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RESEARCH ARTICLE

Fertility and urban context: A case study from Ghana, West Africa, using remotely sensed imagery and GIS

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Abstract

Sub-Saharan Africa has the highest levels of fertility in the world, despite rapid urban growth in most nations of the region. While there are many reasons for the fact that fertility decline is slow in Africa, we hypothesize that the relationship between fertility and urbanization is obscured by the fact that urbanization takes place along a gradient. In the most urban places (e.g., neighborhoods of the largest cities), fertility is apt to be very low, but most urban residents are residing in places that are somewhere along a continuum from completely rural to the most urban possible. All previous attempts to define that urban gradient and relate it to fertility levels rely in one form or another on census data. Because sub-Saharan-African countries are among the least prolific in terms of census gathering, a measure that relies solely on satellite imagery to gage a place's position along the urban gradient could be extremely useful. This paper describes a methodology for doing this and then uses data from the West African country of Ghana to examine how spatial patterns of land cover are associated with fertility. Satellite imagery and landscape metrics are used to create an urban context definition based on landscape patterns using a gradient approach. Census data are used to model the association between urban context and fertility through ordinary least square regression and spatial autoregressive models. Results indicate that there are significant differences in fertility between different urban contexts.

KEYWORDS

fertility, urbanization, West Africa

1 | INTRODUCTION

United Nations (UN) projections estimate that between now and 2050, most of the world's population growth will be absorbed by cities of the developing world (UN Population Division, 2012), where natural increase along with continuous migration from rural areas is driving rapid urbanization. Literature on urbanization of the developing world is mostly focused on large cities and their prevailing slums while largely ignoring the magnitude of urban growth that is taking place in small and mid-size cities (Montgomery, 2008). However, most urban dwellers in Asia, Africa, and Latin America live in urban settlements with less than 1 million people (Satterthwaite, 2000), and it is in those intermediate cities and market towns that we can expect the most rapid rates of population growth (Cohen, 2006). The expansion of social networks that is brought by urban growth is not only changing landscapes but it is also reshaping traditional ways of thinking in areas such as family strategies (Newson & Richerson, 2009). Studies in sub-Saharan Africa have found that urbanization is linked to decreasing fertility levels (Brockerhoff & Yang, 1994; White, Tagoe, Stiff, Adazu, & Smith, 2005). However, as places are urbanizing rapidly, the rate of assimilation to the urban lifestyle varies, and little is known about how the association between urbanization and fertility varies among heterogeneous urban contexts. This paper examines the connection between urban and fertility transitions by expanding on the classic rural/urban classification of place of residence traditionally used in population studies.

Within sub-Saharan Africa, total fertility rates (TFR) are especially high in West Africa, a region that lags in the pace of urbanization and where fertility is declining at a relatively slow pace. Within the region, Ghana is leading the fertility transition (Agyei-Mensah, 2006). Data from the 2008 Demographic and Health Surveys indicate that with a TFR of four children, Ghana was ahead of neighbors such as Côte D'Ivoire, with a TFR of five, or Burkina Faso, with a TFR of six. At the same time, results from the 2014 Ghana Demographic and Health

Surveys (GDHS) show that there has been a slight increase in the TFR over the past 6 years, from 4.0 to 4.2. This is in contrast to the marked decline in fertility observed between the mid-1980s and the 1990s (GDHS, 2014). Ghana is at the same time leading the urbanization trend spreading throughout the region, having become one of three countries with over 50% of their populations residing in urban areas as of 2010 (UN Population Division, 2012). Understanding the demographic changes taking place in Ghana will help anticipate the demographic changes that will take place in the rest of the region as West Africa becomes increasingly urban.

This study investigates how characteristics of land cover can be used to identify differences in the urban context of a place, which in turn is hypothesized to be associated with fertility levels. An alternative definition of urban places is proposed, expanding on the usual classification of place of residence as either rural or urban. In contrast with other approaches to defining the urban gradient that use only census data (especially measures of population density), we rely solely on data derived from remotely sensed satellite imagery. These data have the advantage of being more readily and frequently available than are census data, thus offering the potential ability to track changes in fertility over time by evaluating changes tracked from the imagery. The overall objective is to test the hypothesis that the landscape characteristics defining the urban environment in a region are associated with fertility outcomes.

2 | BACKGROUND

2.1 | Fertility and local environment

Fertility decline, as Notestein defined in the 1950s, is part of the demographic changes involved in the transformation from agrarian societies into industrial ones. Urban industrial societies facing a lower demand for agricultural labor and a higher demand for better education experience a decline in the economic value of children (Bongaarts & Watkins, 1996). Studies in developing countries have also established a correlation between higher incomes and lower fertility rates (Bollen, 2007; Bollen, Glanville, & Stecklov, 2002), but this correlation has not been able to explain the fertility behavior of people in many parts of the developing world (Mason, 1997), probably because urbanization in developing regions, especially in Africa, has not been associated with the same rise in income experienced in the more developed countries (Garenne & Joseph, 2002; Teitelbaum, 1975).

Research in Sub-Saharan Africa has shown that reproductive decisions are highly influenced by social context, meaning that fertility transitions cannot be purely explained by indicators of socio-economic growth (Lesthaeghe, 1989). Davis's (1963) theory of demographic change and response emphasized the importance of social structure in shaping demographic behavior. Fertility decline, as Davis posits, results from changes in lifestyles characterized by marriage postponement, increased use of contraception, and migration to the city. These lifestyle changes identified by Davis are embedded in a spreading urban way of life.

In West Africa, Addai and Trovato (1999) mention the prevalence of a high ethnic fertility characterized by a cultural background that promotes high reproductive expectations. Fertility levels that seem to be strongly influenced by this ethnic component are susceptible to a process of structural assimilation, where assimilation is defined by increasing levels of education, later marriages, and a stronger female presence in the labor force (Goldscheider, 1971; Weeks, Getis, Hill, Gadalla, & Rashed, 2004). Research in Sub-Saharan Africa has found that universal schooling (Caldwell & Caldwell, 1997; Lloyd, Kaufman, & Hewett, 2000), delaying marriage (Bledsoe & Cohen, 1993; Cohen, 1998; Garenne & Joseph, 2002), access to family planning (Caldwell & Caldwell, 1997; Cohen, 1998), and migration to the city (White et al., 2005; White et al., 2008) are associated with fertility onsets. At the same time, studies suggest that there is no one theoretical model that explains fertility decline but rather, there are multiple causal pathways that interact in both direct and indirect ways to influence reproductive decision-making (Martine, Alves, & Cavenaghi, 2013; Shenk, Towner, Kress, & Alam, 2013).

