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Research Article

Evaluating links between dynamic urban landscapes and under-five child mortality in Accra, Ghana

Sory Touré

John Weeks

David Lopez-Carr

Douglas Stow

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Evaluating links between dynamic urban landscapes and under-five child mortality in Accra, Ghana

Sory Touré¹

John Weeks²

David Lopez-Carr³

Douglas Stow⁴

Abstract

OBJECTIVE

The primary objectives of this study are to examine intra-urban spatial variation in the rates of under-five-years-old child mortality (5q0) in Accra in 2000 and 2010, as well as between those two dates, and to evaluate potential connections between the physical characteristics of urban neighborhoods and their levels of child mortality.

METHODS

Decennial census data of Ghana are used to estimate rates of 5q0 in 2000 and in 2010 and to note changes between 2000 and 2010 for the neighborhoods of Accra. Remote sensing data and methods are then used to derive urban land-cover and land-use change (LCLUC) information for the same neighborhoods and during the same time period. Population and housing demographic characteristics are derived and summarized at the neighborhood level to serve as potential covariates of the measures of urban change. Regression analyses are utilized to evaluate the relationships between child mortality and neighborhood environmental factors.

RESULTS

Results indicate spatial variability in rates of 5q0 in Accra for the year 2000. Such variations are minimal in 2010 due to the dramatic decline in child mortality between 2000 and 2010. Under-five child mortality was 20% in 2000 and 12% in 2010. Nontraditional toilet types and water supply sources are associated with high rates of 5q0.

¹ Office for Coastal Management, NOAA, Charleston, USA. Email: istoure@gmail.com.

² San Diego State University, USA.

³ University of California, Santa Barbara, USA.

⁴ San Diego State University, USA.

CONCLUSIONS

Less reliance on public and informal toilets as well as improving housing drinking water quality have the potential to reduce under-five child mortality in Ghana.

CONTRIBUTION

By analyzing an extensive list of exploratory variables derived by combining remote sensing and demographic data, this paper increases our understanding of the factors associated with under-five child mortality.

1. Introduction

Throughout human history the very young have been most vulnerable. The global rise in life expectancy has been fueled especially by the drop in infant and child mortality (deaths occurring at ages under 5). In Chinua Achebe's novel *Things Fall Apart*, a key character comments about her daughter, "I think she will stay. They usually stay if they do not die before the age of six" (Achebe 1958: 42). This folk expression highlights the fact that at a societal life expectancy of 20 years (common for most of human history and characteristic of Nigeria around 1900, the setting of Achebe's book), less than half of children born alive could be expected to survive to age 5 (Coale and Demeny 1983). The rate of under-five child mortality (5q0) in a country or a subregion is a strong indication of the overall health of its population. This rate has been decreasing globally since the end of World War II, with particular speed since the beginning of the millennium, encouraged by the United Nations' Sustainable Development Goal 3.2, which includes ending preventable deaths of newborns and children under 5 by 2030. In 1950, 213 out of every 1,000 children born in the world died before age 5. The rate was 311 per 1,000 in Africa (United Nations Population Division 2019). In the half century leading up to the year 2000, these rates dropped to 70 for the world and 130 for Africa. Only 15 years later, in 2015, the United Nations estimates the rates to be 40 for the world and 71 for Africa.

Several studies have examined the causes of under-five mortality on the African continent. Akinyemi et al. (2016) find that combined exposure to cigarette smoke and solid fuel increased risks of infant and child mortality in 15 sub-Saharan African countries. Clark and Hamplová (2013) investigate the relationship between single motherhood and child mortality in 11 countries in sub-Saharan Africa. They concluded that children born to single mothers who never married were significantly more likely to die before age 5 compared to children born to married parents in six of those countries. Pickering and Davis (2012) use data from almost 200,000 respondents to Demographic

and Health Surveys carried out in 26 sub-Saharan countries to assess the relationship between the time it takes to walk from their household to a water source and child health outcomes. They find that time spent walking to water sources is a significant determinant of under-five child health. A 15-minute decrease in one-way walk time to a water source is associated with a 41% average relative reduction in diarrhea prevalence and an 11% relative reduction in under-five child mortality. A study on the effect of investment in malaria control on child mortality in sub-Saharan Africa between 2002 and 2008 by Akachi and Atum (2011) concludes that, along with other key child survival interventions, increasing insecticide-treated nets and indoor residual spraying significantly contributed to child mortality reduction. Important spatial differences in under-five mortality have also been observed in most countries (Burstein et al. 2019). For example, researchers have known for a long time that 5q0 rates are higher in rural areas compared to urban settings (e.g., Kazembe, Clarke, and Kandala 2012). At the same time, Garenne (2010) shows that slums located in large cities of developing countries that have the presence of extreme poverty; family disintegration; lack of hygiene, sanitation, and medical care; low nutritional status; emerging diseases; and other health hazards (e.g., environmental hazards, accidents, and violence) also experienced high rates of 5q0.

Several researchers have examined the drivers and spatial variability of under-five child mortality in Ghana, which is our focus in this paper. To assess the factors that contributed to the accelerated decline in child mortality in Ghana, especially since 2000, Nakamura et al. (2011) use Demographic and Health Survey data. They identify birth intervals, bed-net use, maternal education, and maternal age at birth as being primarily associated with 5q0. The increase in use of bed nets in particular makes a substantial contribution to the decline in under-five mortality. A mother's level of education, age, and marital status and the presence of co-wives have all been found to be significant predictors of under-five mortality in rural northern Ghana (Kanmiki et al. 2014). In the same upper east region of Ghana, Adjuk et al. (2010) look at the spatial distribution of under-five mortality. They find a higher than average clustering of 5q0 in villages located in the northeastern part of the district, which they attribute to poor health-care delivery systems. Data from the Demographic and Health Surveys show that there is a clear spatial pattern in Ghana for child mortality rates to be higher in the northern part of the country and lower in the southern part. The capital city of Accra, in the southern part of the country, has the lowest 5q0 levels, but even there Jankowska, Benza, and Weeks (2013) find evidence that child mortality is connected to environmental factors such as housing quality, slum-like conditions, and neighborhood levels of vegetation. Their findings are consistent with those of Garenne (2010), as discussed above, and lead them to conclude that there is a need to examine intra-urban child mortality because of

considerable variation in the rates of 5q0 among the different zones that make up the city of Accra.

