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Research Article

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Table of Contents

Demographic Research: Volume 28, Article 2
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Estimating spatial inequalities of urban child mortality

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Abstract

BACKGROUND
Recent studies indicate that the traditional rural-urban dichotomy pointing to cities as places of better health in the developing world can be complicated by poverty differentials. Knowledge of spatial patterns is essential to understanding the processes that link individual demographic outcomes to characteristics of a place. A significant limitation, however, is the lack of spatial data and methods that offer flexibility in data inputs.

OBJECTIVE
This paper tackles some of the issues in calculating intra-urban child mortality by combining multiple data sets in Accra, Ghana and applying a new method developed by Rajaratnam et al. (2010) that efficiently uses summary birth histories for creating local-level measures of under-five child mortality (5q0). Intra-urban 5q0 rates are then compared with characteristics of the environment that may be linked to child mortality.

METHODS
Rates of child mortality are calculated for 16 urban zones within Accra for birth cohorts from 1987 to 2006. Estimates are compared to calculated 5q0 rates from full birth histories. 5q0 estimates are then related to zone measures of slum characteristics, housing quality, health facilities, and vegetation using a simple trendline R^2 analysis.

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RESULTS
Results suggest the potential value of the Rajaratnam et al. method at the micro-spatial scale. Estimated rates indicate that there is variability in child mortality between zones, with a spread of up to 50 deaths per 1,000 births. Furthermore, there is evidence that child mortality is connected to environmental factors such as housing quality, slum-like conditions, and neighborhood levels of vegetation.

1. Introduction

Despite a half-century of improvement in life expectancy, levels in sub-Saharan Africa remain low. Almost three decades ago Farah and Preston (1982:381) noted that "mortality levels in sub-Saharan Africa are the highest in the world and are the object of substantial national and international concern." That conclusion has been repeated over time (Balk et al. 2004; Ewbank 1993), and it is still the case today even as mortality declines. Hill (1993) estimated that in 1936 the probability of a child in Ghana dying before age five was 0.371. By 1980 it had dropped to 0.164, and the 2003 Ghana Demographic and Health Survey (GDHS) produced a rate of 0.111 (GSS, NMIMR, and Orc Macro 2004). Most recently, the 2008 GDHS showed a continued drop to .080, although that rate is believed to slightly understate the actual level of child mortality (GSS, GHS, and ICF Macro 2009). While decreasing, rates are still stubbornly high and ten times higher than in the United States.

High levels of child mortality are a major contributing factor to low life expectancy as sub-Saharan societies move through health and mortality transitions. These transitions are pushing mortality risks into the very young and very old cohorts due to the double burden of acute communicable and chronic degenerative diseases (Boutayeb 2006; Weeks 2011). As income and wealth rise in the context of an improving economy, they almost always do so in an unequal fashion leading to widely different risk profiles for acute and chronic illness. Child mortality is a direct consequence of high-risk profiles for acute illness. In West Africa, as in almost every other part of the world, chances of survival for children and adults are higher in cities than in rural areas (Balk et al. 2004). Yet, research indicates that the averages used to compare urban and rural areas mask significant urban inequalities (Timæus and Lush 1995; Vlahov et al. 2010).

As interest in urban child mortality differentials increases, there remains a gap in our understanding of the spatial components of child mortality inequality. Spatial inequality can highlight aspects of child mortality that poverty or urban/rural classifications cannot – namely, the processes that link individual health outcomes to characteristics of a place. Context, or a person's social and physical surroundings, has been demonstrated by multiple studies to be a statistically significant factor for diverse health outcomes (Montgomery and Hewett 2005; Pickett and Pearl 2001; Riva, Gauvin, and Barnett 2007). As Dunn and Cummins (2007:1822) noted, "changes in context may produce changes in the risk profile for whole populations, rather than just for the people who receive and are successful with individually-oriented interventions." In this regard spatial demography, or the demographic study of attributes aggregated to a level within a geographical hierarchy (Voss 2007), can contribute to understanding which aspects of urban context are meaningful for child mortality.

