Inter-regional pattern of urbanization in southern Ghana in the first decade of the new millennium

Douglas A. Stow^{1a}, John R. Weeks¹, Hsiao-chien Shih¹, Lloyd L. Coulter¹, Harry Johnson¹, Yu-Hsin Tsai¹, Andrew Kerr¹, Magdalena Benza¹ and Foster Mensah²

¹ Department of Geography, San Diego State University, San Diego, CA 92182-4493, USA

² Center for Remote Sensing and Geographic Information Services, University of Ghana, Legon, Ghana

^a Corresponding author: stow@mail.sdsu.edu, 01-619-594-5498

1 1. Introduction

2 Rural to urban migration is a ubiquitous trend within countries of the Global South (Aide et al
3 2004). On top of this, countries within Sub-Saharan Africa have birth rates that greatly exceed
4 the replacement level (ICF International 2015). The result of these two demographic trends for
5 Sub-Saharan Africa has been the rapid expansion and densification of cities over the past decade
6 or two (United Nations Population Division 2012). Within Ghana, the Sub-Saharan African
7 country of focus in this study, the total population increased from almost 19 million in 2000 to
8 nearly 25 million in 2010—an annual rate of growth of 2.7%—based on data from the censuses
9 in the respective years (Ghana Statistical Service 2012b). During the same period, the Accra
10 Metropolitan Area (AMA) and Kumasi Metropolitan Area (KMA) census districts (analogous to
11 counties in the U.S.), containing Ghana’s two largest urban populations, grew 24.5 % and 73.6%,
12 respectively. Concomitant with such rapid urban population growth has been extensive land
13 cover and land use change (LCLUC), particularly from urbanization--the increase in the
14 percentage of the population living in urban places (Weeks 2015), and urban sprawl--the
15 expansion of urban areas into the adjoining countryside (Bruegmann 2005). Urban expansion has
16 occurred as Built LCLU on formerly agricultural lands in peri-urban and urban hinterlands of
17 Accra and Kumasi, reducing convenient food sources for the growing population (Møller-Jensen
18 et al. 2005; Cobbinah, Gaisie & Owusu-Amponsah 2015).

19 Here we build on previous studies of LCLUC in Ghana, with greater emphasis on
20 urbanization and on the 2000 to 2010 time period. Yorke and Margai (2007) mapped LCLUC in
21 the Densu river basin, located east of Accra using Landsat imagery and post-classification
22 comparison and found that the primary changes in the basin were urban growth, expansion of
23 agricultural land, and decreasing forest cover. Pabi (2007) mapped LCLUC for eight sites in the

24 district of Kitampo in northern Ghana using Landsat imagery and a post-classification
25 comparison approach, finding that a decrease in dense woodlands and an increase in non-
26 intensive cultivation were the primary changes. Also for northern Ghana, Braimoh (2004) used a
27 similar approach to correlate land use change and migration, and determined that decreasing
28 woodlands and increasing agricultural land were useful correlates of higher migration rates. For a
29 similar study area, Braimoh and Vlek (2005) found that the effect of accessibility to roads on
30 agricultural land cover was greater than the effect of population growth. For western Ghana,
31 Kusimi (2008) used image differencing of Landsat data to analyze LCLUC in the Wassa West
32 district and determined that substantial changes in LCLU had occurred due to expansion of
33 mining, farming, urbanization, lumbering and fuel wood extraction. Studies by Møller-Jensen
34 and Yankson (1994) and Møller-Jensen et al. (2005) are among the few that have examined
35 LCLUC in the more urbanized southern Ghana by analyzing patterns of peri-urban development
36 in the outskirts of Accra.

37 While the specific focus is on Ghana, our research builds on and contributes to an ever-
38 wider literature on urbanization and urban sprawl throughout the developing world (see
39 especially Seto 2003, Seto 2005 and Seto, Sánchez-Rodríguez & Fragkias 2010). Every country
40 in the world not already highly urbanized is moving in that direction, with Sub-Saharan Africa
41 lagging behind other regions but in the process of catching up. These trends seem obvious to
42 people on the ground in each locale, but the vast number of growing cities throughout the world
43 renders it impossible to track broader patterns of LCLUC without the assistance of remotely
44 sensed imagery (Sutton 2003; Montgomery 2008; Schneider & Woodcock 2008; Sutton, Taylor
45 & Elvidge 2010).

46 In this paper we analyze the spatial pattern of LCLUC within four contiguous regions

47 (equivalent to states or provinces) of southern Ghana in relation to population change from 2000
48 to 2010. The emphasis is on New Built LCLU, as determined from post-classification
49 comparison of LCLU maps derived from classification of Landsat 7 Enhanced Thematic Mapper
50 Plus (ETM+) for circa 2000 and circa 2010. We use “circa” as a date qualifier because of some
51 uncertainty and variability in the LCLU map representations that stem from imagery limitations
52 due to prevalent cloud cover. For brevity, we refer to the years 2000 and 2010 in the remainder
53 of the paper. We use “Built” to represent a class of LCLU that can include various stages of
54 urban development from land clearing with the intent to build settlements, to completely dense
55 urban core, or forms ranging from a village of huts to industrial land uses. This Built class is
56 similar to the Urban and Built Up Level 1 class of the US Geological Survey Land Use and Land
57 Cover classification system (Anderson et al. 1976); this is the level of urban LCLU classification
58 and mapping that is appropriate for Landsat ETM+ data, especially in areas of predominant
59 cloud cover. The result of LCLUC involving transition from non-Built to Built from 2000 to
60 2010 is referred to as New Built.

61 Within the geographic and temporal context defined above, our objectives in this paper
62 are three-fold: (1) to understand the degree of urban expansion relative to urban densification
63 during this time frame; (2) to understand the relationship between population growth and
64 LCLUC at the census district level; and (3) to explain the patterns of New Built LCLUC.

65

66 2. Study Area

67 The study area consists of the Ashanti, Central, Eastern and Greater Accra regions (four of the
68 ten regions within Ghana), which contain the two most populous metropolitan areas (Accra--
69 including Ashiaman and Tema--and Kumasi) as well as an additional three of the country’s

70 seven most populous cities in 2010 (Cape Coast, Obuasi, and Koforidua). Overall, the study area
71 includes 55% of the total population of Ghana as of 2010, as depicted in Figure 1. Because of its
72 political and economic stability compared to neighbors in the region, Ghana is the focus of
73 extensive research and economic development interest, and one of the few West African
74 countries having good population census and health survey data dating back to at least the 1990s.
75 In 1950 the population of Ghana was 5 million, but the 2010 census counted 25 million
76 Ghanaians and the United Nations (UN) projects the population to be 50 million by 2050 (United
77 Nations Population Division 2015). In 1950 only 15% of the population lived in urban places,
78 but by 2010 52% of the population was urban and by 2050 three-fourths of its people are
79 projected to be urban. In 2010, Ghana Statistical Service (2012a) reported that 2,076,546 people
80 lived in the AMA district (based on consistent boundaries between the two censuses; with an
81 additional 330,756 people in Ashiaman and Tema, which are both part of the Greater Accra
82 Metropolitan Area), 2,035,064 in the KMA district, 169,894 in Cape Coast, 143,644 in Obuasi,
83 and 120,971 in Koforidua (Ghana Statistical Service 2013).