The Jankowska, Benza, and Weeks (2013) study combines data from several different surveys in which complete birth histories had been conducted. They calculate under-five mortality values from those data, ultimately aggregating them into 16 areas within Accra that had sufficient numbers of respondents to have a low level of sampling error in the results. The major purpose of that paper was to test a new method of using summary birth histories to calculate 5q0 values, in which the only data available are the number of children ever born and the number of those who had died (Rajaratnam et al. 2010). However, since the purpose of the study by Jankowska, Benza, and Weeks (2013) was to test the validity of a method using only summary birth history data, the comparison with complete birth history data was necessary, and this meant that census data were not included in the analysis. Furthermore, the results of the 2010 census of Ghana had not yet been released, so it was not possible to compare changes over time in Accra, especially at a relatively fine spatial scale.

Our purpose is to fill in those gaps by using data from the 2000 and 2010 censuses to evaluate which variables were associated with under-five mortality at each date and to assess which variables were most closely associated with the rapid drop in 5q0 that took place in Accra, as in the rest of Ghana, between those two dates. The specific objectives are to:

- 1) Examine the intra-urban spatial variation of under-five mortality rates in Accra in 2000, in 2010, and between 2000 and 2010;
- 2) Analyze the relationships that exist between rates of under-five mortality and the physical environment, as defined by sociodemographic, housing, and neighborhood characteristics (e.g., a woman's level of education or marital status; a household's source of water, bathing availability, or toilet type; and a neighborhood's function as being primarily for residential or commercial purpose); and
- 3) Analyze potential connections between changes in under-five mortality and changes in the social and physical environment between 2000 and 2010.

2. Study area and data

2.1 Vernacular neighborhoods

The study area is the Accra Metropolitan Assembly (AMA), which is the core district of the Greater Accra Metropolitan Area and the capital city of Ghana (Figure 1). Although

the boundary of the AMA changed over time, we chose that of 2000, which corresponds to the start of the study period. Accra has experienced substantial population growth since the country's independence in 1957. It grew from 1.6 million in 2000 to more than 2 million in 2010. Weeks et al. (2010) create a set of neighborhoods called “vernacular” neighborhoods, which are places broadly recognized and agreed to by residents. The boundaries were originally identified from tourist and government maps and then were verified or modified by field work that included asking people in each neighborhood where their neighborhood began and ended (for more details, see Engstrom et al. 2013). In this research component, we used a digital version of the field-modified vernacular neighborhood (FMV) boundaries to conduct our analysis. Census data are collected at the level of the enumeration area (EA) in Accra. However, EAs are designed to contain about 1,000 persons and are generally too small in area, population, or both to be considered a neighborhood. Each FMV is thus an aggregation of EAs, allowing the census data to be defined for each neighborhood. The file used contained 100 FMVs with consistent boundaries in 2000 and 2010.

2.2 Census data

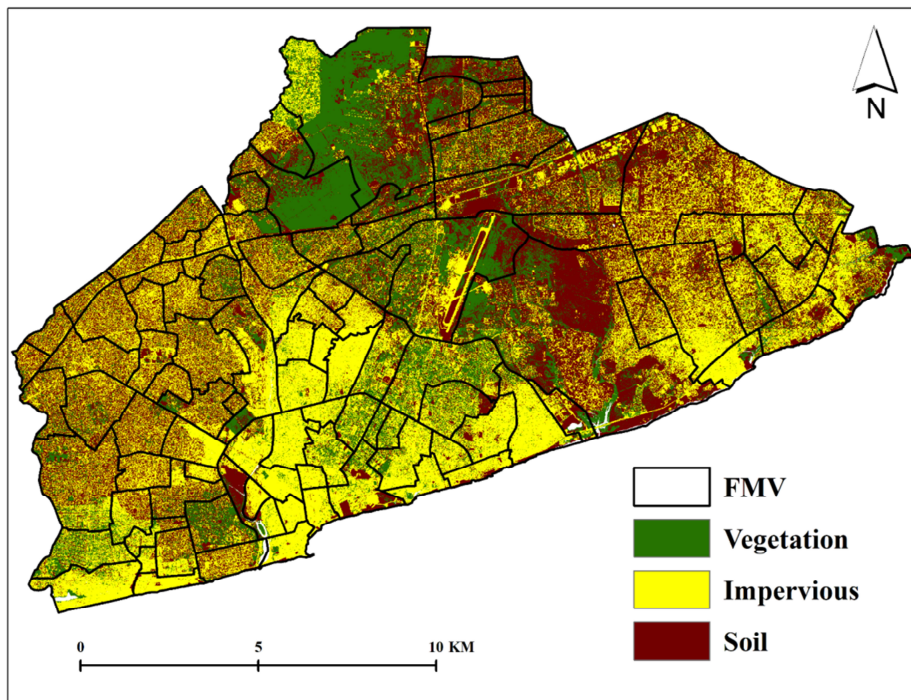
The study period for this research is the decade between 2000 and 2010. The period was selected to coincide with the Ghanaian population and housing censuses and to correspond to the availability of fine spatial resolution commercial satellite imagery for the study area. We used microdata samples from both the 2000 and 2010 censuses, allowing for the derivation of measures from individual/household-level data. The census data contain information about population demographics and housing quality.