Unfortunately, the analysis of intra-urban child mortality patterns is exceedingly difficult due to data and methodological constraints. Rajaratnam et al. (2010) have recently developed and validated a new set of low-cost methods that efficiently use summary birth histories for creating local-level measures of under-five child mortality (5q0). In their paper, they apply the low-cost method using census data for jurisdictions (*municipios*, roughly equivalent to US counties) in Mexico. The method has significant potential for deriving local-level measures of 5q0, but its applicability for limited data input at the micro-scale is as yet untested. The purpose of this study is two-fold: 1) to test the utility of the Rajaratnam et al. method with small numbers at the micro-scale level of zones within a developing world city – Accra, Ghana and 2) to compare the variability of intra-urban 5q0 with characteristics of the environment that may be linked to child mortality (housing, vegetation, health care facility access).

1.2 Child mortality in the urban context

Analysis of poverty and demographic differentials within cities and between urban areas emphasizes disparities that can lead to unequal morbidity and mortality (Garenne 2010; Perera, Østbye, and Jayawardana 2009). Songsore and McGranaham (1993; 2007) analyzed two week prevalence of diarrhea and respiratory problems in children under five in Accra, Ghana and consistently found the poorest participants to have significantly higher rates of illness than middle- and high-income participants. Van de Poel, O'Donnell, and Van Doorslaer (2007) found that the magnitude in the urban-rural gap for stunting in 47 developing countries falls dramatically when controlling for wealth, and their analysis confirms the existence of higher socioeconomic inequality in stunting and child mortality for urban areas as compared to rural areas. In reviewing research on health of children in Asian cities, Fry, Cousins, and Olivola (2002: ii) concluded that "without exception, disaggregated data show dramatic differences in health indicators between slum and non-slum populations or between the lower and upper economic quintiles. There is a great need to promote disaggregated urban data collection."

Besides poverty and demographic differentials, child mortality has also been examined through a hierarchical lens by testing the effects and differences between households, communities, and countries (Entwisle 2007). Findings emphasize the importance of community education as well as access to health care and basic infrastructure at courser spatial scales (Fay et al. 2005; Harttgen and Misselhorn 2006; Kravdal 2004; Ladusingh and Singh 2006). In one of the few studies that focuses exclusively on urban areas, Antai and Moradi (2010) used Demographic and Health Survey (DHS) data over time to find that rapid urbanization in Nigeria has been associated with increasing rates of under-five mortality as more and more people crowd into disadvantaged urban areas. The relationship between urban disadvantage and child mortality held steady, even after controlling for child and mother risk factors.

Antai and Moradi's study provides significant evidence that urban context matters for child mortality, but the small sample size of the DHS did not permit a spatial analysis within cities. Health issues in rapidly developing third world cities are extremely complex (Montgomery 2009), partly because they are characterized by wide swaths of poverty of varying magnitude as well as by pockets of extreme affluence (Montgomery and Hewett 2005). A consequence of urban complexity is that traditional individual-level risk factors for child mortality can become complicated by overwhelming environmental burdens of living conditions such as lack of sanitation and poor air quality (Boadi and Kuitunen 2006; Cameron and Williams 2009). This can also work in the positive direction with environmental characteristics, such as improved access to nutrition, medical care, or pure drinking water in the form of sachets that shield children from higher-than-expected mortality (Stoler et al. 2012b). The impact of these urban interactions may create a dissonance between the risk profile of an individual and observed health outcomes among local residents.