Decreasing mortality levels among children is considered to be an important precondition for fertility decline (Davis, 1963; Reher, 2004), a condition that is met most readily in the city, where public health, sanitation infrastructure, and medical health services are concentrated. In Ghana, migration to the city and the process of assimilation to its lifestyle have been shown by White et al. (2005) to lower reproduction levels.

Even though urbanization and migration to the city have been consistently linked to fertility decline (Goldstein, White, & Goldstein, 1997; Guo, Wu, Schimmele, & Li, 2012; Mason, 1997), the density and diversity of cities of the developing world bring along diverse reproductive strategies that generate a wide range of fertility levels (Montgomery, 2003). Studies of intra-urban fertility have discovered pockets of above average fertility levels within the city comparable to those of rural areas (Weeks, Getis, Hill, Agyei-Mensah, & Rain, 2010), and divergences resulting from changes in reproductive behavior taking place at specific age groups (Weeks et al., 2010). The spatial disparities in fertility levels that have been found within urban environments of the developing world indicate that the characteristics of the urban neighborhood could have an impact on shaping reproductive decisions (Montgomery, 2003).

Studies examining determinants of fertility decline in the developing world have established the need to consider the characteristics of the local environment, neighborhood, or community as significant influential factors (Bilsborrow & Guilkey, 1987; Entwisle, Casterline, & Sayed, 1989; Schoumaker, Dabire, & Gnoumou-Thiombiano, 2006; Weeks, Stoler, Hill, & Zvoleff, 2013). In Egypt, Entwisle et al. (1989) showed that fertility rates are highly influenced by the structural characteristics of villages, whereas Weeks et al. (2000) uncovered spatial diffusion effects in the use of contraception when examining the spatial distribution of fertility rates around Egyptian villages. Less research has been conducted in more developed countries because fertility levels are generally low in both rural and urban areas, but Kulu (2013) found that in Finland, the contextual effects especially of housing characteristics help to explain a fertility gradient from rural to small towns to large cities. Kulu and Washbrook (2014) also found that in Britain, fertility levels decline as the size of the urban population increases, thus suggesting a gradient even in an otherwise low fertility society.

Our concept of an urban gradient is even more “local” than that implied by Kulu and Washbrook and most other researchers, because the context even within a given city can vary, thus having a potential effect on fertility. In Ghana in the early 1970s, Brand (1972) described how even as the city of Accra grew, traditional lifestyles persisted within the city. His paper on spatial organization of residential neighborhoods in Accra classified neighborhoods based on the degree of modernization of enumeration areas (EAs), identifying bourgeois migrant communities and urban villagers as the extremes. Brand (1972) attributes modernization to education, lower reproductive levels, and contact with western culture through non-African in-migration. These characteristics of modernization can be interpreted as demographic characteristics of a population moving through the demographic transition, catching up with both the urban and fertility transitions. Caldwell and Caldwell (1997) described the export of western social systems and the ramification of ideas that accompany it as key triggers of fertility decline.

The hypothesis guiding this research is that the diverse landscapes that define the urban context are associated with a wide range of fertility rates. This is an exploratory analysis that evaluates whether the physical characteristics of the landscape can be used to identify variations in fertility levels. The purpose of the study is to assess if reproductive decisions are associated with environmental variables that can be combined and used as a proxy measure of degree of urbanization. We expect to differentiate urban environments where fertility rates are well below average from those where the fertility rates are just below average or even above average. By expanding on the classic rural/urban scheme, we expect to improve the understanding of the relationship between urbanization and fertility transitions in Sub-Saharan Africa.

2.2 | Defining urban

The UN guidelines commonly used to define urban places for data collection assign population counts to administrative boundaries, ignoring the extent of the built environment within those boundaries (Champion, 2004). Satellite imagery and image processing and analysis techniques are advancing urban mapping globally by improving detection of artificial land cover characteristic of the built environment (Lu & Weng, 2006; Potere, Schneider, Angel, & Civco, 2009; Small, 2005; Ward & Phinn, 2000). In developing countries, where urbanization is spreading at the fastest pace (UN Population Division, 2011) and population data are scarce (Weber, 2003), satellite imagery has become an important source of data for monitoring human settlements (Harris & Longley, 2002; Small, 2003; Tatem, Noor, & Hay, 2004; Weeks, 2004a; Weeks, 2004b).

Settlements are defined as urban or rural based on a variety of criteria such as population density, access to basic infrastructure, and predominant economic activity (Tacoli, 1998), in most cases using an arbitrary cutoff point (Antrop, 2004) that does not account for heterogeneity in land use intensity or function (Seto et al., 2012). Although these definitions vary widely throughout the world (Bilsborrow, 1998), they are all based on the assumption that there are significant differences between rural and urban spaces and their populations (Champion & Hugo, 2004; Lacour & Puissant, 2007). Rural/urban classifications portray rural and urban spaces as independent places while overlooking the flows of people connecting them (Hugo, Champion, & Lattes, 2003; Rain, 2007; Seto et al., 2012). Yet urban growth is transforming landscapes within cities as well as in the countryside, where connectivity to the city is creating hybrid landscapes in which rural and urban livelihoods overlap and the contrasts between rural and urban spaces are blurred (Hugo et al., 2003; Lacour & Puissant, 2007; Seto et al., 2012).

Alternative categorizations of urban places include the use of different combinations of population size and density, adjacency to a city, degree of urbanization, predominance of economic activity, and access to services (Adair, Vanderslice, & Zohoori, 1993; Butler & Beale, 1994; Cromartie & Swanson, 1996; Ghelfi & Parker, 1997; McDade & Adair, 2001; Van de Poel, O'Donnell, & Van Doorslaer, 2009). The transition of urban environments into the countryside has been studied by ecologists who are interested in identifying changes in habitats through an urban gradient (Blair, 1996; Blair & Launer, 1997; Kühn & Klotz, 2006; Niemelä et al., 2002) and also by remote sensing specialists who are interested in capturing spatial patterns of urban growth (Luck & Wu, 2002; Weng, 2007; Yang, Zhou, Gong, & Wang, 2010). Studies in urban landscape ecology have proposed alternative characterizations of the urban environment that incorporate measures of fragmentation and dispersion with the goal of examining habitat fragmentation and its impacts on ecosystems (Alberti, 2005; Breuste, Niemelä, & Snep, 2008).