2.3 Remote sensing classification products

We derived land-cover and land-use change (LCLUC) information for the city of Accra through the classification of satellite imagery. High spatial resolution commercial satellite images covering the periods 2000–2004 (c.2000) and 2009–2010 (c.2010) were integrated and processed to coincide with the census years. These included multispectral image data from the IKONOS, QuickBird, WorldView-02, and GeoEye satellite imaging systems, with spatial resolutions varying between 1.7 and 3.4 meters. All images have a panchromatic band and at least three visible and one near-infrared multispectral bands. Full details of the land-cover and land-use classification and mapping procedures are described in Touré et al. (2018). We adopted geographic object-based image analysis and backdating approaches to estimate land-cover and

land-use changes between 2000 and 2010 for the study site. The primary classes of interest in the classification of the satellite images were vegetation, impervious, and soil (VIS), based on the Ridd (1995) model of characterizing the urban environment. We also summarized the percentage of an FMV that was used for residential purposes and the percentage used for commercial purposes. That summary also included parts of the city that were still left undeveloped. Therefore, the six LCLUC information classes represented at the FMV level were the three VIS land-cover classes plus residential, nonresidential, and undeveloped land-use classes.

Figure 1: Study area: Accra Metropolitan Assembly. Field-modified vernacular neighborhoods (FMV) overlaid on the land-cover classification of Accra in 2010



3. Methods

We conducted the exploratory analysis in two stages. The first stage constituted a macroanalysis where all of the 100 neighborhoods in Accra were considered. In this stage, we first estimated rates of under-five mortality in Accra for the years 2000 and 2010 and the change between 2000 and 2010. We then derived physical environmental characteristics at the neighborhood level of Accra for the three time frames. Finally, we ran several regression analyses between rates of under-five mortality and values of LCLUC to identify possible connections between child mortality rates and changing neighborhood environments at each of the three time frames. In the second stage of our work, we divided the field-modified vernacular neighborhoods into three groups based on their 5q0 values in 2000. FMVs with rates of under-five mortality greater than or equal to 90 belonged to the first group. The results of a preliminary analysis on the range of 5q0 values in 2000 indicated that 90 was an appropriate cutoff value for FMVs with high rates of under-five mortality. The second group was made up of FMVs with rates of under-five mortality greater than or equal to 80 but less than 90. Finally, the FMVs in the third group had values lower than 80. We compared the three groups in 2000 and 2010 to look for statistically significant differences in their environmental composition. We also analyzed the changes that occurred within the groups between 2000 and 2010.

3.1 Estimating rates of under-five mortality (dependent variables)

The lack of complete vital statistics in Ghana means that rates of under-five child mortality have to be estimated indirectly. As noted above, these could be drawn from survey data that include the collection of complete birth history data, but such data are not available at the spatial scale of the neighborhood. Building on the work of Jankowska, Benza, and Weeks (2013), we used summary birth history data from the 2000 and 2010 censuses to estimate values of 5q0 for each neighborhood in Ghana.

The usual indirect methods (Brass 1975; Rajaratnam et al. 2010; United Nations Population Division 1983) incorporate a variety of regression coefficients to equate data on children born and surviving to 5q0. We do the same but with a slight variation on the theme of Rajarantham et. al. (2010): (a) They use all available DHS surveys to create their coefficients, while including country-specific error terms, whereas we use only DHS data for Ghana, allowing us to control for regional trends in fertility and mortality, and (b) Rather than calculate the ratio of children surviving to children ever born, which is the basic idea of the Brass method (implemented in Qfive in MortPak; United Nations Population Division 2013), we calculate the proportion of mothers who have

lost one or more children. We look at only mothers because in Ghana a major cause of fertility decline is the delay in childbearing among younger women, so we control for this fertility trend by looking at only mothers – furthermore, we know that some women lose a disproportionate share of children (Silva 2012). In a spatial analysis we are less interested in the individual characteristics of women than we are in the aggregate characteristics of people living in a given area. This is because child mortality is about not only maternal characteristics but also local environmental resources, including education for males and females, clean water, sewerage, housing that is protective, and economic activity sufficient to make ends meet.

Note that since the DHS data provide direct measures of child mortality, we are able to relate that measure at the region level to the proportion of mothers who have lost a child. We also restrict our analysis to women aged 25 to 49 since younger women are known to have disproportionately high levels of child mortality that can distort the aggregate results (United Nations Population Division 1983). We go out to age 49 in order to have an adequate number of women per spatial unit for the analysis. As a result of the age range, our 5q0 estimates refer to a time period that is approximately 10 years prior to the collection of the data.

We created a data set that included direct measures of 5q0 at the region level in Ghana from the DHS in 1988, 1993, 2003, 2008, and 2014. For each region at each survey date, we then calculated the proportion of mothers aged 25 to 49 who had lost at least one child. We calculated the regression equation in which we predict 5q0 based on the proportion of mothers having lost a child. There is a very high R^2 between the proportion of mothers aged 25 to 49 who have lost a child and DHS direct measurement of 5q0. However, the relationship is not quite linear. The best fit is provided by the quadratic equation

$$5q0_{est} = 33.5 + (46.885 \times \text{childlost}) + (390.710 \times (\text{childlost})^2); R^2 = .911.$$

3.2 Explanatory variables

The independent (explanatory) variables used in our analysis, listed in Table A-1, aim to describe the social and physical environment of each neighborhood, factors known from the literature to be associated with spatial differences in under-five mortality. Andriano and Monden (2019) make a convincing case that maternal education “plays a key role in determining children’s chances of survival in low- and middle-income countries” (p. 1765). This is consistent with our research for Ghana at the district level (second administrative boundaries), in which we found that in both 2000 and 2010, the percent of women in a district who reported in the census that they had no education

was the single most important predictor of a district's level of under-five mortality (Weeks 2019). Related personal variables such as marital and employment status may also affect a mother's knowledge of ways to prevent child death and her resources for doing so. Other key household variables relate to water sources, cooking facilities, and sanitation facilities. These variables were calculated for each household and then aggregated to the FMV level for statistical analysis.