There is an urgent need for better understanding of health and demographic processes in the dynamic and rapidly-developing third world urban areas. Unraveling the complexities of urban child mortality necessitates a spatial view of *where* children in cities are suffering in order to better grasp how the urban physical and social environment plays a role in child mortality. Only a handful of studies have attempted to analyze child mortality disparities between urban neighborhoods, the most prominent completed by the African Population and Health Research Center (APHRC) (2002) in Nairobi, Kenya. The APHRC found very high rates of child mortality within slums, as well as differences between slums, which ranged from 100 to 254 deaths under five years of age per 1,000 children. The spatial scope of the study was a comparison of the eight districts within the Province of Nairobi, and the emphasis was only on differences between slum and non-slum districts. Currently there is almost no spatially explicit research statistically linking urban environments to intra-urban 5q0 outcomes. Such research is important for a number of reasons including the need to explore links between place and child mortality, to assess the effectiveness of urban interventions, and to better understand how other demographic processes like migration and family structural changes are impacting child mortality.

1.3 The issue of spatial data

In accepting the potential importance of intra-urban child mortality differentials, we arrive at a significant problem: the lack of geo-referenced child mortality data and methods that can accommodate limited data inputs. In the absence of an accurate vital statistics system, which is often the case in the developing world, the probability that a child will survive from birth to their fifth birthday (5q0) can best be calculated from complete birth history data collected from women, as is done in the DHS. Such data are expensive to collect, and to our knowledge no survey has attempted a thorough spatial sample of a developing world city to assess patterns of 5q0 derived from birth histories. DHS samples rarely exceed several hundred respondents per city, thus limiting the spatial comparisons that are possible. However, methods that rely on summary birth histories focusing on the ratio of children who have died (CD) to the number of children ever born (CEB), are less resource-intensive and can expand potential data sources. “Specifically, the proportions of children dead classified by the mother’s five-year age group or duration of marriage can provide estimates of the probabilities of dying between birth and various childhood ages” (United Nations Population Division 1983: 73).

Unfortunately, it is very rare to find summary birth history data at the fine spatial scale of urban neighborhoods. Some censuses include questions about CEB and CD, but many developing countries do not have a recent or existing census. Furthermore, data collected must also include a geographical component. There are, however, methods of ‘amplifying’ existing spatial data that may assist in providing enough birth history data for estimating under-five child mortality. In this paper we pull from Schenker and Raghunathan (2007) and Roberts and Binder (2009) by combining sample surveys from the same year into pooled datasets, thus enhancing our CEB and CD measures within each geographical unit of analysis.

We then use these data to test the Rajaratnam et al. (2010) method developed at the Institute for Health Metrics and Evaluation, University of Washington, which offers a new low-cost method for calculating 5q0 from summary birth histories. The Rajaratnam et al. method was developed using 166 Demographic and Health Surveys (DHS) and four separate calculations of 5q0 from a combination of birth history, mother’s age, and time since first birth. Depending upon data availability, the method allows anywhere from one to all four calculations to be placed into a region-specific regression model, resulting in a smoothed 5q0 trend. Furthermore, data from surveys in past years can be run through the four methods and included in the final regression that generates the 5q0 estimates. However, the problem of disaggregated data is still applicable to the method – without enough data for CEB or CD in each age cohort or geographical region, estimates may become unreliable. As noted above, the Rajaratnam et al. method has been validated for *municipios* in Mexico by comparing vital statistics with census data, but it has not been tested for small data sets at the micro-scale. Doing so is the major purpose of this study.

2. Study site and data

2.1 Geography

The study site is the Accra Metropolitan Assembly (AMA)—the core district of the Greater Accra Metropolitan Area (GAMA) and the capital city of Ghana, located on the Gulf of Guinea. It exemplifies third world urban growth with an increase in population from approximately 0.5 million in 1965, to 1.6 million people in 2000, to an expected 3.5 million by 2025 (United Nations Population Division 2010). Ghana Statistical Service (GSS) has created geographic delineations for the city varying in scale, the finest of which are the 1,731 enumeration areas (EA), similar to US census blocks. EAs provide the geographical sampling basis for the four health surveys from which we draw our data for this analysis, as well as for the 2000 Census of Housing and Population. A coarser scale of GSS geographic delineations are localities, of which there are 43 within the AMA, each one belonging to one of the six sub-metro areas within the AMA district as of the 2000 census. Localities were aggregated into zones with the help of satellite imagery and expert knowledge of the city so that identifiable neighborhood areas are reflected in the resulting zones. Additionally, each zone was built to include a sufficiently large sample size—a minimum of 50 births per age cohort—to run the 5q0 analysis (Figure 1).

