The Urban Transition in Ghana and Its Relation to Land Cover and Land Use Change (LCLUC) Through Analysis of Multi-scale and Multi-temporal Satellite Image Data

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Presentation Objectives

• NASA IDS project progress report; emphasis on remote sensing – Stow

• Dissertation research findings; emphasis on demographic analysis – Benza-Fiocco (a new early-career investigator)
The Urban Transition in Ghana and Its Relation to Land Cover and Land Use Change Through Analysis of Multi-scale and Multi-temporal Satellite Image Data

Douglas Stow (PI), John Weeks (Co-PI), Pete Coulter (Project Manager), Li An (Co-Investigator) – San Diego State University

Ryan Engstrom (PI) – The George Washington University

David Lopez-Carr (Co-Investigator) -- University of California Santa Barbara

Samuel Agyei-Mensah and Foster Mensah (Collaborators) -- University of Ghana Legon
Participating Students

**SDSU**

- Doctoral (w/ UCSB)
  - Magdalena Benza-Fiocco
  - Stephen Crook
  - Sory Toure
  - Cindy Tsai

**GWU**

- Post-doc
  - Qin Yu

**U. Ghana Legon**

- Master’s
  - Avery Sandborn

- Doctoral
  - Foster Mensah

**Undergraduate**

- Nicholas Ibanez
Doctoral Dissertations and Master’s Thesis Associated with NASA IDS Project

**Doctoral Dissertations**

Benza-Fiocco, Magdalena (SDSU/UCSB) Degree of Urbanization and Population Dynamics: A Case Study in Sub-Saharan Africa Utilizing Remotely Sensed Imagery, John Weeks, Adviser, completed February 2014


Toure, Sory (SDSU/UCSB) Urban Land Use and Land Cover Change in Ghana: Connections to Demography, Health and Wealth, Doug Stow, Adviser, in progress.

**Master’s Theses**

Sandborn, Avery (GWU), Quantifying Spatial Features of Built-Up Areas and Their Relationship to Quality of Life Indicators in Accra, Ghana, in progress.

Shih, Hsaio-Chien (SDSU), Identification of land cover and land use change based on discrete analyses of dense Landsat time series and spatial and temporal filtering, in progress.

Vejraska, Milo (SDSU) Image Metrics As Indicators of Socioeconomic and Demographic Characteristics in Slum Neighborhood of Accra, Ghana, John Weeks advisor, completed June 2013.
Project Progression

• Nominal start: 01 August 2012
• Effective start: 01 November 2012
• Nominal end: 31 July 2015
• Likely end: 31 January 2016
• Nominal duration: 55%
• Effective duration: 40%
• Expenditures of total fund allocation: 45%


Central Hypotheses

• Inter-regional LCLUC in Ghana driven by rural-urban migration

• Demographic, health and environmental outcomes in Ghanaian cities strongly impacted by LCLUC
Study Areas: Regional & Urban

Ghana
Greater Accra region in gray
Accra Metropolitan Area – dense enumeration area units
Rural village
Dense urban settlement
Urban densification
New suburban residential
Peri-urban residential development
Commercial agricultural expansion
Geo-tagged Ground Reference Imagery

• Supported by Foster Mensah, University of Ghana

• Conducted January-February 2014

• Emphasis on location and land cover characteristics of new built development
Challenges of Remote Sensing in Ghana

- Prevalent continuous cloud cover (May – Dec)
- Partial clouds and cloud shadows (Jan – Apr most cloud free; dry season)
- Atmospherically thick optical properties on clear days (water vapor and aerosols)
- Wind borne dust – Harmattan effect; dusty West African trade wind in winter
- Minimal Landsat 5 Thematic Mapper coverage
- Landsat 7 ETM+ scan-line corrector off 2003-13
- Most agriculture mixed with natural vegetation
- Soil and metal roofs contain iron oxides
- Confusion between impervious and soil cover
Mixed agriculture and natural vegetation
Benefits and Challenges of Demographic and Health Research in Ghana

- Decadal demographic census 2000 and 2010
- Census “geography” for 2010 decadal census not yet released
- Multiple DHS and WHS for selected enumeration areas
- Relatively stable and safe environment
- Complex land ownership and development policy between national and tribal governments
- Residential building a slow process
- Technology leader in West Africa
Inter-regional Scale LCLU Mapping and Change Identification
Greater Accra Landsat Footprint (193/056)
Inter-regional LCLU and LCLUC Mapping Process

All Landsat TM/ETM+/OLI: 1986-2014
(surface reflectance, LEDAPS processing)

Scene selection: < 33-50% cloud/scene

Mask cloud, cloud shadow, water, and SLC-off (fmask)

Include derived image products:
ND21, ND31, ND43, ND45, ND47, stack stdev 123, 457, 123457,
additive local texture (3x3-11x11)

