong></td>
<td><strong>713.45</strong></td>
<td><strong>100.0</strong></td>
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</table>
Major Land Use/Cover Conversions
1976-1988

Land Use/Cover Changes
- Mixed Rangeland to Urban
- Agriculture to Urban
- Bushland to Urban
- Shrubland to Urban
- Transitional areas to Urban
- Bushland to Agriculture
- Agriculture to Forests
- Mixed Rangeland to Shrub
- Bushland to Shrubland
- Forest to Bushland
Major Land Use/Cover Conversions
1988-2000

Land Use/cover Changes
- Mixed Rangeland to Urban
- Agriculture to Urban
- Open/Transitional to Urban
- Forest to Urban
- Bushland to Urban
- Shrubland to Urban
- Bushland to Agriculture
- Mixed Range to Agriculture
- Forest to Agriculture
- Open/Transitional to Agriculture
- Shrubland to Agriculture
- Forest to Bushland
- Mixed Range to Bushland
- Agriculture to Shrubland

Legend:
- Agriculture to Open/Transitional
- Forest to Open/Transitional
- Mixed Range to Open/Transitional
- Other Changes
- No Changes
- Roads
Land Use/Cover Conversion Trends


Urban

Mixed

1 - 5 (km)
5 - 10
10 - 20
20 - 30
### Land Use/Cover Conversions

<table>
<thead>
<tr>
<th>“From”</th>
<th>“To”</th>
<th>1976-1988 (km²)</th>
<th>1988-2000 (km²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mixed Rangeland</td>
<td>Urban</td>
<td>22.00</td>
<td>29.61</td>
</tr>
<tr>
<td></td>
<td>Agriculture</td>
<td>10.90</td>
<td>22.01</td>
</tr>
<tr>
<td></td>
<td>Bush Land</td>
<td>12.98</td>
<td>16.48</td>
</tr>
<tr>
<td></td>
<td>Transitional</td>
<td>27.95</td>
<td>16.67</td>
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<tr>
<td>Bush Land</td>
<td>Urban</td>
<td>8.40</td>
<td>3.65</td>
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<tr>
<td></td>
<td>Agriculture</td>
<td>24.20</td>
<td>21.53</td>
</tr>
<tr>
<td>Transitional</td>
<td>Urban</td>
<td>4.38</td>
<td>8.56</td>
</tr>
<tr>
<td></td>
<td>Agriculture</td>
<td>6.34</td>
<td>19.34</td>
</tr>
<tr>
<td>Shrub/Bush range</td>
<td>Urban</td>
<td>8.61</td>
<td>11.27</td>
</tr>
<tr>
<td></td>
<td>Agriculture</td>
<td>7.90</td>
<td>10.38</td>
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<tr>
<td>Forest</td>
<td>Urban</td>
<td>4.03</td>
<td>2.75</td>
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<tr>
<td></td>
<td>Agriculture</td>
<td>12.99</td>
<td>4.99</td>
</tr>
<tr>
<td></td>
<td>Transition</td>
<td>13.95</td>
<td>1.02</td>
</tr>
<tr>
<td></td>
<td>Bush Land</td>
<td>13.38</td>
<td>10.06</td>
</tr>
<tr>
<td>Agriculture</td>
<td>Urban</td>
<td>2.07</td>
<td>3.76</td>
</tr>
</tbody>
</table>
Modeling Nairobi’s urban growth using Cellular Automata.
Urban Modelling with Clarke CA Model

General formula for cell states in Cellular Automata (CA) Model

\[ S_{t+1} = f \left( S_t, \Omega_t, TP \right) \]

Where: \( S_{t+1} \) is cell’s state, \( \Omega_t \), neighbourhood and, TP transition potential.

\[ t \ TP_{u, x, y} = (1 + t \ A_{r, u, x, y}) (1 + S_{u, x, y}) x (1 + t \ Z_{u, x, y}) (t \ N_{u, x, y})^\nu \]

Where,

- \( TP_{u, x, y} \) is the CA transition potential of cell \((x, y)\) for land use \( u \) at time \( t \)
- \( A_{r, u, x, y} \) is the accessibility of cell \((x, y)\)
- \( S_{u, x, y} \) is the suitability of cell \((x, y)\) for land use \( u \)
- \( Z_{u, x, y} \) is the zoning status
- \( \nu \) is the scalable random perturbation
Model Framework

**GIS module**
- Road
- Slope
- Protected Areas
- Excluded Areas
- Multi-temporal Landsat Data
  - Land Use/Cover Change Analysis

**CA module**
- Suitability Analysis
- Constraints Analysis
  - Defining CA Neighbourhood
  - Parameter Initialization (Monte-Carlo Calibration)
  - Applying Change Rules
  - Descriptive Statistics Computation
  - Urban Growth Simulation

**Iterations**
# Data for Model Building

<table>
<thead>
<tr>
<th>Data</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slope</td>
<td>1:50,000 Topographic Map</td>
</tr>
<tr>
<td>Excluded Areas</td>
<td>1:50,000 Topographic Map</td>
</tr>
<tr>
<td>Roads</td>
<td>Road map (1976, 1988)</td>
</tr>
<tr>
<td>Hillshade</td>
<td>1:50,000 Topographic Map</td>
</tr>
<tr>
<td>Population</td>
<td>Population census</td>
</tr>
<tr>
<td>GDP</td>
<td>Economic Survey</td>
</tr>
<tr>
<td>Etc.</td>
<td></td>
</tr>
</tbody>
</table>
Urban Extents