Figure 1: Accra Metropolitan Area in the south of Ghana

Notes: Enumeration Areas (EAs) nested within aggregated zones. EAs sampled in each health surveys are colored gray.

2.2 Birth histories

The study draws on several different surveys as sources of summary birth history data including: the Women's Health Study of Accra (WHSA) for 2003 and 2008, the Ghana Demographic and Health Survey (DHS) for 2003 and 2008, the 2003 Accra Slum Survey (AccraSS)**,** and the 2009 Housing and Welfare Study of Accra (HAWS). All surveys were conducted as two-stage cluster probability samples where EAs served as the sampling frame. The DHS was designed to be representative of the GAMA, and all others were designed to be representative of the AMA: no survey was designed to be representative of the EA level, and as such no weighting is utilized in reporting results. Surveys were also not designed to be spatially representative of the city, and therefore do not have an equitable spatial spread of EAs.[4] Nonetheless, the fact that EAs and households within EAs were selected at random provides data that have a spatial spread reflecting the distribution within the city. While this is not an ideal spatial sample, the data offer spatial insights not otherwise available. The non-DHS surveys were modeled after the DHS and included questions regarding education, religion, ethnicity, and economic situation as well as an extensive health and reproductive history.

[4] We are not aware of any surveys currently in existence that are spatially representative of fertility and child mortality outcomes in urban areas – this is a challenge for conducting spatially explicit research on child mortality at finer spatial scales.

The 2003 and 2008 Ghana DHS include national samples of 5,691 and 5,096 women respectively (GSS, GHS, and ICF Macro 2009; GSS, NMIMR, and ORC Macro 2004). GPS data points were acquired for the DHS sampling clusters within Accra, and were related to EA boundaries for women surveyed in the AMA—443 women in 2003 and 348 in 2008. The 2003 WHSA includes 3,174 women, with over-sampling for older women (Hill et al. 2007). In the 2008 WHSA, 1,819 women were successfully re-interviewed, and 995 women (from the same EAs sampled in the 2003 survey) were asked to participate to replace women who could not be located or had passed away. The HAWS and AccraSS are very similar to the WHSA except that they targeted households in slums as part of a UN-Habitat effort to obtain DHS-style data from neighborhoods defined as slums in Accra. In 2003, the AccraSS surveyed 607 women aged 18 and over, while the HAWS surveyed 1,703 women in 2009 (Stoler et al. 2012b; Un-Habitat and Ghana Statistical Service 2003). All surveys were given by trained survey personnel, who interviewed women in their homes.

Given that each survey is modeled after the DHS, including sampling structure and method of interview, the surveys are good candidates for pooling data. We pooled the 2003 datasets and then the 2008 datasets with the goal of maximizing sample numbers for each zone and minimizing missing data within particular age cohorts. The result was two data sets with a five-year offset that could then be placed into the final 5q0 regression calculation. The surveys meet a number of criteria for data pooling including same variables of interest, similar types of respondents, same modes of interviewing, same survey context, same sample design, and same time of surveys (Roberts and Binder 2009; Schenker and Raghunathan 2007). Some concern could arise over the spatially targeted approach of the AccraSS and HAWS surveys, since the focus on slum neighborhoods might bias unweighted aggregated numbers. However, the spatial nature of the study allows these sampling points to be assessed within their localized spatial context rather than as part of the city average. Table 1 provides selected descriptive statistics for each survey and the pooled 2003 and 2008 data sets.