Create c.2000 and c.2010 composites
(max. value for NDVI, ND23, stack stdev 123)

(cloud free) (composite) (ERS SAR)

c.2000 to c.2010 change detection and updating
(NDVI for urban change)

Discrete spatial filter and manual editing

Maps of LCLU and LCLUC
Regional Landsat Data:
Usable data frequency -- 48 images 1999-2013 < 33% cloud
Regional Landsat Data: Greater Accra
c.2000 NDVI maximum
(23 Landsat 7 ETM+ images, 1999-2003)
c.2010 NDVI maximum
(28 Landsat 7 ETM+ images, 2009-2013)
Identifying and Mapping Agriculture Fields (Landsat 7 ETM+)

RGB = bands 321

RGB = bands 345

Grayscale = Std. Dev. of ETM+ reflective bands
2010 ENVISAT ASAR enhanced Lee filter - Kumasi
CERGS Reference 2000 Land Cover/Land Use Map with MODIS IGBP Cloud-fill

- Agricultural Land
- Forest
- Savanna
- Shrub-thicket
- Non-biotic Constructed
- Bare Land
- Water Body
- Wetland
- Fire Scars

0 Kilometers 300 Kilometers
Data collection
(66% cloud free images)

Spectral indices generation
(NDBG, NDRB, NDBG, NDVI, and NDII)

Noise masking and layer stack generation
(screen out clouds and their shadows, water, and SLC)

Image classification
(classify into urban, natural vegetation, and agricultural land)

Temporal filter
(filter out no data and misclassified pixels)

Change detection

Spatial majority filter
(filter out single pixel change)

LCLUC maps
(changing situation in time sequence)

Change time identification
(identify the change time for changed pixels)
Intra-urban Scale Mapping of LCLU and Change for Accra, Cape Coast, Kumasi and Obuasi with High Spatial Resolution Satellite Imagery
Intra-urban LCLU and LCLUC Mapping Process

1. Time 1 Imagery
   - Hi-Res & Mod-Res
   - Spatial Co-registration

2. Hi-Res Imagery
   - c.2000
   - Segmentation
   - Classification
   - LCLU Map

3. Hi-Res Imagery
   - c.2010: Area 1
   - Segmentation
   - Classification
   - LCLU Map

4. Mod-Res Imagery
   - c.2000
   - Segmentation
   - LCLU Map
   - Export Results
   - Vector Shapefile

5. Hi-Res Imagery
   - c.2010: Area 2
   - Segmentation
   - Classification
   - LCLU Map

6. 2000-2010 Comparison
   - Change Map 1

7. Final Change Map
   - Change Map 2

8. Change Statistics
High Spatial Resolution Image LCLU/C for Portion of Accra

High Res. Data Composite c. 2000:
- Ikonos 02/10/2000
- Ikonos 05/22/2002
- QuickBird 04/12/2002

Multitemporal set:
- QuickBird 04/12/2002
- QuickBird 01/12/2010
c.2000 LCLU Classification for Portion of Accra
2002 to 2010 LCLUC Map
Based on OBIA and Manual Editing
Intra-urban LCLUC Identification Research
Professor Ryan Engstrom

Decision trees

• Binary-built-up versus pervious
  – 2002 & 2010 QuickBird multispectral
  – Mapping at the EA and FMV Neighborhood

Formal vs Informal housing

• Image Features, testing a new open source software
  – Pantex, histogram oriented gradients, line support regions, probabilistic Hough transform, local binary patterns, structural feature set textures and other “neighborhood” features
  – Creates inputs to decision tree classifiers to classify formal vs informal settlement
  – Testing on SPOT 2003, Panchromatic image
Neighborhood Change in Percent Built-up

Increase in Percent Built Up
- Decrease - 0
- .1 - 10
- 10.1 - 20
- Over 20
- Not Covered By Both Images

KM
0 1.25 2.5 5 7.5 10
Using **Born in Another Region** as the dependent variable and land cover classes as predictor variables:

\[ R^2 = 0.332 \]  

with Natural Vegetation  
(Beta = -.766; p=.000) and Mixed Agriculture/Vegetation  
(Beta = -.547; p=.000) as the significant predictors
Migrants into and out of Accra between 1995 and 2000 were predominantly inter-urban migrants.
Two-level Multinomial Regression

**Dependent Variable:** Migration (defined as no migration (baseline), rural migration, and urban migration)

**Independent Variables:** (available at the household and district level (aggregated):
- *Population variables:* e.g., household size age and structure (WHSA and DHS)
- *Health variables:* e.g., a rich array of communicable and degenerative diseases (and related factors such as diet) can be examined with available data (WHSA and DHS)
- *Socioeconomic Variables:* income, employment, literacy, highest schooling achieved

