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

SAN DIEGO STATE UNIVERSITY

THE GEORGE WASHINGTON UNIVERSITY
WASHINGTON, DC

UNIVERSITY OF CALIFORNIA SANTA BARBARA

UNIVERSITY OF GHANA

Research Team

Douglas Stow (PI), John Weeks (Co-PI), Lloyd Coulter (Project Manager), Li An (Co-Investigator), Magdalena Benza-Fiocco (PhD student), Sory Toure (PhD Student), Sean Taugher (MA student), Milo Verjaska (MS student) -- San Diego State University (lead)

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.

Objectives

1. Identify, map, and quantify land cover and land use change (LCLUC) within an extensive study area in Ghana, particularly for the period 2000 through 2010.

2. Understand the regional impacts of LCLUC associated with rural-to-urban migration in driving these changes.

3. Assess LCULC and its effect on demographic and quality of life factors for four major urban centers during this time period.

Research Approach

• Map and quantify LCLUC at two spatial scales: (1) inter-regional scale for the Greater Accra, Central, and Ashanti regions of southern and central Ghana, and (2) intra-urban scale for Accra, Kumasi, Cape Coast and Obuasi, the four major cities within the study area.

• Inter-regional identification of LCLUC based on moderate spatial resolution, multi-temporal image data from Landsat ETM+, Terra ASTER and SPOT HRV optical satellite systems, and ERS-2 synthetic aperture radar (SAR).

• Intra-urban identification of LCLUC based on high spatial resolution image data from QuickBird, WorldView, IKONOS and Geoeye commercial satellites.

• c. 2000 through 2010 study period coincides with a period of available demographic and health survey data for Ghana.

• Utilize quantitative spatial analysis techniques to examine relationships between LCLUC and magnitudes and changes of demographic, socioeconomic, and health variables using generalized linear and multi-level regression models, multinomial logit models, regression tree analysis, and agent-based models.

• Emphasis on the effects of LCLUC on quality of life indicators such as child mortality, slum indices, and food security, within four of the major cities of Ghana.

Study Area and Methodology

Figure 1. Map of regional study area (tan) and study cities (red) in Ghana.

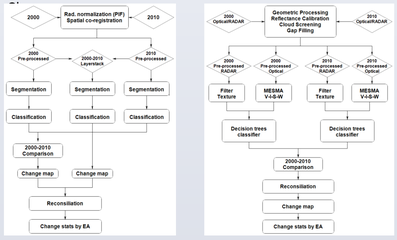

Figure 2. Processing flow: a. Regional-scale LCLUC mapping; b. Urban LCLUC mapping.

Table 1. Characteristics of commercial high spatial resolution satellite (CHSRS) systems and data.

City	Satellite Sensor	Temporal Coverage	Spectral Bands	Spatial Resolution
Accra	QuickBird-2	2002, 2010	VNIR	2.4 m MS, 0.6 m PAN
Kumasi	IKONOS-2	2001, 2009	VNIR	4 m MS, 1 m PAN
Cape Coast	OrbView-3, IKONOS-2	2005, 2009	VNIR	4 m MS, 1 m PAN
Obuasi	IKONOS-2	2008	VNIR	4 m MS, 1 m PAN

Table 2 Characteristics of moderate spatial resolution satellite (MSRS) systems and data.

Satellite Sensor	Temporal Coverage	Spectral Bands	Spatial Resolution
ASTER	2000-present	VNIR, SWIR*	15 m VNIR, 30 m SWIR
ERS-2	1995-present	C-Band**	30 m +
Landsat TM	1986-1999	VNIR, SWIR	30m MS
Landsat ETM+	1999-present***	VNIR, SWIR	30 m MS, 15 m PAN
LDCM OLI	2014+	VNIR, SWIR	30 m MS, 15 m PAN
ENVISAT ASAR	2002-present****	C-band	30 m +
SPOT (4,5)	1998-present	VNIR, SWIR	20/10 m MS, 10/2.5 m PAN
AWIFS	2004-present	VNIR, SWIR	56 m MS
DMC$_{II}$	2002-present	VNIR	22/32 m MS

*ASTER SWIR not functional after April 2008

** Polarization mode: VV

*** Scan Line Correction off (SLC--off) imagery after May 2003

**** Polarization modes: VV, HH, VV/HH, HV/HH, or VH/VV

Inter-regional Land Cover/Land Use Classification Scheme

1. Agriculture to Built – expansion of urban edge, village expansion, new village or dwelling clusters;
2. Family to Industrial Agriculture – intensification of agricultural land use through change in land ownership and mechanization;
3. Natural Vegetation to Agriculture – smaller private plots, large agro-business fields;
4. Natural Vegetation clearing – initial stage of agricultural or urban development; and
5. Natural Vegetation to Built – forest to dwelling cluster or village.

Intra-urban Land Cover/Land Use Classification Scheme

1. Soil or Natural Vegetation to Residential – undeveloped to residential dwellings;
2. Soil or Natural Vegetation to Non-Residential Built – undeveloped to nonresidential buildings or infrastructure;
3. Agriculture to Residential – urban periphery or conversion of urban agriculture;
4. Agriculture to Non-Residential Built – urban periphery or conversion of urban agriculture; and
5. Urban Densification – increase in density of buildings or infrastructure.