Table 1: Descriptive statistics for each survey included in this study and the pooled 2003 and 2008 datasets

Statistic	AccraSS	DHS03	WHSA03	Pooled 2003	HAWS	DHS08	WHSA08	Pooled 2008
Women (live births)	388	243	1325	1956	1101	197	1236	2533
Mean women per zone	32	15	83	122	92	12	77	158
Mean age	33	35	33	34	33	35	36	34
CEB	1102	691	3432	5225	2892	533	3425	6850
Mean (Std. Dev.)	2.84 (1.68)	2.84 (1.86)	2.59 (1.61)	2.67 (1.66)	2.63 (1.67)	2.71 (1.56)	2.77 (1.55)	2.7 (1.6)
CD	99	94	171	364	211	36	174	421
Mean (Std. Dev.)	0.26 (0.56)	0.39 (0.69)	0.13 (0.48)	0.19 (0.53)	0.19 (0.32)	0.18 (0.46)	0.14 (0.45)	0.17 (0.48)
Deaths under 5	90	81	103	274	173	36	104	313
Deaths under 5, 5-10 years before survey	24	12	19	55	43	5	20	68

Data from each survey were extracted from the full birth histories of women aged 18 to 49, resulting in summary birth histories for each woman (CEB and CD) as well as data for children who died under the age of five including year of birth. The mean age, CEB, and CD values demonstrate limited variability between surveys within each year, giving confidence to the pooled data. By pooling the surveys, the resulting average number of women *per zone* who have given birth in 2003 goes up to 122 while in 2008 it is at 158.

2.3 City data

Zone measures of child mortality are compared to housing quality, a slum index, vegetation, and number of health facilities per zone (Table 2). The Ghana Census of Population and Housing provides data for Accra’s 1.6 million inhabitants and approximately 350,000 households in the year 2000. It includes individual characteristics, such as education and ethnicity, and household characteristics such as building materials, infrastructure, and cooking fuels. This study uses data from a ten percent sample of anonymized individual-level census data, georeferenced to the EA level to create a zone-aggregated measure of housing quality and a slum index. Housing quality is measured by placing household characteristics[5] into a principal components analysis (PCA), using the first component from the rotated matrix to create the measure (for a full description of the measure please see Weeks et al. 2012). Higher values indicate better housing quality. The slum index draws on the UN-Habitat (2003) criteria for what constitutes a slum[6], creating a score for each household that is aggregated to the zone level where higher values are more slum-like areas (Weeks et al. 2007). The measures are similar in that they are assessing communal living standards but are able to provide unique evaluations due to the differences in the variables they draw upon. Table 2 demonstrates variability of the slum index and housing quality measure for zones throughout the city.

Vegetation can be used as a proxy for overcrowding and socio-economic status of an area (National Research Council 2007). It is of particular interest in the developing world as an obtainable measure of social processes through remote sensing when on-the-ground data is limited. Vegetation for the city is calculated based on Ridd's vegetation-impervious surface-soil (VIS) model (Ridd 1995) from a combination of QuickBird and ASTER imagery of Accra in 2002 and 2001. The high spatial resolution QuickBird image was the primary data source used as it covered most of the study area. Some EAs in the eastern part of the city not included in the QuickBird image were filled in with ASTER imagery (Stoler et al. 2012a). Each zone's percent of vegetation was calculated from the imagery using the VIS model. Finally, georeferenced data for 239 health facilities functioning in the AMA in 2008 were gathered from Ghana Health Services and are coded into government, private, and non-profit facilities. These data do not include all of the non-profit facilities functioning in Accra.

[5] Household characteristics for the housing quality index include: electricity, source of water, type of toilet, type of bathing facility, methods of waste disposal, cooking fuel, kitchen facility, and number of persons per sleeping room.
[6] UN-Habitat defines a household as a slum if it lacks one or more of the following characteristics: structural quality and durability of dwelling, access to safe water, sufficient living area, access to sanitation facilities, and security of tenure.