84 The biophysical setting for the study area is mostly influenced by the equatorial wet-dry
85 climate that varies along an aridity gradient from the Gulf of Guinea (which creates the southern
86 boundary of Ghana) to drier lands in the north and particularly the northeast. Variability in
87 natural vegetation conforms to the aridity gradient. Equatorial forests once covered most of the
88 southern and western portions of the study area, but with deforestation, agricultural development
89 and abandonment, forests have been replaced by secondary forest and shrub thicket. Much of the
90 Eastern region and eastern portions of the Greater Accra region are covered by savanna
91 vegetation, which has a high burn frequency from fires set to produce charcoal for cooking. Few
92 non-vegetated lands occur in the study area and are mostly limited to tidal flats near the coast

93 and some rock outcrops in more mountainous areas. Topography is generally flat to hilly, with
94 the exception of low mountains west of Lake Volta and near Obuasi.

95

96 Figure 1. Map of southern Ghana study area depicting four study regions, four major cities and
97 Landsat Thematic Mapper satellite scene boundaries.

98 Agricultural land use is dispersed throughout the non-urban portions of the study area, with
99 small subsistence agricultural plots intermixed with natural vegetation in a complex manner. The
100 predominant crop types are cassava, yam, maize, banana, and plantain. Larger agricultural plots
101 associated with commercial agriculture vary from palm oil plantations in the Central and Ashanti
102 regions to larger mixed crop commercial farms in the savanna lands of the Afram Plain of the
103 Eastern region.

104

105 3. Data and Methods

106 Our general methodological approach was to generate 2000 and 2010 LCLU and LCLUC maps
107 through classification of a dense time series of Landsat multispectral image data, extract
108 population data from decadal census at the district level for the same years, and then to analyze
109 distributions, changes and co-variability of Built LCLU and population variables. We derived
110 and analyzed relative and absolute change, and normalized LCLU and population variables.
111 Descriptive and inferential statistics and district-level map comparisons supported these
112 analyses.

113 Data on LCLUC and particularly urbanization were derived from Landsat 7 ETM+ data.
114 Four adjacent Landsat image scenes, each covering approximately 165 km x 165 km, are
115 required to cover the study area. A very small part of the western portion of the Ashanti region
116 (5% of region and 2% of four-region study area) is not covered by these four Landsat scenes and

117 was excluded from the study due to the high cost of data production relative to the limited added
118 coverage. This area is mostly rural and experienced almost no urbanization within the study
119 period (as interpreted from GoogleEarth imagery). Cloud-free images of the study area are rare
120 and most scenes near the coast typically contain 20%-80% cloud cover, with the mean cloud
121 cover per-scene around 50%. In addition, with the scan line corrector failure in May 2003
122 (resulting in SLC-off conditions), substantial data gaps are present near the edges of all Landsat
123 7 ETM+ scenes collected after 31 May 2003 (Markham et al. 2004). Thus, a multi-temporal
124 compositing approach was used to attain coherent, cloud-free image products from a series of
125 images collected over five-year periods at the beginning (1999-2003) and end (2009-2013) of the
126 study period.

127 A threshold-based, discrete decision rule image classification approach was applied,
128 where each LCLU class was classified in a sequential manner using ERDAS Imagine software.
129 Spectral and texture indices were generated from Landsat 7 ETM+ surface reflectance images
130 and maximum value composite images for each index image for each time period (i.e., 1999-
131 2003 and 2009-2013) were used as input to the image classifier. These indices included: (1)
132 normalized difference vegetation index (NDVI) $[(\text{NIR}-\text{Red})/(\text{NIR}+\text{Red})]$, (2) normalized
133 difference water index $[(\text{Green}-\text{NIR})/(\text{Green}+\text{NIR})]$ spectral variability vegetation index (SVVI)
134 $[\sigma_{\text{infrared}} - \sigma_{\text{all}}]$ and texture SVVI, where Green, Red and NIR are ETM+ bands 2, 3 and 4,
135 respectively, σ_{infrared} is the pixel-wise standard deviation of bands 4,5 and 7, σ_{infrared} is the pixel-
136 wise standard deviation of bands 1 through 7 (not included the band 6 thermal infrared band),
137 and texture SVVI is the spatial standard deviation of a 3 x 3 kernel of SVVI values. Threshold
138 values used to classify the LCLU classes were calibrated using visual and quantitative methods,
139 and the calibration work was performed with 1999-2003 Landsat imagery not affected by SLC-

140 off data gaps. Threshold values were determined through visual interpretation and trial and error
141 adjustments based on accuracy statistics for test areas. Following classification of individual
142 LCLU classes, resulting layers were merged into single multi-class products using discrete
143 decision rules and a specific priority, as described at the end of this section.

144 Synthetic aperture radar imagery from ERS-2 and ENVISAT satellites was also
145 incorporated to aid in the detection of small settlements in rural areas. A layered (class-by-class)
146 image classification approach based on threshold values of composited spectral indices and
147 derived spatial texture products was implemented. Visual interpretation of the Landsat 7 ETM+
148 and Landsat 8 OLI data enabled the automated classification products to be refined and edited.
149 Further details of the image classification procedures used to generate LCLU maps for 2000 and
150 2010 and subsequently data on LCLUC between 2000 and 2010 are provided in Coulter et al.
151 (submitted).

152 The output classification products portray eight LCLU classes: Water, Forest, Built,
153 Agriculture, Secondary Forest, Savanna, Commercial Agriculture, and Mining. Water, Forest,
154 Built, Secondary Forest, Savanna, and Agriculture were classified using semi-automated
155 processing, while Commercial Agriculture and Mining were delineated using visual
156 interpretation.