Landscape metrics have become an important tool for researchers to study the effects of fragmentation on the biophysical environment, and they are also increasingly being recognized as a useful set of indicators of human activity (Wickham, O'Neill, & Jones, 2000). Research in human environment interactions indicates that a detailed understanding of landscape characteristics provides important information about context that can shed some light into important social processes (Entwisle, Walsh, Rindfuss, & Chamratrithirong, 1998). Researchers have found that urbanization is driving habitat fragmentation (Wickham et al., 2000); however, its impacts on urban form and function are not well understood (Liu & Herold, 2007; Longley, 2002; Seto & Shepherd, 2009).

3 | STUDY AREA

Urban growth in Ghana is spreading at a fast pace. Census data show that by 2010, more than half of the country's population resided in urban areas (defined by Ghana Statistical Service as any settlement with at least 5,000 people), and the UN estimates that by mid-century, at least three-quarters of its population will be found in urban places. In Greater Accra, Ghana Statistical Service estimates that the population doubled between the mid 1980s and the early 2000s, going from 1.5 million to 3 million. The 2010 census indicates that Greater Accra's population has grown by another third in the 2000–2010 time period, reaching 4 million people. Research in the area has shown that urban growth is not restricted to major cities and its surroundings areas but is also spreading in and around a wide range of settlements (Moller-Jensen & Knudsen, 2008). This rapid growth in urban population translates into dramatic changes in land cover and land use. Research in Accra has found that between the mid 1980s and early 2000s, a significant and unplanned extension of the city into peri-urban areas occurred, which witnessed agricultural and other vegetated land being replaced by buildings (Møller-Jensen, Kofie, & Yankson, 2005; Møller-Jensen & Yankson, 1994; Stow et al., 2016; Yeboah, 2003).

The study area for this research is located in southern Ghana, composed of 18 districts (second-level administrative boundaries), five of which are within the Greater Accra Region and 13 are in the adjacent Central, Eastern, and Volta Regions (Figure 1). Population and urbanization have been growing at a steady rate in coastal Ghana because of the predominance of Accra's metropolitan area, but also because of growing intermediate cities such as Cape Coast, Takoradi, and Tema. The study area covers a wide range of settlements that stretch from the most urban metropolitan Accra into the most rural Volta and Eastern regions, capturing suburban sprawl, scattered settlements, and sparsely populated areas in between. Data are circa 2000, because the 2010 census data were not yet available as this analysis was underway.

4 | METHODOLOGY

4.1 | Defining the urban context

A Landsat ETM+ scene for path 193 and row 56 from December 26, 2002 (~30 m spatial resolution) was analyzed using spectral mixture analysis to estimate proportions of vegetation, impervious surfaces, and soil and classified into a built and vegetation land cover map. The resulting spectral mixture analysis-based built and vegetation land cover map was used to estimate measures of landscape fragmentation. A 450 × 450 m uniform grid (15 × 15 pixels) was defined as the landscape unit to analyze patterns of landscape fragmentation. Note that other grid cell sizes were also investigated, but the decision was made that this size best captures variability at a local level. Smaller grid cell sizes can produce variability that is essentially "noise", whereas larger grid cell sizes mask important variability that should be captured.

Radar imagery from the European Space Agency's ERS-2 satellite (~12 m spatial resolution) was used to generate an additional proxy measure of man-made features through the classification of a measure backscatter's texture. The measures of landscape fragmentation plus a

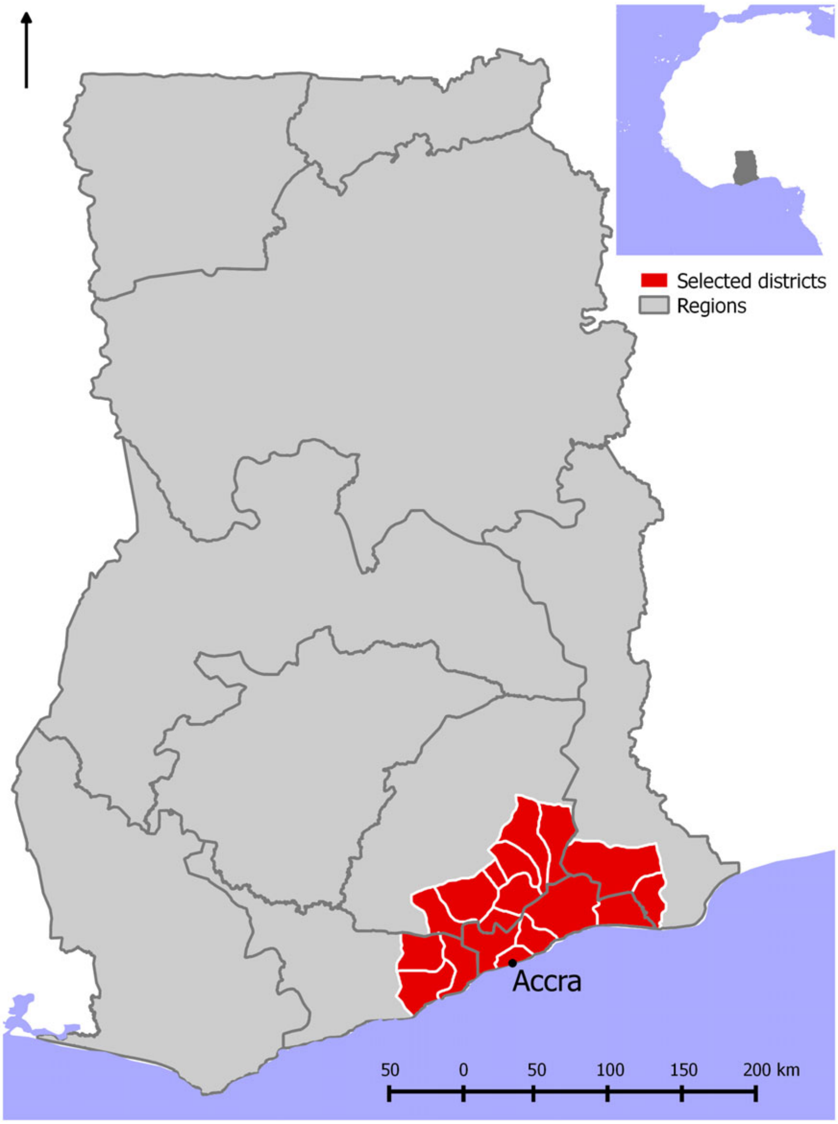

FIGURE 1 Study area in southern Ghana, in West Africa

measure of variability of the classified radar texture were used as inputs for a decision tree classifier that classified each of the 450-m cells into a nine-class urban context classification scheme that is exclusively based on landscape patterns (Figure 2).