Among the subcategories that make up the marital status variable, not being currently married appears to be associated with a greater chance of a woman having lost a child. We therefore combined all other categories into the reference category and recoded the marital status variable into a binary categorical variable, with 1 for women not currently married and 0 for women married or in a union. Similarly, rain and well water, the two water source subcategories that appeared to increase the chance of a woman having lost a child in the preliminary analysis, were coded into 1 while all other water sources categories were recoded as 0 and used as the reference category. Under the toilet facility category, using a public toilet or having no toilet facilities at all yielded higher rates of under-five mortality. Finally, low levels of education for women show a negative impact on under-five mortality. We defined low education level as having completed only primary school. All educational attainments above primary school were combined into the reference category, following the example of Nakamura et al. (2011).

We also derived a slum index for each neighborhood based on the work of Weeks et al. (2007), who use the UN definition of slum to create an index that characterizes how slum-like a household is. This index was then aggregated at the neighborhood level. Finally, we derived land-cover and land-use information from the classification of satellite imagery, as described above. The proportion of land that is composed of vegetation, impervious surface, or soil is an indicator both of the socioeconomic status of a neighborhood (a known predictor of mortality levels at all ages; Stow et al. 2013) and an indicator of the level of environmental hazards that might exist in a neighborhood that could influence the health of infants and children. They are important indices of the urban context in which people are living. We derived all independent variables for the years 2000 and 2010 and the change between 2000 and 2010.

At the neighborhood level, we ran a multiple linear regression by comparing rates of under-five mortality to the independent variables derived from the classification of satellite imagery and from the census data (LCLUC). After this analysis, we created another dependent variable representing the answer to the question of whether a neighborhood 5q0 estimate is greater than the average 5q0 of Accra. We compared this dependent variable to the significant independent variables derived from the previous analysis in a binary logistic regression.

4. Results

4.1 Explaining under-five mortality in Accra in 2000

Figure 2 shows the spatial distribution of estimated 5q0 by field-modified neighborhood for the year 2000. The mean 5q0 is 84.23 deaths under the age of 5 per 1,000 live births in Accra for the year 2000. The range of the 5q0 values is 80.79, with a minimum of 49.96 and a maximum of 130.75. Out of 100 neighborhoods, 33 have 5q0 values between 80 and 90 (i.e., near the city's average).

However, there is considerable spatial variability in under-five mortality, as can be seen in Figure 2, including a few neighborhoods with high 5q0 values surrounded by neighborhoods with low values.

Figure 2: 2000 estimates of under-five child mortality

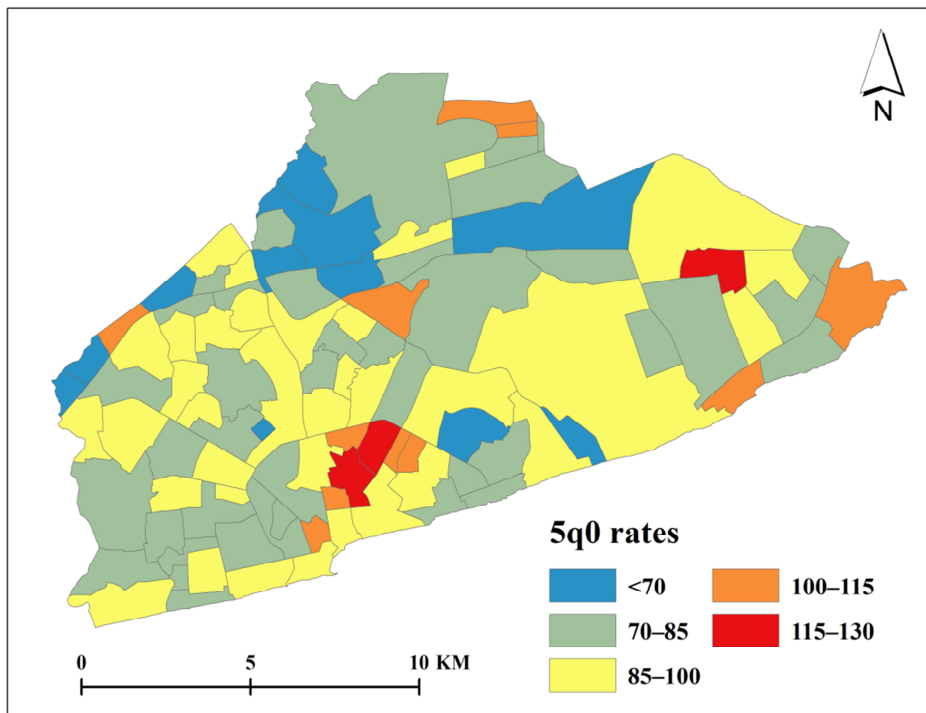


Table 1 presents the results of the stepwise linear regression model at the neighborhood level. About one-fifth of the variance in under-five mortality (the dependent variable) is explained by the following statistically significant dependent variables: (1) percentage of undeveloped land in a FMV ($p\text{-value} = 0.000$); (2) percentage of HH with no toilet facilities ($p\text{-value} = 0.001$); (3) percentage of FMV that is residential ($p\text{-value} = 0.020$); and (4) percentage of HH cooking in an enclosed structure with no roof ($p\text{-value} = 0.021$). Whereas the no toilet facility variable increases the explanation of under-five mortality variability, a unit increase in the remaining three variables decreases rates of under-five mortality.

Six neighborhoods were identified as outliers in the analysis. Outliers were defined as FMVs with under-five mortality rates outside of two standard deviations of the predicted under-five mortality value. These were FMVs that had estimated 5q0 values very different from the values predicted by the regression model. They are (with their estimated 5q0 values compared to the values predicted by the model) Awoshie ($58.51 < 88.08$), Greda Estates ($130.75 > 97.11$), Medina Estate ($106.97 > 78.73$), Niiiboye Town ($54.79 < 85.21$), North Labone Estate ($54.85 < 85.34$), North Ridge ($122.75 > 92.92$), and Roman Ridge ($114.42 > 84.31$). No spatial contiguity exists between the six neighborhoods.

A binary logistic regression model was run to compare the significant independent variables to the dependent variable representing the answer to the question of whether a neighborhood 5q0 estimate is greater than the average 5q0 of Accra. This model did not yield a statistically significant result.