157 The accuracy of c.2000 and c.2010 LCLU maps and associated LCLUC product was
158 assessed based on stratified random sampling. For the LCU maps 30 samples were selected for
159 each of the six classes (strata), except for the Built class. Given the importance of the Built class
160 for urbanization and population analyses, 60 samples were selected for the accuracy assessment.
161 Mapped areas within the four-region study area that were selected for accuracy assessment were
162 limited to: (1) patches of c.2000 LCLU where 5x5 blocks of pixels (150x150 m) contain the

163 same class and represent consistent LCLU and (2) areas containing cloud-free c.2000 SPOT 10
164 m (10 scenes) and 5 m (one scene) panchromatic imagery to be used for visual reference for the
165 accuracy assessment. The overall accuracy of the 2000 and 2010 LCLU maps is 95% and 89%,
166 respectively. In addition, the Built class was found to have a user's accuracy of 100% and 100%
167 and a producer's accuracy of 98% and 100%, for 2000 and 2010, respectively..

168 Maps and tabular data on LCLUC were derived by post-classification comparison of the
169 LCLU maps representing the beginning and end of the study period. An emphasis is placed on
170 Change to Built (an indicator of urbanization), meaning that LCLU transition was "from" non-
171 Built (e.g., Forest, Agriculture, Secondary Forest, or Savanna) in 2000 and "to" Built in 2010, for
172 the LCLUC transition sequence. The accuracy of the LCLUC product was based on the three
173 primary classes of interest: Built, Agriculture, and Natural Vegetation. Thirty stratified random
174 points were generated for each of six transition types that did not represent Built in c. 2000 (since
175 these should not change). The accuracy of Agriculture to Built and Natural Vegetation (i.e.,
176 Forest, Secondary/Degraded Forest, and Savanna) to Built is 83% and 72%, respectively, and the
177 commission error of Agriculture to Built and Natural Vegetation to Built is 17% and 19%,
178 respectively.

179 Areal amounts and percentages of LCLU classes were tabulated at the census district
180 level. Census data and accompanying district (and other) boundary geographic information
181 system (GIS) files for 2000 and 2010 were obtained from Ghana Statistical Service. Substantial
182 reconciliation of district boundaries between the 2000 and 2010 census by manual editing was
183 required because of shifting boundaries and inconsistent base maps. In 2000, the country had
184 been divided into 110 districts (the second-level geographic boundaries) distributed within the 10
185 regions (first-level geographic boundaries, comparable to states in the U.S.) and by 2010 the

186 number of districts **had** increased to 170 because of population growth (**Ghana Statistical Service**
187 **2012c**). In order to measure change over time, it was necessary for us to create a crosswalk
188 between the 2000 and 2010 district boundaries so that data for 2010 could be aggregated back to
189 the 2000 boundaries. We began with the geographically more detailed and more accurate 2010
190 district boundary files and adjusted all 2000 district boundaries accordingly. Then we dissolved
191 the 2010 boundaries into the 2000 district polygons to form a consistent set of geographic units
192 for temporal change analysis.

193 Buffers based upon distance from major roads were generated to analyze the association
194 of urbanization with major roads. Road GIS layers were obtained from OpenStreetMap. We used
195 the two highest (primary and secondary) categories of major roads. These vector maps were
196 overlaid on orthorectified high spatial resolution satellite imagery to verify major road status and
197 edit road positions. Buffers of 0 -250 m, 250-500 m, 500 – 1000 m, 1000 – 2000 m, 2000 –
198 5000 m and > 5000 m were generated, based on the expectation that the percentage of New Built
199 would follow a distance decay pattern.. Thus, percentages of New Built LCLUC pixels were
200 derived for each distance from road buffer.

201 Quantitative and qualitative examinations of spatial-temporal patterns of change to Built
202 LCLU in relation to total population and its change during the study period were conducted
203 through descriptive and inferential statistical analysis and visual map interpretation. Various
204 derivative measures, such as relative change (absolute change per 2000 baseline) and density
205 (quantity per district for 2000 Built or Non-Built areas), were calculated and analyzed for both
206 LCLU and population variables. We conducted bivariate regression analysis for different
207 combinations of Built and New Built versus population and population change variables. Linear,
208 log-linear, and semi-log regressions were run. We also ran stepwise multiple regressions to

determine how well 2010 Built variables could be estimated from 2000 population and Built variables, and insured that models met regression criteria of normality, non-collinearity and spatial independence.

4. Results

4.1 Amount and distribution of New Built LCLU

A total of 872.4 km² in land area or 1.5% of the four-region study area transitioned to Built LCLU, based on post-classification comparison of the 2000 and 2010 LCLU maps derived from Landsat image data sets, as shown in Table 1. This represents a 55.5% increase relative to the area of Built in 2000. The largest areal extent (294.7 km²) of New Built LCLU occurred in the Ashanti region, followed closely by the Greater Accra region with 278.9 km². Much less Built development occurred in the Central and Eastern regions and where it did occur was mostly in peri-urban areas of Accra that lie within the Central region.

Table 1 (landscape format) at bottom of document – to be inserted here

A map of change to Built LCLU from 2000 and 2010, which also depicts the 2000 (“from”) class for the entire four region study area is shown in Figure 2. The general pattern of urbanization during the study periods portrayed in Figure 2 is dominated by urban sprawl (Bhatta et al. 2010) in suburbs and peri-urban developments, particularly north and west (along the coast) of Accra, surrounding Kumasi in most directions, and as strip development along major highways and roads. Infill also occurred within Accra and to a lesser degree in Kumasi. Urban development is more scattered around the mid-size cities of Obuasi, Cape Coast and Koforidua. Most small towns and larger villages exhibit some degree of expansion from 2000 to 2010. Very

231 few instances of scattered or isolated Built development (i.e., New Built located away from 2000
232 Built) are evident.

233 The vast majority (85%) of the transition to Built LCLUC map occurred from Agriculture
234 land cover, while 15% of the New Built transitioned from Natural Vegetation. Most of the peri-
235 urban expansion of Built occurred as a replacement of Agriculture, while some (but still a
236 minority) of the expansion of Built in more rural areas and around small settlements involved
237 replacement of Natural Vegetation.

238

239 Figure 2. Maps of New Built LCLU occurring between 2000 and 2010 for the entire four region study
240 area, and enlarged display of region surrounding Kumasi (top right) and Accra (bottom right). The map
241 of New Built is based on spatial cross-tabulation (pixel-level) of 2000 and 2010 LCLU maps derived
242 from a layered, rule-based classification of a dense time stack of Landsat ETM+ images for each
243 period.