This approach incorporates morphology into the urban classification scheme and produces a nuanced classification of spaces using a method similar to statistical clustering measures. The decision tree classifier generated nine classes that form a gradient as follows: (a) unsettled land (48,039 cells), (b) fragmented unsettled land (5,084 cells), (c) fragmented transition (8,430 cells), (d) sparsely populated areas (1,295 cells), (e) scattered settlements (509 cells), (f) fragmented suburban (594 cells), (g) dense and dispersed small urban patches (877 cells), (h) fragmented large urban patches (752 cells), and (i) compact urban core (870 cells; see Figure 3). More details about the conceptualization, methods, and accuracy assessment of the urban context definition can be found at Benza, Weeks, Stow, López-Carr, and Clarke (2016).

The urban context classification identifies compact urban cores in the city centers of large coastal cities such as Greater Accra, Tema, and Ada Foah, but also in smaller intermediate inland cities including Koforidua, Winneba, and Akosombo (Figure 4). Contiguous to the compact urban core are fragmented large urban patches found within city centers, whereas dense and dispersed small urban patches are located on the outskirts of cities and settlements. The suburban sprawling class (fragmented suburban) appears to be limited to urban development taking place around large cities within the coastal region. Spreading out from the fringe of intermediate cities and towns, scattered settlements are dispersed inland throughout the study area, and sparsely populated places extend beyond the periphery of towns. Finally, on the most rural end of the urban gradient places are identified as fragmented transitional landscapes where very scattered clearings are starting to infringe into unsettled lands.

There is no definitive method for validating the urban context classifications derived from the imagery, but we compared them with

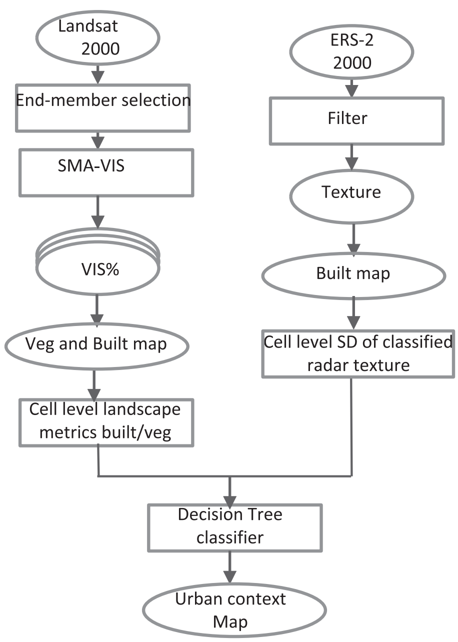

FIGURE 2 Flow chart for urban context classification based on the combination of Landsat 2000 imagery and ERS-2 2000 imagery

measures of population density—a commonly used index of urban—to see if density varied in expected ways from one urban context to another. The results in Figure 5 show that population density generally declines as the urban context moves from least urban to most urban and there is a clear gradient to population density by urban context, which reinforces our hypothesis that a gradient approach is superior to a dichotomy.

4.2 | Census variables

EA boundaries defined by Ghana Statistical Service have very heterogeneous shapes and sizes (see Figure 6a) and are heavily influenced by the presence of settlements. Converting the census data from the EA level into a continuous grid generates units of analysis of comparable size and incorporates both rural and urban areas as a means for representing the entire rural–urban gradient. The uniform cell unit of analysis was defined as a solution to the problem of linking population and land cover data collected at different scales and for different areal zones. Individual and household level data from the 2000 census were assigned to corresponding towns outside of Accra (Figure 6b) and EA centroids within the city of Accra. Individual and household level data were used to create variables describing the characteristics of the head of household, housing, and women in the household, and they were then aggregated to the cell level, which is the unit of analysis for the urban context map.

A proxy measure of fertility was created using the variable children ever born (CEB) by estimating an age-standardized *CEBz* score (Benza, 2013; Weeks et al., 2013). The *CEBz* score is expressed in terms of standard deviations from the mean CEB for each 5-year age group of women of reproductive age within the study area, capturing the age-specific variability of CEB:

$$CEBz = \frac{(CEB - \mu CEB_{age\,group})}{\sigma CEB_{age\,group}},$$

where *CEB* is a woman's number of CEB, $\mu CEB_{age\ group}$ is the average number of CEB to women within her 5-year age group, and $\sigma CEB_{age\ group}$ is the standard deviation of the number of CEB for women within her 5-year age group. This measures an individual woman's fertility level in terms of standard deviation units away from the mean for her age group, and at the aggregate level, the average *CEBz* for all women in a grid cell represents an age-standardized relative measure of fertility for the area.