Table 2: Housing quality, slum index, vegetation, and health facilities for each zone and for Accra as a whole

Zones	Housing quality	Slum index	Vegetation (prop. covered)	Health facilities (total)
101	2.0	2.1	0.1	5
103	1.9	2.1	0.1	6
104	1.9	2.0	0.2	39
107	2.0	2.0	0.2	3
108	2.5	1.7	0.2	15
201	1.5	2.5	0.0	18
301	2.3	2.0	0.2	32
401	2.2	2.0	0.2	12
405	2.9	1.8	0.4	15
406	1.8	2.3	0.1	5
407	1.9	2.2	0.2	4
501	1.9	2.1	0.1	15
502	1.5	2.3	0.1	21
506	3.0	1.5	0.5	21
601	2.3	1.8	0.2	18
605	2.0	2.0	0.2	10
Accra	2.1	2.0	0.2	239

3. Methods

3.1 MAC, MAP, and LOESS

The Institute for Health Metrics and Evaluation offers a free tutorial and R software code for running the Rajaratnam et al. (2010) low-cost method, which can be downloaded from their website (www.healthmetricsandevaluation.org) or as an attachment (Text S1) from the PlosMedicine website for the original paper. The method offers four measures of 5q0 using a combination of birth history, mother's age, and time since first birth. As the goal is to test the applicability of the method for basic birth histories, we exclude all measures utilizing time since first birth and are left with two measures: Maternal Age Cohort (MAC) and Maternal Age Period (MAP).

The MAC method is based on the standard indirect method adapted by Feeney (1980), which estimates child mortality from the portion of CD out of CEB modified to generate cohort-specific estimates and includes country-specific random effects (equation 1).

$$\text{logit}(5q0) = \beta_{0i} + U_{ij} + \beta_{1i}\,\text{logit}\left(\frac{CD_i}{CEB_i}\right) + \beta_{2i} CEB_i + \beta_{3i}\frac{P(15-19)}{P(20-24)} + \beta_{4i}\frac{P(20-24)}{P(25-29)} + \varepsilon_i \qquad (1)$$

Where *i* is the five-year maternal age group, P is the parity (average CEB) for each specified maternal age group, CD_i is the total dead children from maternal age group *ii*, CEB_i is the total children ever born from maternal age group *i*, U are country-specific random effects, and β-s are region and age cohort-specific coefficients estimated using DHS complete birth histories. The country-specific random effects were generated by comparing a traditional measure of under-five child mortality (from long birth histories) to Rajaratnam et al.'s CD/CEB measure from a composite of DHS surveys from around the world. These effects are provided by Rajaratnam et al. in the downloadable version of the program.

The MAP method is based on the same standard indirect method as MAC but, in this case, is modified to estimate a period-based ratio of CD to CEB that allocates births and deaths to each year previous to the survey. Regional frequency distributions of births and deaths calculated by Rajaratnam et al. (2010) as a function of time prior to the survey are used to generate expected allocations of births and deaths over time (equation 2).

$$\text{logit}(5q0) = \beta_t^0 + U_t + \beta_t^1\,\text{logit}\left(\frac{CD_t}{CEB_t}\right) + \varepsilon_{tjk} \qquad (2)$$

Where *t* is the index of calendar time (years), CD_t is the total dead children in time bin *t*, CEB_t is the total children ever born in time bin *t*, U are country-specific random effects, and β-s are region and calendar time-specific coefficients estimated using DHS complete birth histories.