244 The association of New Built with distance from major roads for the four regions and the
245 entire study area (not including the already urbanized AMA and KMA districts) is portrayed in
246 Figure 3. Eighty-nine percent of New Built occurred within 5 km of major roads; the lowest
247 percentage (11%) occurred for areas greater than 5 km from major roads. Within the 5 km buffer,
248 the percentages of New Built are fairly evenly distributed for the six interval classes shown in
249 Figure 3, with 0 – 250 m and 2 – 5 km having the highest percentages at about 21%. Since the
250 intervals for these distance buffers were selected to increase as a function of distance from major
251 roads, the relatively equal distributions per interval class confirms our expectations and visual
252 observations that percentage New Built decreases non-linearly as a function of distance from
253 major roads. Development in the more rural districts almost exclusively occurred along major
254 roads, which explains why almost a third of New Built occurred within 250 m in the Eastern

255 region that is mostly rural. Greater amounts of New Built occurred at farther distances from
256 major roads in suburban and peri-urban districts of the mostly urbanized Greater Accra region,
257 because of the presence of minor roads that enable more convenient transport of building
258 materials and access to infrastructure, food sources and employment opportunities.

259

260 Figure 3. Bar graphs showing percentages of New Built land area for five distances from road interval classes, for
261 each of the four regions and all four regions combined. Data for heavily urbanized Accra Metropolitan Area and
262 Kumasi Metropolitan Area districts were excluded.

263

264 4.2 District level analysis of Built and population distributions and changes

265 Distributions of percentage Built and population density for 2000 and 2010 and their
266 changes between those dates are portrayed as census district-level maps in Figure 4. The highest
267 densities of Built LCLU and population for both years are located in the AMA and KMA
268 districts as well as in several suburban/peri-urban districts surrounding them, consistent with
269 other research (Doan and Oduro 2012). The degree of correspondence between population
270 change and land cover change to Built is visually apparent between 2000 (Figures 4a and 4d) and
271 2010 (Figures 4b and 4e) (i.e., static) maps and less apparent for maps depicting changes in Built
272 cover and population density (Figures 4c and 4f).

273

274 Figure 4. District-level maps of percentage Built and population density for 2000 and 2010 and 2000 to 2010
275 changes between those dates. (a) 2000 Built percentage, (b) 2010 Built percentage, (c) change in Built percentage,
276 (d) 2000 population density, (e) 2010 population density, and (f) absolute change in population density.

277

278 The amounts, percentages and densities of Built LCLU and total population for 2000,
279 2010 and change from 2000 to 2010 for the four-region study area and for the top 15 districts in
280 terms of % New Built are listed in Tables 1 and 2, respectively. In 2000 the AMA district had the
281 highest percentage of Built and population density, and both variables increased substantially in
282 the intercensal period. As can be seen in Table 2, Built percentage in the AMA increased over
283 time as the AMA was becoming built out (89% Built in 2010), so we can infer that population
284 pressure was pushing LCLUC. At the same time, LCLU and population change were much more
285 dramatic in the four districts surrounding the AMA--Tema, Ga, Dangbe West, and Awutu.
286 However, Built percentage in those mostly peri-urban districts was declining over time due to
287 the fact that the Built area was increasing at a faster rate than the population, as Built
288 development preceded population growth.

289 As was true for the AMA, the KMA district exhibited a high (indeed, the highest)
290 increase in both Built percentage and population density. However, its surrounding districts
291 (Bosomtwi, Afigya/Kwabre/Skeyere, and Ejisu/Juaben) exhibited an increase in percent Built
292 that was faster than population growth, as was true for the peri-urban areas of Accra.

293 *Table 2 (landscape format) at bottom of document – to be inserted here*

294 By far the greatest amount of land area of New Built occurred in suburban and peri-urban
295 areas of Accra and particularly in the Ga district (143.1 km²), followed by Awutu and Tema
296 districts at just over 83 km². Unlike the AMA--which was already largely built out in 2000--
297 much of the urban expansion of the Kumasi metropolitan area occurred within the KMA (49.0
298 km²), although the adjacent district of Bosomtwi had an even greater increase of 51.7 km² Built
299 land area.

The highest rates of urbanization, represented by New Built as a percentage of 2000 Built (i.e., relative change in Built) can be observed in Table 2 and are shown in Figure 5a. The districts surrounding or nearby the AMA (particularly Awutu, Ga and Tema) and KMA (e.g., Afigya, Bosomtwi and Ejisu) had the highest rates of New Built, showing that most of the New Built occurred as either part of or a prelude to suburbanization and peri-urban development. The Tema district, just to the east of AMA, which was already established as an urban satellite center to Accra in the 2000 period, still had the second highest percentage of New Built within the district.

The spatial distribution of Built change per developable (i.e., Non-Built) land ([2010-2000 Built]/2000 Non-Built) is displayed in Figure 5b and shown in Table 2. As would be expected, the districts that were already heavily urbanized in 2000 exhibit the highest rates of urban development per land available for development, with AMA (40.4%) and KMA (58%) having much higher percentages. By 2010 the AMA and KMA were 89% and 85% respectively “built out”, with Tema district at 50% and the other districts < 40%.

Figure 5. District-level maps of Built change. a. Relative Built change ([2010-2000 Built]/2000 Built), b. Built change per developable land ([2010-2000 Built]/2000 Non-Built).

With respect to population, the greatest numerical (860,160 people), relative (+73.6%) and density (3560 km^{-2}) increases occurred within the KMA district, almost twice the same measures as for the AMA. The Ga district that surrounds the AMA to the north and west exhibited numerical (458,650), relative (+83.0%) and density (541 km^{-2}) population increases that were second highest to KMA (higher in relative change) and higher than AMA. These population change measures for the urban core districts of the study area are substantially higher

324 than the other districts, even though areal amounts and rates of Built change were higher in the
325 suburban and peri-urban districts. This reflects both the already high population size and density
326 at the beginning of the study period in the urban core districts, and the desire of people to live
327 close to the urban core. Since residential housing tends to be low-rise throughout sub-Saharan
328 Africa, the demand for housing is best met in the suburban and peri-urban areas, which explains
329 the development occurring in those areas in anticipation of demand.

330 Note that we are introducing a new measure of density that relates population size in a
331 district to that district's Built area (population per Built area). This measure is shown at the
332 region level in Table 1 and for the top 15 districts in Table 2, and is portrayed in Figure 6. An
333 important use of this population per Built area measure is in its change over time. If it declines, it
334 may indicate change to Built is proceeding at a faster pace than population growth, and thus the
335 change in LCLU is foreshadowing an increase in the population. If, on the other hand, the
336 population per Built area is increasing, we infer that population is increasing more quickly than
337 the conversion of land to Built, although that reaches its limit as the percent Built approaches
338 100% in any given district (e.g, AMA and KMA). An interesting spatial-temporal pattern is
339 observed, where the AMA and KMA urban core areas exhibit some of the highest levels of
340 population per Built area, as expected, but the highest levels actually correspond to the most
341 rural, savanna districts in the northeast portion of the study area. Some of the latter could be due
342 to rural populations living in areas not identified as Built, e.g., residential structures that are
343 small or may exist under vegetated canopy and thus not directly observable by the satellite
344 imagery. A general trend can be seen in Figure 6c where the northern part of the study area
345 (particularly Ashanti region) exhibits strong declines in population per Built area density while
346 the southwestern portion shows slight increases. Again, declines in population per built Built

347 area likely signify that the New Built area is expanding faster than (e.g., ahead of) population
348 growth.