5 | RESULTS

5.1 | Fertility levels by urban context

Our dependent variable is fertility, and so we first examine its relationship to urban context. Figure 7 shows that the mean *CEBz* varies substantially throughout the urban context, but not in a strictly linear fashion. For example, the lowest fertility level is found in the class labeled as dense and dispersed small urban patches (third most urban), followed by the fragmented suburban class (fourth most urban) and the fragmented large urban patches (second most urban). The highest fertility level is found in the unsettled land (least urban) and fragmented transition (third least urban) classes, whereas intermediate fertility levels are found both in the most urban compact urban core

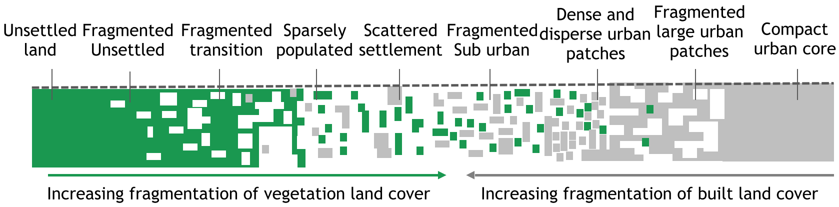

FIGURE 3 Visualization of the urban context classification scheme

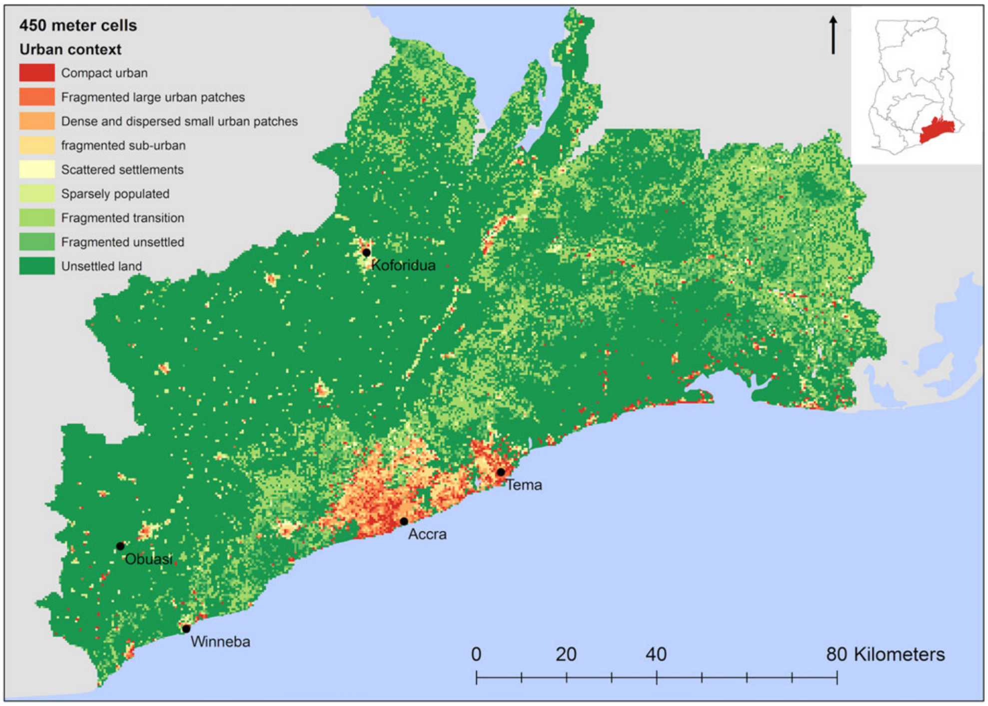

FIGURE 4 Landscape pattern-based definition of the urban context for the study area using a 450 × 450 m cell unit of analysis with nine classification categories

and the scattered settlements classes located in the middle of the urbanization scale. The classic rural–urban divide with respect to fertility is apparent in Figure 7. If we, for example, treat the four urban contexts on the right hand side of the graph as "urban" and all contexts on the left as "rural", the resulting *CEBz* values are −0.008 for urban and 0.267 for rural. But the urban gradient suggests that the real world is more complicated than implied by this simple dichotomy.

The spatial distribution of the *CEBz* variable shown in Figure 8 indicates that the lowest fertility levels are highly concentrated in the metropolitan area of Greater Accra, with a few scattered pockets within the city and its surroundings showing clear above average fertility levels. Outside of the Greater Accra Metropolitan area, fertility levels appear to be predominantly above average with a few exceptions of dispersed settlements spread throughout the study area, especially along major highway arteries where the spread of urban lifestyle values may be taking place.

5.2 | Variables that differentiate urban contexts

What are some of the factors that might differentiate urban contexts and thus help to explain variability in fertility levels? Household structure may vary from place to place, so variables were included in the analysis to describe the characteristics of the head of household and housing characteristics. Previous research in the region found that reproduction decisions are influenced by religion and ethnicity (Caldwell & Caldwell, 1987; Takyi & Dodoo, 2005) and by migration (White et al., 2005; White et al., 2008), so variables were created to identify the household head's religion and ethnicity focusing on the most common ones throughout the study area. Households were also categorized according to whether the household head had moved into the district within the last 5 years as a way to account for migration (note that this is the only variable in the census that captures migration patterns).

Income has been consistently found to be associated with fertility levels (Bollen, 2007), but the census did not collect any data on income or wealth. Variables describing the characteristics of the housing were used as proxy measures of socioeconomic status. A long list of variables describing housing characteristics and access to a range of household goods were examined in detail and used in preliminary regressions to identify those that minimized multicollinearity and maximized explanatory power.

Variables describing the characteristics of women within the household were created, which included two variables for education,