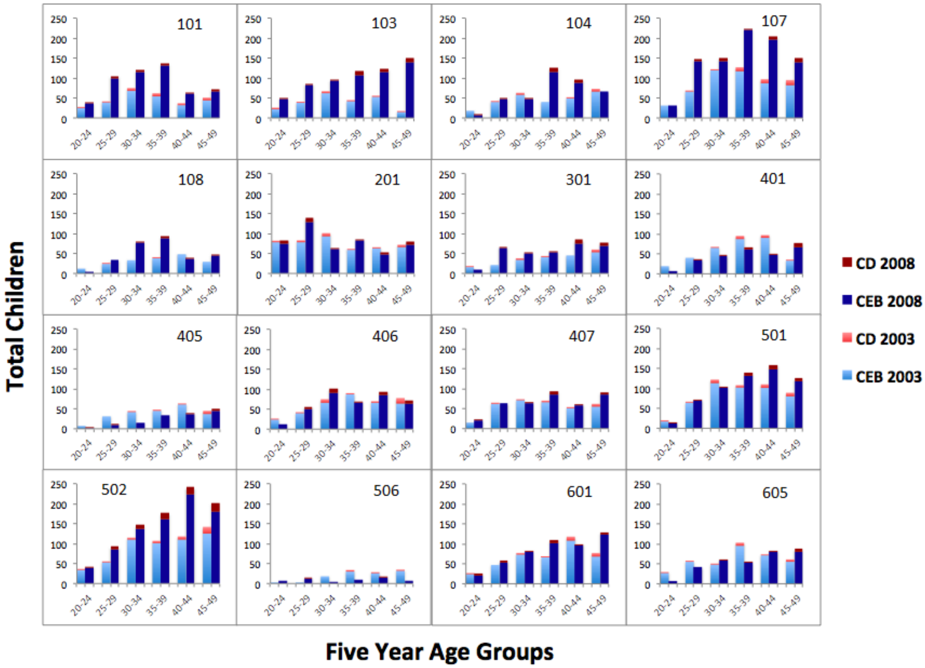
In effect, the MAC and MAP measures allow the limited local birth history data to be honed by country and regional specific data from past DHS full birth histories. The measures are then smoothed using a local regression smoothing technique (LOESS) (Cleveland and Loader 1996) to provide trends over time. MAC and MAP measures from other survey time points can also be simultaneously placed into LOESS, providing more data for the regression analysis. We calculated MAC and MAP measures for the 2003 and 2008 data, placing them into the LOESS regression for each zone and for the city as a whole. Some minor modifications were made to deal with limited data at the zone level, as discussed in 3.2 below. LOESS 5q0 results are mapped for five-year intervals. Results are compared to zone measures of the slum index, housing quality, health facilities, and vegetation using a simple trendline R^2 analysis.

3.2 Estimating 5q0 with limited data

While the MAC and MAP measures pull strength from DHS country effects, they are calculated from provided data of births and deaths for each age cohort and therefore are reliant on sufficient input data. Rajararatnam et al. do not specify what ‘sufficient’ data inputs might be as their example draws on census data with large numbers of women in each *municipio* in Mexico. We set a loose standard of 50 births per age cohort in each zone (with the exception of the 18-19 cohort) in at least one of the two pooled survey sets. However, in balancing enough data per zone and creating zones that are logical in terms of cohesive areas in Accra, not all zones have 50 births in all age cohorts. Figure 2 illustrates, for each zone, numbers of children ever born (CEB) and children dead (CD) by women’s five-year age cohorts with the exception of the 18-19 age group due to very low numbers across localities. The data limitation issue presents itself as more complex than simply ‘not enough’ in this figure. Some zones barely meet the 50 births per age cohort standard (e.g., zones 405 and 506). Others have relatively good data but are missing CEB or CD data in one or more age cohorts (e.g., zones 104 and 107).There is a general trend of very few observations in the 20-24 age cohort, raising some concern as to estimates produced from these cohorts.