349

350 Figure 6. District-level maps of population per Built land area with pie charts showing percentage of Built (black)
351 and non-Built (white) areas for each district. (a) 2000; (b) 2010; (c) 2000-2010 change.

352

353 4.3 Explaining the Observed Patterns

354 Bivariate linear regression results for static (single year) population vs. Built variables
355 (district level) are shown in Table 3, with scatterplots and least square lines and regression model
356 parameters for the relationships with the highest R^2 values for 2000 and 2010 shown in Figures
357 7a and 7b. All population vs. Built variable combinations yielded significant relationships for
358 linear and non-linear models, with R^2 values ranging from .36 to .95. Linear models and
359 particularly those based on population density (population per unit area) vs. % Built area per
360 district area yielded the highest regression coefficients (exceeding .90). Non-linear models
361 yielded higher R^2 values for a few of the population vs. Built combinations, but none were as
362 high as the population density vs. %Built linear model. Extreme population and Built
363 magnitudes for AMA and KMA districts enhance an apparent linear trend and ensure high R^2
364 values for many variable combinations as can be seen in Figure 7.

365 Table 3. Linear regression model coefficients (R^2 values) for
366 various combinations of static Built LCLU on population variables.
367

	Bu2000	%Bu2000	Bu2010	%Bu2010
Pop2000	.79	.88	.54	.82
Pop2010	.83	.87	.62	.86
PopDens00	.63	.94	.36	.84
PopDens10	.65	.95	.39	.88

368

369 *Note:* $n=43$; all coefficients are statistically significant at $p<.05$

370 Pop = population, Dens = density, Bu = Built

371

372 Bivariate regression results for linear and log-linear models and dynamic (change)

373 population vs. Built variables (district level) are shown in Table 4, with scatterplots and least

374 square lines and regression model parameters for the relationships with the highest R^2 values for

375 2000 and 2010 shown in Figures 7c and 7d. The highest R^2 values were for the log-linear model

376 of population density change vs. %New Built (.57) and the linear model of population density

377 change vs. New Built area/2000 Non-Built area (.86). None of the models for population change

378 vs. relative Built change (New Built/2000 Built) were significant.

379

380 Figure 7. Scatterplots and least square lines for significant regression models of several population vs. Built variable

381 combinations: (a) 2000 population density vs. 2000 %Built, (b) 2010 population density vs. 2010 %Built, (c) log

382 population density change vs. log %NewBuilt, and (d) population density change vs.

383 NewBuiltArea/2000NonBuiltArea. $n=45$ and $p<.05$.

384

385

Table 4. Regression model coefficients (R^2 values) for various combinations of New Built on population change variables. a. Linear models, b. Log-linear models

a.	NewBu	%NewBu	RelNewBu	NBu/NnBu00
PopChng	.27*	.56*	.00	.84*
RelPopChng	.23*	.27*	.00	.19*
PopDnsChng	.08	.43*	.02	.86*

$n=46$

* models significant at $p < .05$

b.	NewBu	%NewBu	RelNewBu	NBu/NnBu00
PopChng	.31*	.30*	.00	.36*
RelPopChng	.08	.11*	.00	.11*
PopDnsChng	.25*	.57*	.01	.65*

$n = 43$

* models significant at $p < .05$

Pop = population, Dens = density, Bu = Built, Chng = change,

Rel = relative, N = new, Nn = non-

Stepwise multiple regression models yielded two informative models for estimating

%Built in 2010 based on 2000 population and Built variables that met all normality, non-

collinearity and spatial independence criteria. A two-component model with log 2000 population

density and 2000 Built area as independent variables resulted in an adjusted R^2 of .91. A three-

component model that also included 2000 population per 2000 Built area was not significantly

different than the two-component model.

5. Discussion and Conclusions

5.1 Distribution of New Built as an indicator of urbanization

A substantial amount of Built LCLUC occurred between 2000 and 2010 in the four-region study

area of southern-central Ghana, mostly as urban expansion associated with a relatively rapid

increase in population. Almost 52% of this New Built LCLU occurred in six suburban and peri-

urban districts near the AMA and KMA, suggesting that most of the development occurred as

412 urban sprawl, as described by Cobbinah and Amoako (2012) for the KMA. Residential structures
413 in the study area are rarely more than two stories, and most of the AMA and much of the KMA
414 were already covered by Built LCLU in 2000. Thus, most New Built development in the major
415 urban centers occurred primarily as “expansion” growth, according to the five classes of urban
416 growth defined by Wilson et al. (2003). Limited densification associated with multi-story
417 development or “infill” growth occurred in the AMA, which already had 80% Built cover in
418 2000 and was 89% built out by 2010. The form of urbanization in both the Greater Accra and
419 Kumasi metropolitan areas (the larger and less officially defined metropolitan extents that
420 include Accra and Kumasi cities) can also be classified as “expansive-growth cities with
421 extensive dispersion at low population densities” following the urban growth classification
422 system of Schneider and Woodcock (2008). The only “outlying” type of urban development
423 occurred in the southeastern portion of the Central region (e.g., the town of Kasoa), along the
424 coastal strip just west of and beyond the sprawling expansion of the Greater Accra metropolitan
425 area. These new and expanding settlements are close enough to the economic activities in Accra
426 and Tema for residents to commute to work.

427 The Built area of most small cities and villages in rural areas also expanded between
428 2000 and 2010, as urbanization occurred in patterns that included expansion and infill.
429 Substantial strip development or “linear branch” growth (Wilson et al. 2003) occurred along
430 primary and secondary roads in rural areas, particularly in the Ashanti and Eastern regions. The
431 only isolated New Built occurred among small villages away from major roads, where residents
432 travel mostly by foot to subsistent agricultural plots. “Isolated” growth—the formation of new
433 villages away from other development--was not observed.

434 5.2 Field observations

435 In winter 2014 two of the authors conducted a field reconnaissance trip throughout much of the
436 four-region study area. Geo-tagged ground images were captured to document evidence of recent
437 Built development. All four of the major cities were visited, with most observations occurring
438 along the expanding urban edge and along major roads extending from and connecting the cities.
439 Though the observations were made four years after the study period and were limited in spatial
440 extent with spatial bias (e.g., expansion over infill), they were very useful in helping to explain
441 satellite-derived patterns of LCLUC for the study period.