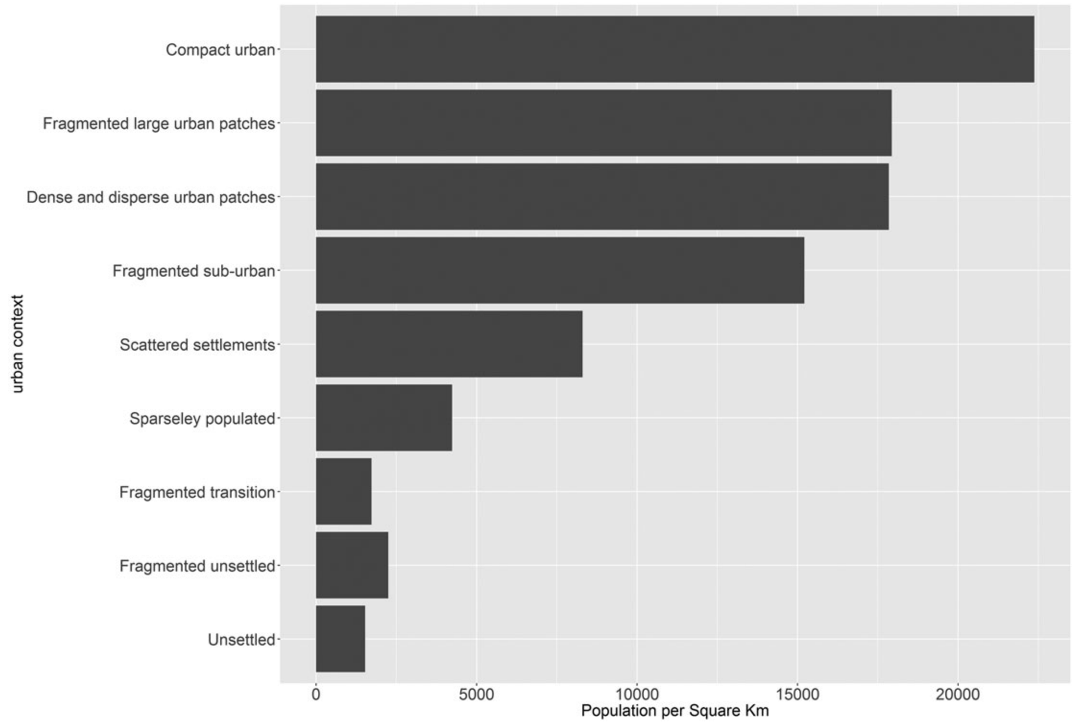

FIGURE 5 Population density by urban context classification

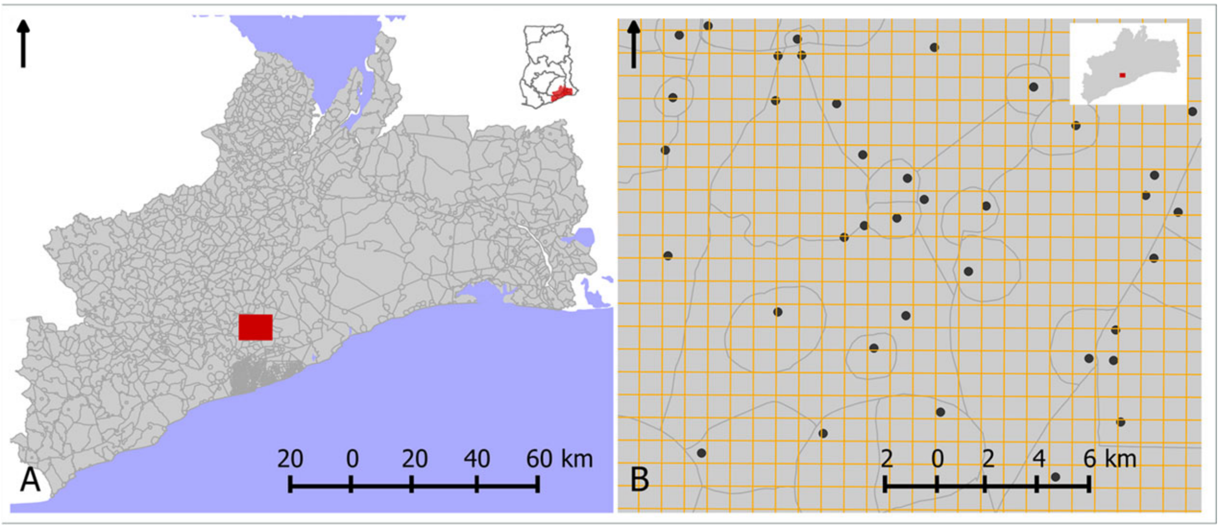

FIGURE 6 (a) Enumeration areas from the 2000 census and (b) 450-m grid overlaid onto towns (the centroids of which are represented by points) that were assigned enumeration area level data, shown as an enlargement of the box in the middle of the map in part (a)

one for employment and one for marital status. The marital status variable seeks to detect the influence that delaying marriage has on fertility levels. The complete list of variables included in the analysis and their summary statistics are included in Table 1.

5.3 | Ordinary least square (OLS) regression model

We observed above that fertility levels vary by urban context, although the pattern is not linear. We turn now to predicting the fertility level of a grid cell. Our hypothesis is that urban context is a proxy for the social and economic environment that is determining those fertility levels. Thus, if we have assembled the correct set of independent variables, the statistically significant differences in fertility by urban context should disappear once those variables are taken into account. Fertility levels were modeled through OLS regression using the urban context variable, converted into dummies, as the independent variable of interest while controlling for the set of independent variables described above. The explanatory variables were added in two blocks, the first block corresponding to a set of dummy variables describing urban context, one for each one of the nine urban classes, using the unsettled land class as the reference class. The second block incorporates the predictor variables describing characteristics of the head of household, housing infrastructure, and characteristics of women in the household. Results are shown in Table 2.