Moderate Spatial Resolution Optical and Radar Satellite Data

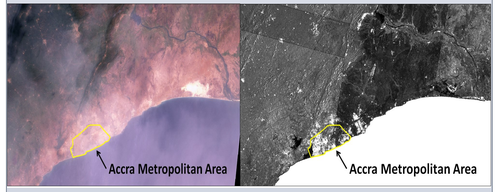

Figure 3. Landsat 7 ETM+ image and ERS-2 "SAR Precision" radar images from circa 2000. SAR data are particularly useful for identifying "Built" and Agricultural LCLUC in rural and peri-urban areas.

Preliminary Results

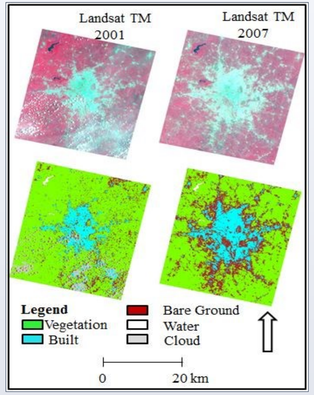

Figure 4. Preliminary evaluation of LCLUC for greater Kumasi area between 2001 and 2007 based on classification of Landsat ETM+ data. "Built" land cover increased substantially particularly in northern and eastern Kumasi, where high spatial resolution satellite image data are available for more detailed analyses.

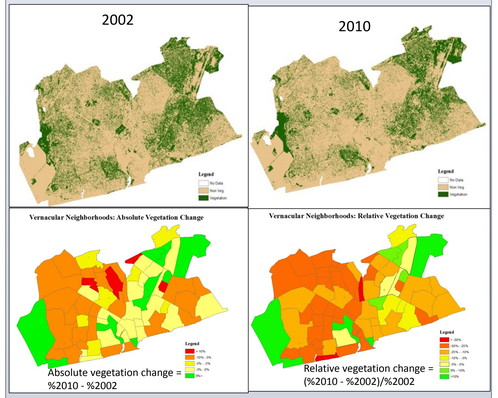

Figure 5. Vegetation change between 2002 and 2010 derived from classification of QuickBird multispectral data. A seven percent area-wide decrease in vegetation cover occurred in this period, with greatest relative decrease in slum areas.

Preliminary Results (cont.)

Connecting QuickBird Derived Metrics With Socio-demographic Survey Data for Accra

Table 4 (below) Results from exhaustive exploratory regression analysis between changes in image-, census- and health survey-derived variables. Metrics were computed from registered QuickBird satellite multispectral data captured in 2002 and 2010 and Ghanaian census and health survey data, reflective of housing quality, socioeconomic status, and health conditions. Significant correlations were found for 31 enumeration areas considered to be located in "slum" neighborhoods based on a definition established by UN-Habitat. Understanding the degree of co-variability between LCLUC and quality of life is an integral step in modeling the changing urban gradient of developing countries in Sub-Saharan Africa.

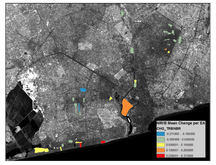

Figure 6. Δ Mean NIR/B values for 31 slum enumeration areas overlaid on a 2002 Quickbird NIR/B image of Accra.

Ordinary Least Squares Regression Results *(only highest reported)*

Dependent Variable	OLS R-squared	Model Predictors					
Δ Charcoal Use	0.25	-Δ Green***					
Δ Trash (dumped offsite)	0.46	-Δ Green/Blue**	-Δ PC 3**	Δ 45^0 Filter **			
Δ Trash (burned or buried)	0.80	-Δ NIR/B***	Δ NIR/B***	Δ Green/Blue***	-Δ PC 3***	Δ Laplacian ***	
Δ Possessions Index	0.40	-Δ NDVI***	-Δ 45^0 Filter **				
Δ % Akan	0.47	Δ Contrast***	-Δ Red**	-Δ Vegetation %**			
Δ % Christian	0.35	Δ Green/Blue*	-Δ PC 2**	Δ Vegetation %**			
Δ % Muslim	0.31	Δ Green/Blue*	Δ PC 2**				
Δ Slum Index	0.70	Δ Homogeneity***	Δ NIR/B***	Δ PC 1***	-Δ Lacunarity***		
Δ Housing Quality Index	0.55	-Δ Homogeneity***	-Δ NIR/R**	-Δ Vegetation %***			

* Significant @ α = 0.10
** Significant @ α = 0.05
*** Significant @ α = 0.01

Benefits of Studying Ghana

- Abundant demographic and health data sets relative to rest of Sub-Saharan Africa
- Stable and democratic government and reasonably safe environment
- Leader in science and technology for Western Africa
- Research team has almost 10 years of experience working there
- Reasonable imagery availability relative to other Western Africa countries

Challenges Studying Ghana

- Prevalent cloud cover and winter Harmattan wind and dust storms
- Limited high spatial resolution satellite coverage for early 2000s
- Limited Landsat-5 TM receiving capability
- Census boundary files require georeferencing and substantial editing by SDSU team

Acknowledgements

- NASA Interdisciplinary Research in Earth Science program grant G00009708, Dr. Garik Gutman, program manager; August 1, 2102 through July 31, 2015
- High spatial resolution satellite data provided through National Geospatial-Intelligence Agency NextView program, facilitated by Jaime Nickeson (NASA GSFC) and Giuseppe Molinario (UMd)