Table 1: Result of stepwise linear regression between mean under-five mortality rates (dependent variable) and land cover/land use and census variables for the year 2000

Model	Unstandardized coefficients		Standardized coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	101.806	5.060		20.12	.000
Undeveloped land	-43.555	8.585	-.695	-5.073	.000
No toilet facility	54.237	16.209	.346	3.346	.001
Residential	-13.862	5.868	-.291	-2.362	.020
Cooking_space enclosure_no roof	-233.314	99.456	-.221	-2.346	.021

Note: Adjusted R square = .196.

4.2 Explaining under-five mortality in Accra in 2010

Figure 3 depicts the results of the 5q0 estimation for the city of Accra in 2010. A big drop in under-five mortality occurred between 2000 and 2010. The mean 5q0 value in 2010 was 41.00, compared to 84.23 in 2000. The 5q0 range is 33.88, with a minimum of 33.5 and a maximum of 67.38. Moreover, there appears to be much less spatial variation in 5q0 rates across the city in 2010 than in 2000. The choropleth map (not shown) portrays a homogeneous distribution when using the same categories as Figure 2 shows for 2000, since every neighborhood in 2010 is estimated to have a child mortality level of no more than 70 per 1,000.

Figure 3: 2010 estimates of under-five child mortality

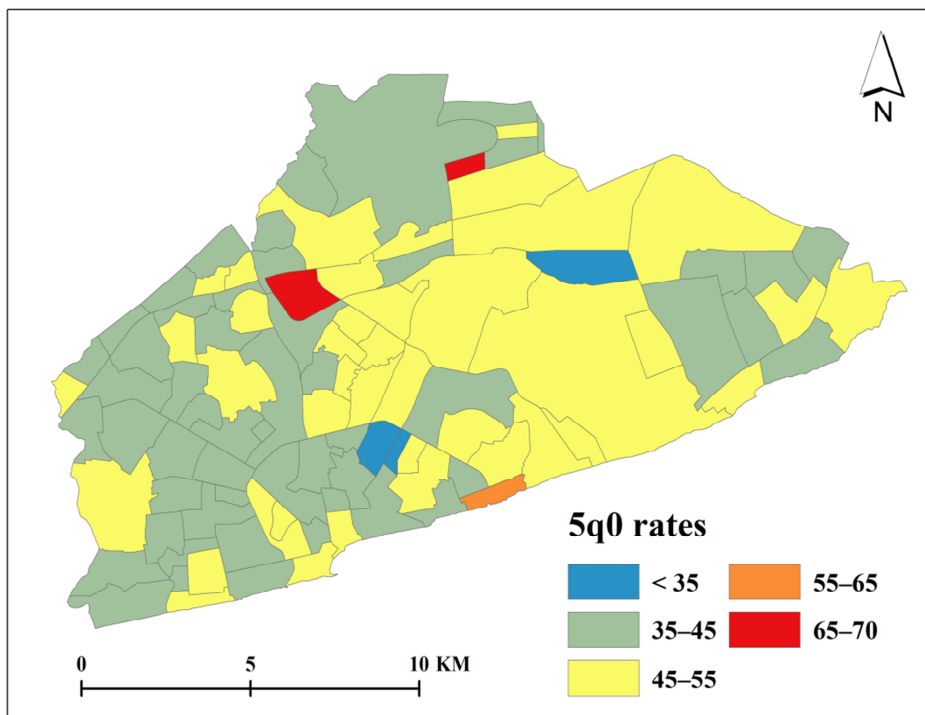


Table 2 shows the results of the multiple linear regression analysis for determining the factors influencing under-five mortality in Ghana for the year 2010 at the neighborhood level. About 12% of the variance in 5q0 is explained in 2010 (adjusted R

square = .121). In the model, using a bucket as a toilet and having a pipe in the house as a source of water supply are significant predictors of under-five mortality. Having a bucket toilet is the most significant predictor with a p-value of 0.005. However, having a pipe in the house as a water source is statistically significant ($p = 0.013$) and positively influences under-five mortality. Four neighborhood outliers were revealed during the analysis. The predicted values of 5q0 are significantly lower than the actual values for Abelemkpe ($46.91 < 67.38$) and South La Estate ($44.54 < 56.80$). On the other hand, the actual 5q0 values of the Airport Hill Residential and University of Ghana are significantly lower than the predicted values ($33.50 < 48.36$ and $37.61 < 49.61$, respectively).

Table 2: Result of stepwise linear regression between mean under-five mortality rates (dependent variable) and land cover/land use and census variables for the year 2010

Model	Unstandardized coefficients		Standardized coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	47.35	1.54		30.84	.00
Toilet_bucket	17.31	6.07	.27	2.85	.01
PipeinHouse	-10.20	4.03	-.24	-2.53	.01