442 Two important types of information related to urbanization in the study area emerged
443 from our field observations that could not be discerned or inferred from interpretation or
444 classification of Landsat ETM+ data, or even high spatial resolution commercial satellite data
445 that we are using for more detailed intra-urban analyses. The first is that residential development
446 in the study area can be a long, protracted process, such that ground breaking to building
447 completion and owner occupancy may take five to ten years or more. Residential structures in
448 incomplete or abandoned states of construction are common elements of the urban and suburban
449 landscape, and are often the sites of residential occupancy by squatters or renters. The other
450 primary observation is that suburban and peri-urban expansion that has been the predominant
451 form of urbanization in the study area is not necessarily occurring as “the seemingly
452 uncontrollable slums sprawling around the capital cities in developing countries” described by
453 Besussi et al (2010:16), but more commonly as lower density settlements of moderate to high
454 quality residential housing, albeit with limited urban infrastructure. Based on qualitative
455 interviews and informal observations, we hypothesize that many of the numerous large and
456 apparently high quality structures are built by wealthier family members with the intention to
457 provide housing for members of an extended family. These may be financed in particular by

458 remittances from family members working abroad. Typical examples of both incomplete and
459 high quality residential structures are shown in Figure 8.

460 5.3 Relationship between LCLUC and population change

461 Determining the relative timing and degree of association between urbanization and population
462 change is challenging, particularly when based on decadal data sets for a single ten-year period.
463 Clearly, population increased substantially within our Ghanaian study area, which has driven the
464 need for greater housing stock and urban infrastructure to support these added residents.
465 Furthermore, the population in these areas was already growing at the beginning of the study
466 period, so the increase in Built area is partly a response to an increase in demand for housing and
467 other buildings associated with urban living. Both static and dynamic measures of Built and
468 population are significantly and linearly correlated at the district level, with the reminder that
469 such correlations are enhanced by the extreme values of AMA and KMA. For example, there is
470 a moderate R^2 (.25) between the intercensal rate of population growth in a district and the
471 percentage of its total area that was converted to Built in the intercensal period. However, if we
472 restrict our attention to only those districts that already had at least 200,000 people in 2000, the
473 R^2 jumps to .73. Urbanization is taking place most decisively in those districts that were already
474 most populous at the start of the study period.

475 It is not possible to draw cause and effect relationships between Built and population
476 change from our limited data, and it is likely that relationships are operating in both directions. In
477 some places it is likely that past or expected future population is driving change in land use,
478 whereas in other locations it may be the opposite. For example, AMA, KMA, Tema and also
479 several rural districts exhibit higher relative population than Built change, while the
480 suburban/peri-urban districts around both Accra and Kumasi experienced much higher relative

481 changes in Built than in population growth. This agrees with our field observations of what
482 appeared to be speculative (unoccupied) housing development around Kumasi and other parts of
483 the Ashanti region, and suggests that in some urbanizing areas Built LCLUC is driving localized
484 population changes. Through surveys of inhabitants and logistic regression models, Appiah et al.
485 (2014) concluded that three important drivers of peri-urbanization in the Bosomtwi district south
486 of Kumasi (a district that went from 3 % Built in 2000 to 10% Built in 2010 -- one of the greatest
487 increases in percent Built among all districts), were: (1) availability of social amenities, (2)
488 increasing physical infrastructure, and (3) easy access to land, although population change was
489 deemed to have an interaction effect.

490 5.4 Data challenges

491 Both primary sources of data used in this study, Landsat TM and GSS census data, presented
492 significant challenges in terms of timeliness and quality. However, in contrast to much of sub-
493 Saharan Africa, at least they are available for studies such as ours.

494

495 Figure 8. Ground images from Ghana study area taken February 2014. a. Example of unfinished residential
496 structure, where building can take five to ten years to complete and squatters may reside during various stages of
497 construction. b. Example of large, moderate to high quality residential structures commonly built in the peri-urban
498 areas of Accra and Kumasi.

499 Landsat imagery availability and quality has been limited because of the lack of a
500 Landsat 5 TM ground station in Western Africa and because the area is prone to cloud cover and
501 associated shadows, smoke, haze and dust transported by the Harmattan (dry desert winds).
502 These factors, along with the Landsat 7 ETM+ scan line corrector off (SLC-off) effect since
503 April 2003 (Storey 2005) result in a noisy and patchy image time sequence. For the Landsat
504 scene that covers Greater Accra and much of the Eastern region during period 1999 to 2014, two

cloud free Landsat 7 ETM+ images were captured and one of these was influenced by SLC-off effects). By exploiting the dense time series of surface reflectance products from Landsat 7 ETM+ we were able to develop reliable LCLU classification products, though for a fairly general level of class specificity (e.g., Built, Agriculture and Natural Vegetation). Thus, our analyses of urbanization are limited to the general Built category, without a differentiation for areas used for residential and non-residential activities.

Accessing and analyzing district-level census data from Ghana Statistical Services also presented a challenge. The 2010 census tables became available in 2013, district boundary files in 2014 and finer level enumeration area boundary files are still not completed for much of Ghana. As mentioned in the Data and Methods section, considerable effort was required to reconcile discrepancies between the 2000 and 2010 district boundaries. Using 2010 district boundaries as the basis facilitated this reconciliation. We are reasonably confident that population numbers have been apportioned to the proper spatial units in a manner that is consistent between the two years.

5.5 Policy implications

At first glance, impacts of urbanization on food security may be considered an issue given that a majority of the urbanization in the study area occurred at the expense of agricultural land use and population increased by approximately 25% and 75% respectively in the greater metropolitan areas of Accra and Kumasi. However, while replacement of Agriculture by Built LCLU was prevalent, Agriculture lands expanded (i.e., Natural Vegetation to Agriculture LCLUC) by 8860 km² (15.6% of study area). Research by Appiah et al. (2014) in the Ashanti region suggests that farmers may sell land in peri-urban areas as land prices rise. This may then lead them to start up farming in areas beyond the reach of higher land prices.

Information on the rates and distribution of land being converted to Built, and other LCLUC, such as that associated with agriculture, may help national and regional level decision makers to understand land development trends and potentially develop and/or implement comprehensive national policies. In 1999, the Ghana Ministry of Lands and Forestry (1999) instigated a National Land Policy to regulate land development. However, even with regulations in place, illegal development has occurred extensively around the country, because law enforcement may be compromised both by lack of resources and by local tribal chiefs who have strong control over land development. The rapid growth of the Greater Accra Metropolitan area has been characterized by a high degree of informality and a low level of formal infrastructure, with implications for land use planning. Our LCLUC maps may provide insight into locations where past development has occurred in the context of disagreements between government land policy and tribal chief decisions. More regular monitoring of illegal development can support regulation and mitigation of rapid or unwise urbanization, such that the National Land Policy can be better enforced (Cobbinah and Amoako 2014).