**Land Change:**
district (second-level) measures of land use, land cover, and land consolidation at the municipal level (remote sensing data)
Specific Hypothesis

Rapid increase in land consolidation, driven by international investments and measured remotely by a signature pattern shift from mottled mixed land use small farms to large monocropped industrial plantations is a key independent driver of urbanization vis a vis rural farm labor displacement.
Agent Based Modeling

Prof. Li An and PhD student Stephen Crook
• Integrates multi-scale and multidisciplinary data

• Characterizes system dynamics, feedbacks, emergent properties over time and space

• For Accra and Kumasi - simulate effect of individual/household actions and decisions and LCLUC on health:
  ➢ Parameterization of individual and household decisions/actions based on census and survey data -- e.g. child mortality, fertility, marriage timing, migration, mortality
  ➢ Empirically linked to LCLUC
  ➢ Interactions between agents and the environment play out over time, affecting each other
  ➢ Allows scenario exploration: how changes in certain variables affect LCLUC and health -- e.g., Experimentally increasing fertility may cause a increase urban density, decreasing health (which may then lead to ultimately increasing mortality and/or migration)

• Model implementation with Repast: advanced, open source modeling software
Here’sssssssssssss
Magdalena
Charcoal production
Examining fertility throughout an urban gradient

Magdalena Benza$^1$ and John Weeks$^2$
Department of Geography
$^1$ San Diego State University and UC Santa Barbara
$^2$ San Diego State University
An urban world

• Rapid urban growth combined with poverty is creating diverse urban contexts in West Africa

• These urban contexts are linked to diverse lifestyles that generate a wide range of reproductive behaviors
Urban and rural total fertility rates in West Africa 1998

DHS STATcompiler: Accessed online on January 2014
What is an urban place?

- Urban definitions:
  - **Niger**: Capital city, capitals of the departments and districts.
  - **Senegal**: Agglomerations of 10,000 or more inhabitants.
  - **Ghana**: Any settlement with a population of 5,000 or more persons.

Even though definitions vary widely they all assume that there are significant differences between rural and urban places and their population.
Research questions

- Does a pattern-based definition of urban context capture the diversity of urban landscapes?

- Is there a connection between fertility levels and urban context?
Study Area
Data

- Landsat 7 ETM+ from December 2002 path 193 row 56
- 2000 Ghana population and housing census

Individual and household data aggregated to towns and then aggregated to a 450 m uniform grid cell
Image processing

ETM+ six layer stack created (bands 1-5, 7)

- >50% Impervious
- >50% vegetation

ERS-2 SAR (C band)

Filter → Texture → Over Threshold classified as built
Urban context definition

- Unsettled land
- Fragmented transition
- Sparsely populated
- Scattered settlement
- Fragmented Sub urban
- Compact urban core

Increasing fragmentation of vegetation land cover → Increasing fragmentation of built land cover
Fertility and urban context

OLS was used to model fertility using urban context as independent variable of interest controlling for:

1. Characteristics of the head of household
2. Characteristics of the housing
3. Characteristics of the women

### Coefficients for urban Context variables

<table>
<thead>
<tr>
<th>Urban Context Variable</th>
<th>Coefficient</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compact urban</td>
<td>-0.056**</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Fragmented large urban patches</td>
<td>-0.105***</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Dense and dispersed small urban patches</td>
<td>-0.058***</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Fragmented sub-urban</td>
<td>-0.053***</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Scattered settlements</td>
<td>-0.028*</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Sparsely populated</td>
<td>-0.023</td>
<td></td>
</tr>
<tr>
<td>Fragmented transition</td>
<td>0.017</td>
<td></td>
</tr>
<tr>
<td>Fragmented unsettled</td>
<td>-0.019</td>
<td></td>
</tr>
</tbody>
</table>

R²: 0.348
Fertility and Urban context: spatial filter

<table>
<thead>
<tr>
<th>Coefficients for urban Context variables</th>
<th>R² : 0.406</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compact urban</td>
<td>-0.057***</td>
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<tr>
<td>Fragmented large urban patches</td>
<td>-0.095***</td>
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<tr>
<td>Dense and dispersed small urban patches</td>
<td>-0.054***</td>
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<tr>
<td>Fragmented sub-urban</td>
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<td>Scattered settlements</td>
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<tr>
<td>Fragmented transition</td>
<td>0.04**</td>
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<tr>
<td>Fragmented unsettled</td>
<td>0.007</td>
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</tbody>
</table>
Conclusions

• Pattern based characterization of the urban context expands on the classic rural/urban definition of space
  - Pinpoints areas within the city where fertility levels are the lowest and the highest
  - Detects areas in the countryside where fertility levels are above average