Note: Adjusted R square = .12

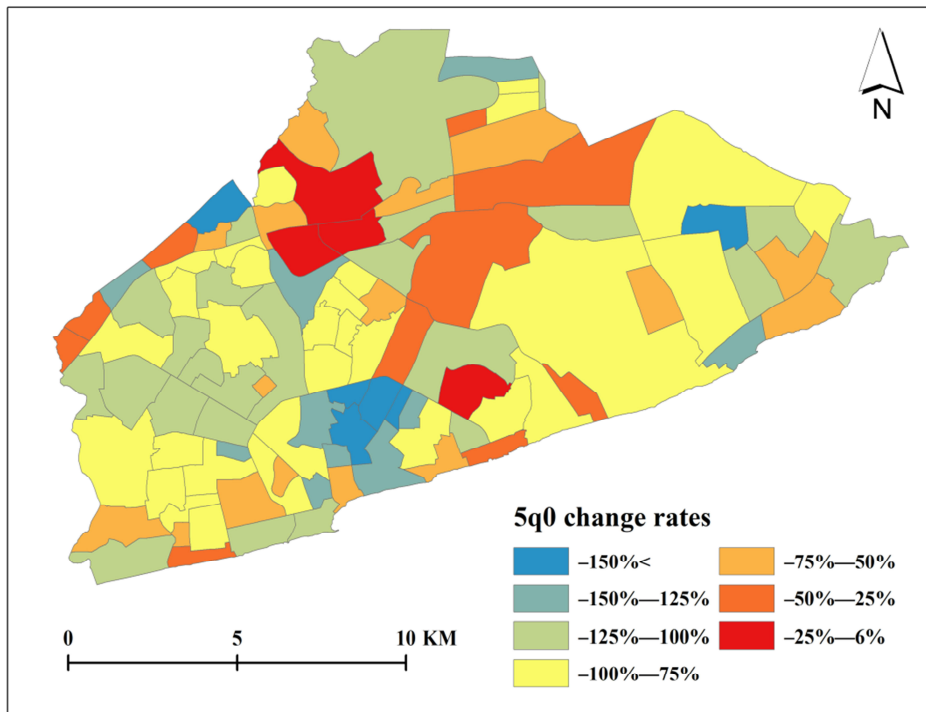
We also conducted a binary logistic regression with the dependent variable being the answer to the question of whether FMV rates of 5q0 were below or above the mean 5q0 of Accra in 2010. The Cox & Snell and Nagelkerke R Square values are .203 and .271, respectively ($p\text{-value} = 0.00$). Two variables are statistically significant: (1) cooking space in a structure with a roof but without walls ($B = 72.95$, $p\text{-value} = 0.01$) and (2) using Kumasi Ventilated-Improved Pit (KVIP) as a toilet ($B = -8.61$, $p\text{-value} = 0.00$).

4.3 Explaining changes in the rates of under-five mortality in Accra between 2000 and 2010

Figure 4 presents a percentage change in 5q0 rates between 2000 and 2010 relative to 2000. All neighborhoods experienced a reduction in under-five mortality. Out of 100 FMVs, 40 experienced a relative drop in their 5q0 rates of more than 100%. However, changes were not homogeneous across the study area. Some FMVs experienced more

or fewer changes compared to others. These were the subjects of a separate group analysis.

Figure 4: Relative change in under-five child mortality rates between 2000 and 2010



The results of the multiple linear regression analysis comparing absolute changes in under-five mortality rates to changes in environmental variables are presented in Table 3. Through this model 12% (adjusted R square = .119, p-value = 0.002) of the variance in 5q0 change is explained.

Three statistically significant variables positively affect change in 5q0: (1) change in soil percentage per FMV, (2) change in percentage of households using a tanker for their water supply, and (3) change in a neighborhood household percentage using a public toilet. The most significant variable is change in using a tanker as a water source ($p = 0.01$), followed by changes in the soil percentage of a FMV ($p = 0.03$). Finally, less use of a public toilet by a woman reduces her chances of losing a child ($p = 0.04$).

Three FMVs were identified as outliers because they experienced particularly dramatic changes in rates of 5q0. The absolute change in 5q0 values from 2000 to 2010 for the neighborhoods of Greda Estates, North Ridge, and Victoriaborg were -91.91, -89.25, and -77.26, respectively. Greda Estates reduced its reliance on a tanker as a water source from 43% to 0%. North Ridge and Victoriaborg are two contiguous FMVs at the heart of Accra with relatively high percentage of nonresidential land use (47.5% and 93.3%, respectively). Therefore, few women of reproductive age resided there. Their counts of children ever born to women aged 25 to 49 were 83 and 17 in 2000 and 11 and 41 in 2010, respectively. The low number of children born in these FMVs might explain the wide variations in 5q0 estimates.

Table 3: Result of stepwise linear regression between change in under-five mortality rates (dependent variable) and change in land cover/land use and census variables between 2000 and 2010

Model	Unstandardized coefficients		Standardized coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	-43.11	1.89		-22.80	.00
Soil_Change	25.87	12.05	.21	2.15	.03
Tank_Water_Change	45.88	17.14	.27	2.68	.01
Public_Toilet_Change	12.76	6.17	.21	2.07	.04

Note: Adjusted R square = .119

4.4 Identifying subgroups

After the exploratory analysis for the entire study area, the neighborhoods of Accra were divided into three categories of high, medium, and low categories of under-five child mortality rates in 2000, and a similar exploratory analysis was conducted for these three groups. The purpose of this follow-up analysis was to identify environmental factors that differentiated neighborhoods with high 5q0 rates from those with medium or low 5q0 values in 2000 and 2010. We were also interested in knowing which, if any, environmental factors (variables) significantly changed within the groups between 2000 and 2010. Table 4 lists the main characteristics of each of the three groups.

The mean 5q0 value of Accra for 2000 is 84.23 with a standard deviation of 15.39. FMVs with 5q0 rates of 90 or higher in 2000 (i.e., higher than average mortality rates) make up Group 1. This group is composed of 35 neighborhoods and has a mean 5q0 value of 100.43 with a standard deviation of 10.28. Neighborhoods with 5q0 values less than 90 but higher than or equal to 80 constitute Group 2. The mean 5q0 value for

Group 2 (33 FMVs) is 84.16 (very similar to the mean of the entire city) with a standard deviation of 2.58. Finally, Group 3 is made up of the remaining 39 FMVs that had 5q0 rates below 80 in 2000. The mean 5q0 value of Group 3 is 69.75 with a standard deviation of 10.17. We adopted a two-sample t-test to check for statistically significant differences between the mean 5q0 values of the three groups. The results in the three groups are statistically different at the .05 level. Comparing Group 1 to Group 2 results in a t-score value of 8.82. This value is greater than the 1.99 threshold, which suggests that the difference between the two groups is statistically significant. Similarly, the t-score values resulting from comparing Group 1 to Group 3 and Group 2 to Group 3 are 12.89 and -9.24, respectively.