Acknowledgements

This work was supported by the Interdisciplinary Research in Earth Science (IDS) program of the National Aeronautics and Space Administration (NASA), NASA award number G00009708. NASA and the National Geospatial-Intelligence Agency (NGA) provided high spatial resolution, commercial satellite imagery through the NextView license agreement. The European Space Agency provided ERS-2 and ENVISAT RADAR image data.

References

553 Aide, T. M., & H. R. Grau (2004). Globalization, migration, and Latin American ecosystems.
554 *Science*, 305, 1915.

555 Anderson, J. R., Hardy, E. E., Roach, J. T., & Witmer, R.E. (1976) A land use and land cover
556 classification system for use with remote sensor data, U.S. Geological Survey Paper 964,
557 Washington, DC: U.S. Government Printing Office, 36 p.

558 Appiah, D. O., Bugri, J. T., Forkuo, E. K., & Boateng, P. K. (2014). Determinants of peri-
559 urbanization and land use change patterns in peri-urban Ghana. *Journal of Sustainable*
560 *Development* 7, 95-109.

561 Besussi, E., Chin, N. Batty, M., & Longley, P. (2010). The structure and form of urban
562 settlements. In *Remote Sensing of Urban and Suburban Areas*, eds. T. Rashed and C.
563 Jürgens, 13-32. Dordrecht: Springer.

564 Bhatta, B., Saraswati, S., & Bandyopadhyay, D. (2010). Urban sprawl measurement from remote
565 sensing data. *Applied Geography* 30: 731–740.

566 Braimoh, A. K. (2004). Seasonal migration and land-use change in Ghana. *Land Degradation &*
567 *Development*, 15, 37-47.

568 Braimoh, A. K., & Vlek, P. L. G. (2005). Land-cover change trajectories in northern Ghana.
569 *Environmental Management*, 36, 356-373.

570 Bruegmann, R. (2005). *Sprawl: A Compact History*. Chicago: University of Chicago Press.

571 Cobbinah, P. B., & Amoako, C. (2012). Urban Sprawl and the Loss of Peri-Urban Land in
572 Kumasi, Ghana. *International Journal of Social and Human Sciences* 6, 388-397.

573 Cobbinah, P. B., Gaise, E., & Owusu-Amponsah, L. (2105). Peri-urban morphology and
574 indigenous livelihoods in Ghana. *Habitat International* 50:120-129.

575 Coulter, L. L., Stow, D. A., Tsai, Y.- H., Ibanez, N., Shih, H.- C., Benza, M., Weeks, J. R., Kerr,
576 A., & Mensah, F. (submitted). Classification and assessment of land cover and land use
577 change in southern Ghana using dense stacks of Landsat 7 ETM+ imagery, *Remote*
578 *Sensing of Environment*.

579 Doan, P., & Oduro, C.W. (2012). Patterns of population growth in peri-urban Accra, Ghana.
580 *International Journal of Urban and Regional Research*, 36, 1306-1325.

581 Ghana Ministry of Lands and Forestry (1999). *National Land Policy*, Accra, Ghana, 27 pp.
582

583 Ghana Statistical Service (2012a). *2010 Population & Housing Census Summary Report of Final*
584 *Results*. Accra: Ghana Statistical Service.

585 ———(2012b). *2010 Population & Housing Census: Summary Report of Final Results*. Accra,
586 Ghana: Ghana Statistical Service.

587 ———(2012c). *Report of the Committee on District Boundary Disputes Relating to the 2010*
588 *Population and Housing Census*. Accra, Ghana: Ghana Statistical Service.

589 ———.(2013). *2010 Population & Housing Census National Analytical Report*. Accra, Ghana:
590 Ghana Statistical Service.

591 ICF International. 2015. *Measure DHS Statcompiler* 2015 [cited 2015]. Available from
592 <http://www.statcompiler.com>.

593 Kusimi, J. M. (2008) Assessing land use and land cover change in the Wassa West District of
594 Ghana. *GeoJournal*, 71, 249-259.

595 Markham, B. L., Storey, J. C., Williams, D. L., & Irons, J. R. (2004). Landsat sensor
596 performance: history and current status. *IEEE Transactions on Geoscience and Remote*
597 *Sensing*, 42, 2691-2694.

598 Møller-Jensen, L., Kofie, R. Y., & Yankson, P. W. (2005). Large-area urban growth
 599 observations—a hierarchical kernel approach based on image texture. *Geografisk*
 600 *Tidsskrift-Danish Journal of Geography*, 105, 39-47.

601 Møller-Jensen, L., & Yankson, P. (1994). Assessing the land cover change of Accra using
 602 Landsat-TM data. *Geografisk Tidsskrift-Danish Journal of Geography*, 94, 21-25.

603 Montgomery, M., (2008). The Urban Transformation of the Developing World. *Science* 319
 604 (5864):761.

605 Pabi, O. (2007). Understanding land-use/cover change process for land and environmental
 606 resources use management policy in Ghana. *GeoJournal*, 68, 369-383.

607 Schneider, A., & Woodcock, C. E. (2008). Compact, dispersed, fragmented, extensive? A
 608 comparison of urban growth in twenty-five global cities using remotely sensed data,
 609 pattern metrics and census information. *Urban Studies*, 45, 659-692.

610 Seto, K. C. (2003). Modeling the Drivers of Urban Land Use Change in the Pearl River Delta,
 611 China: Integrating Remote Sensing with Socioeconomic Data. *Land Economics* 79
 612 (1):106-121.

613 Seto, K. C. (2005). Economies, Societies, and Landscapes in Transition: Examples from the
 614 Pearl River Delta, China, and the Red River Delta, Vietnam. In *Population, Land Use,*
 615 *and Environment*, eds. B. Entwisle and P. C. Stern. Washington, DC: National
 616 Academies Press.

617 Seto, K. C., Sánchez-Rodríguez, R., & Fragkias, M. (2010)Mont. The New Geography of
 618 Contemporary Urbanization and the Environment. *Annual Review of Environment and*
 619 *Resources* 35 (1):167.

620 Sutton, P. C. (2003). A Scale-Adjusted Measure of "Urban Sprawl" Using Nighttime Satellite
621 Imagery. *Remote Sensing of Environment* 86:353-369.

622 Sutton, P., M. J. Taylor, and C. Elvidge. (2010). Using DMSP OLS Imagery to Characterize
623 Urban Populations in Developed and Developing Countries. In *Remote Sensing of Urban
624 and Suburban Areas*, eds. T. Rashed and C. Juergens, 329-348. Dordrecht: Springer.