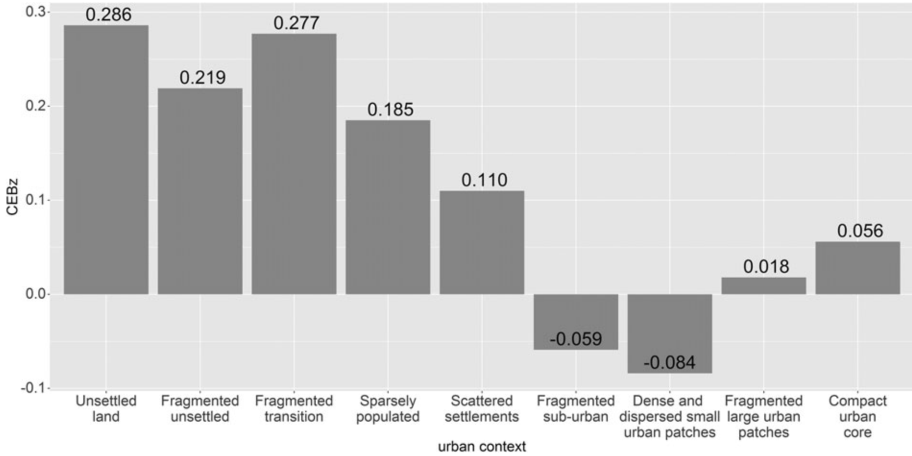

FIGURE 7 Mean *CEBz* by urban context

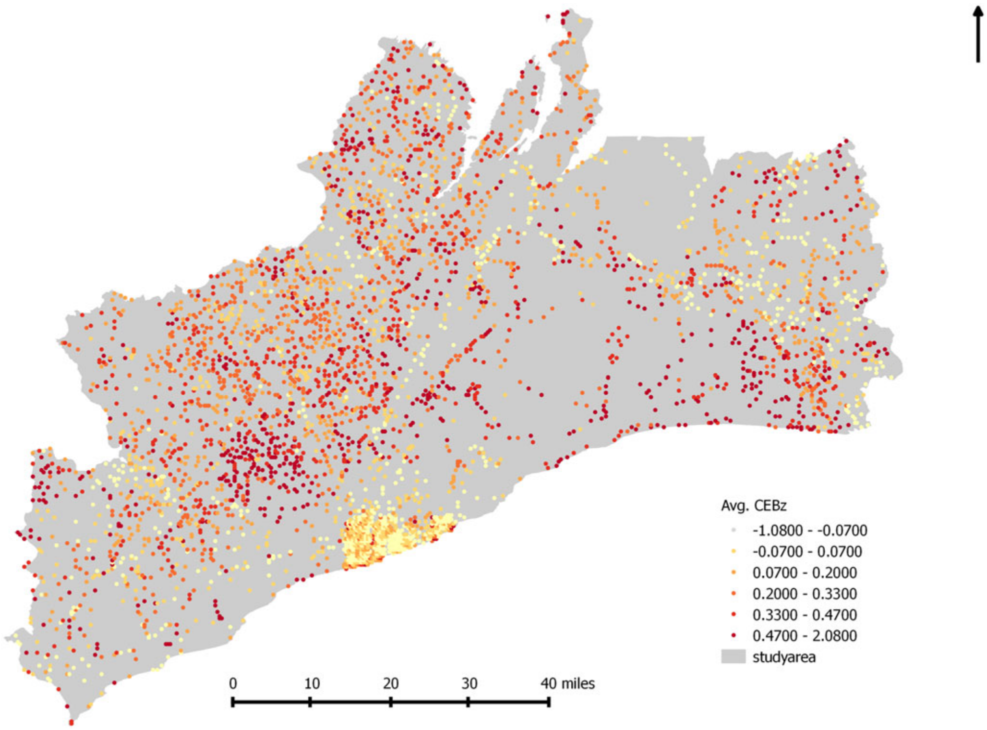

FIGURE 8 Spatial distribution of mean *CEBz* variable for the study area using a 450 × 450 m cell unit of analysis

Results from the OLS regression indicate that, on its own, urban context can account for 16% of the variation from one grid cell to another in fertility levels, as shown in OLS model 1 in Table 2. All classes except the fragmented transition class are significantly related to fertility, but not equally so. The four most urban contexts have the strongest standardized beta coefficients in the initial model, suggesting that they are especially influential with respect to fertility levels. This conclusion holds even after introducing our set of independent predictors. As expected, all urban context coefficients are reduced in the presence of the other predictor variables, but all four of the most urban contexts remain as statistically significant predictors, suggesting that our independent variables are not accounting for all of the variability comprised by the urban context.

The OLS model 2 shown in Table 2 has an R^2 of .35, more than double that of the urban context classes on their own. Thus, there is more going on than is captured solely by urban context. In order of importance based on the standardized beta coefficients, the top five most influential variables are as follows: (a) the percent Protestant (which significantly lowers fertility especially relative to traditional religions), (b) the percent of adult women with no schooling (the higher this is, the higher the level of fertility), (c) the proportion who are of the Ewe ethnic group (the higher this is, the lower is fertility), (d) the proportion of adult women who have primary level education (the higher this is, the higher is fertility), and (e) the percent Catholic (which also significantly lowers fertility, especially in relation to traditional religions).

5.4 | Spatial error model

The drop in standardized beta coefficients for the urban context categories and the rise in R^2 from model 1 to model 2 show that the independent variables that we have measured do help to explain variation

TABLE 1 Variables in the analysis

Variable	Mean	Standard deviation
Average *CEBz*	0.21	0.3
Characteristics of the head of Household (HH)		
%Female head	34	13
%Catholic	9	9
%Protestant	22	14
%Pentacostal/Other Christian	42	16
%Muslim	5	8
%Akan	26	25
%Ga	26	30
%Ewe	26	29
%Moved into district in the last 5 years	6	8
Housing characteristics		
%Permanent walls	29	32
%Permeable roof	16	27
%Piped water	27	38
%Own toilet	22	23
Women's characteristics		
%With secondary education or more	41	21
%Employed in informal sector	71	19
%Women 15–19 single	16	7

TABLE 2 OLS and spatial regression-standardized beta coefficients predicting fertility levels by urban context

	Model 1 OLS	Model 2 OLS	Model 3 Spatial error
Compact urban	−.178*	−.056*	−0.063*
Fragmented large urban patches	−.225*	−.069*	−0.065*
Dense and dispersed small urban patches	−.288*	−.094*	−0.089*
Fragmented suburban	−.162*	−.051*	−0.045*
Scattered settlements	−.095*	−017	−0.016
Sparsely populated	−.080*	−.006	−0.004
Fragmented transition	−.009	.035*	0.044*
Fragmented unsettled	−.053*	. 008	0.020
Reference category: unsettled			
Female head of Household (HH)		−.110*	−0.097*
Catholic		−.146*	−0.068*
Protestant		−.170*	−0.074*
Pentacostal/Other Christian		−.102*	0.006
Muslim		−.057*	−0.041*
Akan		−.054*	−0.044
Ga		.104*	0.046
Ewe		−.155*	−0.150*
Moved into district in the last 5 years		−.029*	−0.030*
Permanent walls		−.139*	−0.117*
Permeable roof		.139*	0.091*
Piped water		−.065*	−0.045
Own toilet		−.108*	−0.089*
With primary education		.154*	0.142*
With no schooling		.168*	0.220*
Employed in informal sector		−.028	0.002
Women 15–20 single		−.127*	−0.114*
Lambda (spatial error variable)			(z = 35.51)
Adjusted R^2	.16	.35	.48
Akaike information criterion	1,069.56	0.91	−599.61
Dependent variable = *CEBz*			

OLS = ordinary least square.
*Statistically significant at or beyond .05.

from one urban class to another, but there is still variability in fertility that the model is unable to account for. One of the factors at work may well be spatial autocorrelation. Grid cells close to one another may be more similar in fertility than those that are at a greater distance, despite differences in urban context.