Table 4: Between and within group comparison of under-five mortality (5q0) and slum index

	Group 1		Group 2		Group 3	
	2000	2010	2000	2010	2000	2010
Mean 5q0	100.4256	43.8958	84.1612	45.6449	69.75	44.6977
5q0						
Std dev.	10.28332	5.15693	2.58071	5.23059	10.17	6.3722
Slum index	1.7025	1.2167	1.8711	1.4447	1.6868	1.3885
Slum index						
Std dev.	0.50307	0.36124	0.3407	0.23657	0.51826	0.27114

We performed several two-sample t-tests to determine whether the differences in land-cover and land-use variables as well as variables derived from the census data are statistically significant between FMVs with high, medium, or low under-five child mortality values. For example, we evaluated the significance of the difference in the amount of vegetation land cover between Groups 1, 2, and 3. In 2000, none of the differences in the 82 independent variables is statistically significant between the three groups. Only the difference in the slum index between the medium and low 5q0 value groups (Groups 2 and 3) was statistically significant at the $p < .10$ level. The mean and standard deviation values of the slum index for Groups 2 and 3 were 1.8711, 0.3407 and 1.6868, 0.51826, respectively. The resulting t-score is -1.75 ($p < .10$).

The difference in under-five mortality rates between the three groups in 2010 is not statistically significant. Similar to 2000, only the difference in slum index is statistically significant in 2010, but only between Group 1 and 2 and between Group 1 and 3. The difference between Group 2 and 3 is not statistically significant.

We also considered changes in the independent variables within each group between 2000 and 2010. The change in slum index is statistically significant within all three groups. Its value dropped by 28.53% within Group 1. Groups 2 and 3 experienced a reduction in the slum index values of 22.78% and 17.68%, respectively. Moreover,

Group 3, the group with the lowest 5q0 values in 2000, saw a reduction in the percentage of liquid waste disposal in compounds (a type of habitation made up of several building units with an enclosure) that is statistically significant. The proportion of liquid waste disposed in the compound reduced from 26.76% in 2000 to 8.26% in 2010 for Group 3.

Finally, we isolated Group 1 and focused on the FMVs in 2000 with the highest rates of 5q0s that experienced the greatest reduction and compared them to those that experienced the least reduction. The mean 5q0 value for Group 1 went from 100.43 to 43.90, with a mean reduction value of 56.59. We considered FMVs that experienced a reduction in their rates of 5q0 of 57 or more to be the FMVs with the highest reduction. We analyzed the changes in the independent variables that occurred within those FMVs between 2000 and 2010 and compared them to the FMVs that experienced the least reduction. The results indicate again that only the change in the slum index variable is statistically significant for the group with the highest change between 2000 and 2010. However, the change in slum index is also statistically significant for the FMVs with the lowest changes.

4.5 Intra-urban variation in under-five mortality

An important objective of the study was to examine variability in the intra-urban rates of 5q0. Sufficient evidence from the analysis demonstrates the spatial variability of under-five child mortality rates among Accra's neighborhoods in 2000. The wide range of 5q0 values, from 49.96 to 130.75, as well as the spatial distribution of those values (Figure 2), suggests a high degree of intra-urban variability. The situation is more nuanced in 2010. The rates of under-five mortality fell enormously across all neighborhoods from 2000 to 2010, with the range of 5q0 in 2010 being only 41.

The toilet types seem to have the most negative association with under-five mortality rates. Having no formal toilet facilities or using a bucket as a toilet increased the chances of losing a child in 2000 and 2010, respectively. Moreover, reductions in the use of public toilets variable is positively associated with a decrease in under-five mortality rates. Other environmental factors associated with low 5q0 rates are cooking in an enclosure with no roof (2000) and having the household source of water being a pipe inside the house (2010). Indeed, the drop in the number of households using a tanker as their water source is also positively correlated to reduction in 5q0 rates. The variables that negatively influence 5q0 are well summarized by the slum index. The slum index represents the sum of five census variables. Two of those variables are related to the water sources and the toilet type of the housing units. A house is more likely to be slum-like if it does not have piped water or if there is no toilet and no

sewage connection. Our group analysis confirms this fact. Changes in slum index value as well as changes in 5q0 rates are consistently significant within the three groups between 2000 and 2010. Finally, living in a neighborhood with a high percentage of undeveloped land use is negatively correlated with high rates of 5q0 in 2000. The undeveloped land use is a composition of vegetation and soil land cover. Previous studies have shown that high socioeconomic neighborhoods had more vegetation cover than low socioeconomic neighborhoods in Accra (Stow 2007). It is also established that populations with low socioeconomic characteristics experienced higher rates of under-five child mortality than populations of a higher socioeconomic status (Sastry 2004). Therefore, the positive influence of undeveloped land use may relate more to economic status than to physical characteristics of the neighborhood.

5. Discussion and conclusion

Only about 20% of the neighborhood-level variance in under-five mortality is explained by the combination of the 82 independent variables we generated for this analysis. This means that key variables or factors are missing for the explanation of why the under-five mortality rate declined drastically in Accra between 2000 and 2010. The most likely explanation is the implementation of health policies and interventions by the Ghanaian government. Reducing child mortality has been a Millennium Development Goal (MDG 4) and more recently a Sustainable Development Goal (SDG) of the United Nations (SDG 6). The MDG 4 target was to reduce by two-thirds the under-five mortality rate between 1990 and 2015.

According to the UN, Ghana acted to reduce under-five mortality from 155 to 60 per 1,000 live births between 1988 and 2014 (based on results from the Ghana Demographic and Health Surveys for those years). The decline we describe here for Accra was in fact occurring countrywide. It was the result of the implementation of the Child Health Policy and Child Health Strategy program. The program is described below:

The strategy outlines key interventions to be scaled up along the continuum of care and focuses on improving access to, quality of, and demand for, essential services. It also includes recent new technologies such as low osmolarity ORS and zinc for the management of diarrhea, and introduction of new vaccines such as 2nd dose measles vaccine, pneumococcal vaccine and rotavirus vaccine through the national EPI. The strategy has contributed to the scaling up and sustenance of the child-health interventions. (United Nations Development Program 2015)

A result of this policy is that the proportion of infants under one year old vaccinated against measles increased from 50% in 1990 to 89% in 2014 (United Nations Development Program 2015). Moreover, between 2009 and 2014, 77% of children aged between 12 and 23 months had been given full basic immunization by 12 months of age (Ghana Statistical Service 2014).