1976

1988

1995

2000
Areas Excluded From Urban Growth

Excluded Areas
- National Park
- Protected forest
- Airport
- Recreational park
- Military base
- Water body

km
Network of Main Roads

1976

Main roads (1976)
City Boundary

1988

Main roads (1988)
City Boundary
Socio-economics

Population in Nairobi

Source: Population census

Nairobi's GDP values

Source: Economic surveys
Model Calibration

✓ Control data used to identify growth parameters through Monte Carlo iterations

✓ Sequential multi-stage reduction (Brute Force Calibration)
Model parameters and Growth Types

Model Parameters

- Diffusion
- Breed
- Spread
- Road gravity
- Slope resistance

Model Growth Types

- Spontaneous growth
- New spreading center growth
- Edge growth
- Road-influenced growth
- Growth on Slope
Best Overall Calibration Coefficients

<table>
<thead>
<tr>
<th>Category</th>
<th>Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cluster $r^2$</td>
<td>0.90</td>
</tr>
<tr>
<td>Edges</td>
<td>0.89</td>
</tr>
<tr>
<td>Population</td>
<td></td>
</tr>
<tr>
<td>(urban pixels) $r^2$</td>
<td>0.86</td>
</tr>
<tr>
<td>Compare</td>
<td>0.99</td>
</tr>
<tr>
<td>LeeSallee</td>
<td>0.40</td>
</tr>
<tr>
<td>Diffusion</td>
<td>4</td>
</tr>
<tr>
<td>Breed</td>
<td>5</td>
</tr>
<tr>
<td>Spread</td>
<td>98</td>
</tr>
<tr>
<td>Slope</td>
<td>4</td>
</tr>
<tr>
<td>Road gravity</td>
<td>75</td>
</tr>
</tbody>
</table>
Final Model Parameters

Model Parameters

- Diffusion: 4
- Breed: 5
- Spread: 98
- slope: 4
- Road gravity: 75
Accuracy assessment

(a) Model results
(b) Actual (from Satellite data)
# Accuracy Assessment

## Year 1995

<table>
<thead>
<tr>
<th>Class Name</th>
<th>Producer’s Accuracy (omission)</th>
<th>User’s Accuracy (commission)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban</td>
<td>47.2 %</td>
<td>69.6 %</td>
</tr>
<tr>
<td>Non-Urban</td>
<td>95.4 %</td>
<td>79.9 %</td>
</tr>
</tbody>
</table>

**Overall Accuracy = 80.0%, Overall $\kappa = 0.81$**

## Year 2000

<table>
<thead>
<tr>
<th>Class Name</th>
<th>Producer’s Accuracy</th>
<th>User’s Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban</td>
<td>45.2 %</td>
<td>67.6 %</td>
</tr>
<tr>
<td>Non-Urban</td>
<td>97.4 %</td>
<td>80.9 %</td>
</tr>
</tbody>
</table>

**Overall Accuracy = 86.0%, Overall $\kappa = 0.83$**
Simulated Urban Expansion (2000 – 2030)

Legend:
- Existing urban (2000)
- Expanded Area
- High urbanization Potential Area
Conclusions

✓ Substantial Land use/cover changes have taken place, with notable rapid urban expansion.

✓ CA based Simulated results show rapid urban growth of Nairobi by 2030

✓ CA modeling for policy scenarios is useful in planning and sustainable management of land resources.

✓ Simulated pattern of urban sprawl will have significant implications in policy making and urban planning
Further Research


- Simulation of spatial patterns
- Spatial-temporal processes
- Social economic variables

Spatial logistic regression + Markov Chain?
Thank You.
## Summary of Growth types simulated by model

<table>
<thead>
<tr>
<th>Growth cycle order</th>
<th>Growth type</th>
<th>Controlling Coefficient</th>
<th>Summary description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Spontaneous dispersion</td>
<td></td>
<td>Randomly selects potential new growth cells</td>
</tr>
<tr>
<td>2.</td>
<td>New spreading breed</td>
<td></td>
<td>Growing urban centers from spontaneous growth</td>
</tr>
<tr>
<td>3.</td>
<td>Edge spread</td>
<td></td>
<td>Old or new urban centers spawns additional growth</td>
</tr>
<tr>
<td>4.</td>
<td>Road-influenced road gravity</td>
<td></td>
<td>Newly urbanized cell spawns growth along transportation network.</td>
</tr>
<tr>
<td>Throughout</td>
<td>Slope resistance</td>
<td>slope</td>
<td>Effect of slope on reducing urbanization</td>
</tr>
<tr>
<td>Throughout</td>
<td>Excluded layer</td>
<td>user-defined</td>
<td>Areas resistant or excluded to development specified</td>
</tr>
</tbody>
</table>
Simulation Flow

Initial conditions

- Model Initialization + Seed +

Generate growth cycles

- Input images
- Slope
- Land Cover
- Excluded
- Urban
- Transportation
- Hillshade

Conclude simulation

- \( S_1MC_1 \)
- \( S_2MC_2 \)
- \( S_nMC_n \)