Regression analysis establishes unbiased linear estimations when the data meet assumptions of normality, homoscedasticity, linear associations, and uncorrelated errors. In geographical analysis, the existence of spatial dependence deviates from the assumption of noncorrelated errors in the data. Moran's I was calculated for the standardized residuals of the OLS shown in model 2 in Table 2, using the five nearest neighbors as the spatial weights matrix. It produced a z-score of 33.3, indicating a highly significant level of spatial autocorrelation in the residuals. Diagnostics within the GeoDa software indicated the specification of a spatial error model, which captures the spatial autocorrelation in key-unaccounted variables by estimating a spatially weighted error term (Chi & Zhu, 2008).

Comparing the results from the OLS regression with those from the spatial error model, we can see that the inclusion of the spatial error term improved the model fit. Both the Akaike information criterion and the R^2 values indicate a clearly higher model fit when spatial dependence is taken into account (see right-hand column of Table 2). The spatial autoregressive coefficient, *lambda*, has a significant z-score of 35.5 indicating high levels of spatial autocorrelation in the variables unaccounted for by the model. The standardized beta coefficients for the urban context variables are essentially unchanged, but several of the independent variables are reduced in their influence, suggesting that at least part of their influence in model 2 (OLS) was due to spatial autocorrelation. For example, the percent Pentacostal/Other Christian was reduced to a level no longer statistically significant, indicating that its effect is highly spatial. The same was true for the Ga and Akan ethnic groups. The Ga are clustered along the coast near Accra, whereas the Akan are clustered inland. Thus, the more “cultural” variables are spatially clustered, whereas the sociodemographic characteristics of women are not. These are variables that best capture the differences from one urban context to the next. Because the regression coefficients are higher and more significant for the more urban context classifications, we can expect that something about the characteristics of those places is especially important in explaining differences from one urban context to another.

6 | DISCUSSION AND CONCLUSION

This research examines the variability in fertility levels throughout an urban gradient that is based on the characteristics of the landscape.

Different urban environments are identified based on the degree of fragmentation of built and vegetation land covers. This urban gradient approach assumes that the characteristics of the landscape change with degree of urbanization and generates a classification scheme based on a scale. On the most urban end of the spectrum, the scheme assumes that city centers are densely built and very compact. Moving away from the city center, the built environment becomes more fragmented and dispersed giving way to higher levels of interspersion with vegetation land cover. Moving beyond consolidated city boundaries, the scheme identifies scattered settlements and sparsely populated areas where the built environment is very fragmented and starts to transition into unsettled areas where vegetation is predominant. By examining the characteristics of the landscape, the urban context classification expands on the common rural/urban definitions of places allowing the differentiation of a wide range of urban environments and inhabited spaces in general.

Results from the OLS regression indicate that there is a significant association between urban context and fertility. As expected, significantly lower fertility levels are seen in areas that are on the more urbanized end of the urban spectrum, and higher fertility levels are seen on the least urbanized end of the spectrum, although the pattern is not strictly linear. Given that urbanization and fertility have been shown to be consistently linked, we anticipated finding the lowest fertility level in the most urban environment, compact urban core class, and that was not the case. Even though the compact urban core was found to be associated with below average fertility levels, its coefficient was weaker than the one for the fragmented large urban patches and the dense and dispersed small urban patches classes. A closer look within the city of Accra indicates that the lowest levels of fertility are found in the oldest most consolidated neighborhoods, which in Ghana are neighborhoods with lower population density and greater levels of vegetation than in the compact urban core. The latter is densely populated by people living on low levels of income (Fink, Weeks, & Hill, 2012) and experiencing low fertility, but not as low as those seen in more consolidated neighborhoods beyond the core. Overall, then, the relative difference in coefficients between the four most urban environments indicates significant variability in the association between fertility levels and urbanization.

A close examination of the characteristics of each one of the urban contexts within Greater Accra indicates that the pattern-based definition of the urban environment parallels the diversity of the city's vernacular neighborhoods as they were identified by Weeks et al. (2012). The very densely populated compact urban core covers the old city center where infill has densified the built environment over the years and urban decay has given place to high density settlements. The slums that spread along the coast line and riverbanks and lagoons (such as the yam market area—see Tutu, 2013) are good examples of very densely populated built environments where the relative difference of coefficients indicates that fertility levels would be higher than most of the rest of the city. On the other hand, the dense and dispersed small urban patches class seems to align with the old established neighborhoods of Accra, where housing has densified through the years but significant vegetation remains interspersed throughout the built environment. An example of a dense and dispersed small urban patches neighborhood would be the Cantonments area, very centrally located, less than 2 km away from the city center, but clearly clustering the city's oldest estates. These wealthier established neighborhoods appear to have the lowest fertility levels in the city, as noted above.

This nonlinear spatial component of the association between urban context and fertility indicates that the connection between fertility and urban transitions is complex and that spatial diffusion may play an important role in shaping both high and low fertility levels. Understanding the spatiotemporal ways in which fertility and urban transitions are connected in a region of the world that is urbanizing quickly and that has TFR among the highest in the world will help anticipate the demographic changes that will take place in the region in the years to come.

This paper proposed an alternative way of characterizing urban environments based on measures of landscape patterns extracted from satellite imagery. The goal was to assess whether it would be possible to identify local environmental characteristics from satellite imagery that would have an impact on reproductive behavior. Our findings are encouraging, in the sense that they point to complex significant associations between landscape patterns and fertility levels. However, it is important to recognize the limitations of the analysis. The pattern-based definition of the urban context is an arbitrary classification of space, although this is also true for all other urban definitions. Even though the urban context variable provides a more detailed and nuanced definition of space, it is not an absolute scale. This analysis is based on relative measures of urbanization built on the fragmentation characteristics of this particular landscape and would most likely show different results in different landscapes. We also analyzed data using a 450-m^2 grid. Although we believe that this provides an optimum solution, a comparison of results at other scales is beyond the scope of this paper. Finally, it is worth mentioning that this exploratory study analyzed aggregated data, which means that we are identifying associations between variables and not necessarily establishing causality. Further research is needed to establish the spatiotemporal connection between fertility and urban transitions by replicating this analysis with different time frames. A more detailed examination of the significance of neighborhood effects could also be advanced through the use of multilevel and structural modeling techniques.

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