625 United Nations Population Division (2012). *World Urbanization Prospects, the 2011 Revision:
626 Glossary of Demographic Terms*. United Nations 2012 [cited 2014]. Available from
627 http://esa.un.org/unpd/wup/Documentation/WUP_glossary.htm.

628 Weeks, J. R. (2105). *Population: An Introduction to Concepts and Issues, 12th Edition*. Boston:
629 Cengage Learning.

630 Wilson, E. H., Hurd, J. D., Civco, D. L., Prisloe, M. P., & Arnold, C. (2003). Development of a
631 geospatial model to quantify, describe and map urban growth. *Remote Sensing of
632 Environment* 86, 275-285.

633 Yorke, C., & Margai, M. P. (2007). Monitoring land use change in the Densu River Basin,
634 Ghana using GIS and remote sensing methods. *African Geographical Review*, 26, 87-
635 110.

Table 1. Amounts, percentages and densities of Built LCLU and total population for 2000, 2010 and change from 2000 to 2010 for the four study regions.

Region	Area (km ²)	Built 2000 (%)	Built 2010 (%)	Absolute Built Change (km ²)	Relative Built Change (%)	New Built (%)	Built Change per nonBuilt 2000 (%)	Natural Vegetation to Built (%)	Agriculture to Built (%)	Pop. 2000 (10 ³ people)	Pop. 2010 (10 ³ people)	Pop. Change (10 ³ people)	Relative Pop. Change (%)	Pop. density 2000 (km ⁻²)	Pop. density 2010 (km ⁻²)	Pop. density change (km ⁻²)	Pop/ Built Area 2000 (km ⁻²)	Pop/ Built Area 2010 (km ⁻²)	Pop/ Built Area change (km ⁻²)
Ashanti	24904.0	2.0	3.2	294.7	59.3	1.2	1.2	15.8	84.2	3621	4766	1146	31.6	148.5	195.5	47.0	7285.9	6021.4	-1264.5
Central	9653.9	2.6	4.2	156.3	62.0	1.6	1.7	24.3	75.7	1589	2207	619	38.9	164.4	228.4	64.0	6321.8	5422.1	-899.7
Eastern	18523.3	1.6	2.4	142.5	45.9	0.7	0.8	20.7	79.3	2118	2632	514	24.3	111.5	138.6	27.1	6892.1	5868.7	-1023.4
Greater Accra	3696.3	13.8	21.3	278.9	54.5	7.5	8.7	8.8	91.2	2916	4012	1097	37.6	786.7	1082.5	295.8	5698.6	5075.5	-623.2
Total Area	56777.5	2.8	4.3	872.4	55.5	1.5	1.6	15.9	84.1	10243	13618	3374	32.9	180.5	240.0	59.5	6535.8	5586.4	-949.4

Table 2. Amounts, percentages and densities of Built LCLU and total population for 2000, 2010 and change from 2000 to 2010 for the top 15 districts in New Built (listed in rank order) for the variable percentage New Built land per district area.

District	Region	Area (km ²)	Built 2000 (%)	Built 2010 (%)	Absolute Built Change (km ²)	Relative Built Change (%)	New Built (%)	Built Change/ nonBuilt 2000 (%)	Pop. 2000 (10 ³ people)	Pop. 2010 (10 ³ people)	Pop. Change (10 ³ people)	Relative Pop. Change (%)	Pop. Density 2000 (km ⁻²)	Pop. Density 2010 (km ⁻²)	Pop. Density Change	Pop/Built Area 2000 (km ⁻²)	Pop/Built Area 2010 (km ⁻²)	Pop/Built Area Change (km ⁻²)
Kumasi (KMA)	Ashanti	241.6	65.0	85.3	49.0	31.2	20.3	58.0	1169	2030	860	73.6	4839.8	8399.6	3559.8	7442.6	9845.3	2402.6
Tema	Greater Accra	424.1	30.4	50.1	83.5	64.7	19.7	28.3	506	675	169	33.4	1192.9	1591.0	398.1	3921.4	3176.1	-745.3
Ga	Greater Accra	847.7	18.2	35.1	143.1	92.7	16.9	20.6	553	1011	459	83.0	652.1	1193.2	541.0	3578.3	3401.2	-177.1
Awutu	Central	600.6	8.9	22.6	83.3	156.5	13.9	15.2	172	266	95	55.0	285.9	443.2	157.3	3226.1	1957.4	-1268.7
Bosomtwi	Ashanti	674.1	3.2	10.9	51.7	240.4	7.7	7.9	147	184	37	24.8	218.5	272.9	54.3	6855.2	2514.2	-4341.0
Accra (AMA)	Greater Accra	225.1	81.6	89.0	16.7	9.1	7.4	40.4	1668	2078	410	24.5	7411.0	9230.3	1819.2	9082.4	10371.3	1288.9
Cape Coast	Central	122.4	22.7	29.8	8.6	31.1	7.1	9.1	119	172	53	44.1	975.1	1404.9	429.8	4295.5	4720.7	425.2
New Juaben	Eastern	159.9	12.9	18.2	8.4	40.6	5.2	6.0	136	185	49	35.8	849.7	1153.8	304.2	6577.7	6351.4	-226.2
Afigya/ Kwabre/ Skeyere	Ashanti	946.9	4.5	9.1	43.8	103.5	4.6	4.8	285	342	57	19.9	300.9	360.7	59.8	6730.5	3963.8	-2766.7
Ejisu/ Juaben	Ashanti	581.6	3.3	7.4	24.3	128.1	4.2	4.3	126	143	17	13.1	217.3	245.8	28.5	6662.3	3303.2	-3359.0
Akwapim South	Eastern	389.0	3.7	7.7	15.5	108.8	4.0	4.1	118	124	6	5.2	303.3	319.1	15.8	8271.5	4169.9	-4101.6
Gomoa	Central	837.1	4.6	7.3	23.1	60.5	2.8	2.9	195	343	148	75.7	233.5	410.2	176.7	5118.3	5609.0	490.6
Komenda	Central	452.6	10.5	13.2	11.9	25.0	2.6	2.9	113	146	33	29.5	248.8	322.1	73.4	2363.9	2449.0	85.1
Dangbe West	Greater Accra	1594.2	2.0	4.3	36.3	113.1	2.3	2.3	95	118	24	24.9	59.4	74.2	14.8	2953.2	1736.2	-1217.0
Mfantiman	Central	577.8	10.3	12.4	12.2	20.4	2.1	2.3	150	192	41	27.3	260.3	331.4	71.2	2521.3	2667.1	145.8

Figure 1

Figure 2

- Built in 2000
- Non-Built/ No Change
- Water
- Agriculture to Built
- Natural Vegetation to Built

Kumasi

Accra

Figure 3

Figure 4

Figure 5

Figure 6

Figure 7

Figure 8

a.

b.