Reduction in premature mortality is part of the demographic transition through which every nation proceeds. Most developing countries are currently in the second phase of their demographic transition, which is characterized by high, albeit declining, birth rates and low child mortality levels. Most countries on the African continent remain at that stage, yet their rates of under-five child mortality are still higher than in most of the world. Even within individual countries, rates of 5q0s are higher in rural areas as compared to urban areas. The recent literature suggests that there is even more differential of under-five death rates within cities of developing countries. In this study, we have examined the possible 5q0 spatial disparities that might exist in the major urban center of Accra, Ghana. We have also tried to identify the physical environmental factors associated with the rates of 5q0 in the different neighborhoods of Accra in 2000 and 2010. Finally, we were interested in knowing if changes in environmental conditions were associated with changes in rates of 5q0.

The results of this study confirm the existence of spatial variability in rates of under-five mortality in Accra for the year 2000. Such variations are minimal in 2010 due to the dramatic decline in child mortality between 2000 and 2010. Moreover, there is evidence that nontraditional toilet types and water supply sources are associated with high rates of under-five child mortality. The public health implications are that providing clean sources of water and more hygienic toilet types in urban areas of the developing world will further reduce rates of under-five mortality. Prioritizing clean water provision and improved sanitation may not only increase child survival, it would also help reduce illness and time lost at school and at work for all ages. As one of 17 United Nations SDGs, clean water and sanitation provision for all (SDG 6) is buoyed by international mandate.

This study did not take into account the effect of the application of national policies for the reduction of under-five mortality. Further work could investigate spatial variation in the implementation and potential outcomes of specific policies, such as immunization campaigns. As our study suggests that spatial location is highly predictive of mortality outcomes, future work could further examine spatial characteristics of mortality with geographically weighted regressions to better understand how predictor variables interact with mortality outcomes differently in hot and cold zones of mortality.

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Appendix

Table A-1: Explanatory variables tested in the analyses. The mean and standard deviation values represent values at the beginning of the study period in 2000

Independent variables	Mean	Std. Deviation
<i>Female aged 25 to 49 characteristics</i>		
Education level:		
preschool	.0053	.0729
primary	.0581	.2340
middle	.3763	.4845
secondary_school	.1269	.3329
vocational_technical	.0854	.2794
post_secondary	.0298	.1702
tertiary_school	.0812	.2732
Employment status:		
employee	.2038	.4028
self-employed	.5456	.4979
self-employed_work	.0684	.2524
unpaid_family_work	.0058	.0758
apprentice	.0161	.1258
domestic_employee	.0061	.0778
other_employment	.0054	.0736
Employment sector:		
public_sector	.0849	.2788
private_informal_sector	.6106	.4876
private_formal_sector	.1167	.3210
NGO	.0042	.0649
semipublic	.0158	.1247
other_sector	.0190	.1364
Marital status:		
married	.6179	.4859
living_together	.0657	.2477
separated	.0394	.1945
divorced	.0604	.2383
widowed	.0266	.1610
single	.1900	.3923

Table A-1: (Continued)

Independent variables	Mean	Std. Deviation
<i>Female aged 25 to 49 characteristics</i>		
Industry:		
fishing	.0192	.1374
construction	.0097	.0981
hotels_restauraton	.0769	.2665
public_administration	.0261	.1594
education_industry	.0324	.1771
health_social_industry	.0162	.1261
private_household	.0113	.1056
extra_territorial	.0015	.0383
<i>Neighborhood characteristics</i>		
Land Cover/Land Use:		
veg_00_mean	.2726	.2093
imp_00_mean	.4958	.2354
soil_00_mean	.2247	.1252
residential_0_mean	.6712	.3226
nonresidential_0_mean	.1733	.2357
undeveloped_0_mean	.1526	.2456
Slum index	1.7488	.4683
Water:		
pipe_inside_mean	.4968	.1938
pipe_outside_mean	.4029	.1733
water_tank_mean	.0307	.0837
well_mean	.0405	.0319
bore_hole_mean	.0028	.0051
spring_mean	.0099	.0088
river_mean	.0010	.0039
dugout_mean	.0028	.0038
other_water_mean	.0027	.0044

Table A-1: (Continued)

Independent variables	Mean	Std. Deviation
<i>Neighborhood characteristics</i>		
Bathing facilities:		
own_bath_mean	.3621	.1893
shared_bath_mean	.2485	.1184
open_cubicle_mean	.0400	.0317
shared_open_cubicle_mean	.2350	.1410
public_bath_mean	.0360	.0895
bath_another_mean	.0102	.0096
bath_openspace_mean	.0387	.0516
bath_river_mean	.0084	.0120
bath_lake_pond_mean	.0056	.0090
bath_other_mean	.0050	.0086
Toilet:		
WC_mean	.3507	.2326
pit_latrine_mean	.0623	.0678
KVIP_mean	.1035	.1136
toilet_bucket_pan_mean	.0978	.0997
toilet_another_facility_mean	.0902	.0414
public_toilet_mean	.2226	.2017
toilet_no_facility_mean	.0627	.1108
toilet_other_mean	.0020	.0027
Cooking space:		
no_cooking_space_mean	.3465	.1924
cooking_separate_room_mean	.3465	.1924
cooking_separate_room_shared_mean	.0448	.0316
cooking_enclosure_norooft_mean	.0208	.0146
cooking_roof_structure_mean	.0202	.0129
cooking_bedroom_mean	.0263	.0170
cooking_veranda_mean	.1934	.1070
cooking_compound_mean	.2674	.1395
cooking_other_mean	.0036	.0034
Liquid waste:		
liqwaste_sewage_mean	.2346	.2105
liqwaste_street_mean	.1575	.1114
liqwaste_gutter_mean	.3783	.2645
liqwaste_compound_mean	.2129	.1902
liqwaste_other_mean	.0053	.0107