The sensitivity of the measures to both high and low extreme CD/CEB ratio values is higher for the MAC method than for the MAP method as MAC creates estimates directly from the age cohort data while MAP estimates period based ratios, allocating births and deaths to each year before the survey. Zero values are particularly problematic as the CD/CEB ratio will be zero for these age cohorts, which may throw off MAC estimates for these cohorts. We excluded the data-sparse 18-19 cohort from analysis due to this sensitivity. From the remaining cohorts, there are a total of 18 age cohorts across the zones in 2003 with no deaths, and in 2008 there are 16 cohorts. In order to account for some of the MAC sensitivity, outputs were examined for extreme outliers before placing estimates into the LOESS regression. Outliers that were clearly not in tandem with both MAC and MAP trends (based on standard deviations) were removed from the LOESS regression resulting in nine removals, one each for zones 103, 104, 201, 401, 405, 407, 501, 506, and 601.

Figure 2: Zone counts of children ever born (CEB) and children dead (CD) for each age cohort for the pooled 2003 and 2008 data sets



3.3 Full birth history 5q0

The LOESS results for estimated 5q0 were compared to 5q0 measures for each zone and for the city, derived from full birth histories. As these measures are derived from very small numbers, caution is necessary when interpreting results. Therefore, we do not claim this data to be a validation of the LOESS 5q0 but rather a source of comparison. The MAC and MAP measures are able to utilize the total number of children born and children who have died, regardless of the age or year in which they died, by drawing on a model that takes regional trends into account. Looking back to Table 1, this means a total of 364 deaths in 2003 and 421 deaths in 2008 (spread across the zones) are used for the 5q0 estimates. Deriving a traditional 5q0 measure from full birth histories takes into account the year and month of birth and death to establish if a child dies before age five and in what time period that child has died. By assessing 5q0 in 5-year intervals, only children born in a particular time frame can be considered for each interval. The 2003 sample has 274 children who died before age 5 while there are 313 in the 2008 data. Taking into account the year of birth for the child, only 55 children died ten to five years before the 2003 survey, and 68 died before the 2008 survey.

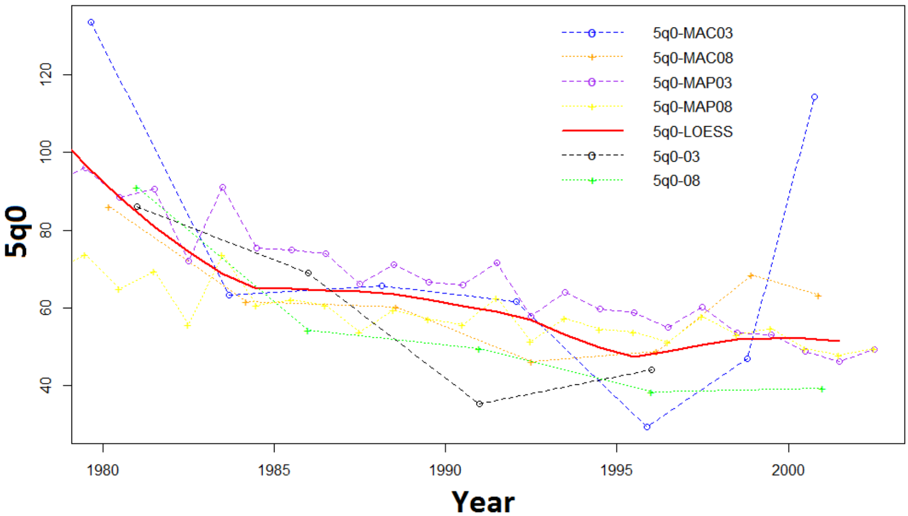
We calculated 5q0 from the full birth histories for 2003 and 2008 for each zone and for the city as a whole. Births and deaths under five were tabulated in five-year intervals starting with 1979 and ending with 1998 for the 2003 data, and starting with 1979 and ending with 2003 for the 2008 data. The 5q0 measure was calculated as a simple ratio of children dead before age five divided by children born, multiplied by 1,000 to arrive at child deaths under-five per 1,000 births. We use the city level 5q0 calculations as a validation for the city LOESS regression. The zone results are too limited in data to be used as validation, but they are the best available comparison for the LOESS regression results.

4. Results

AMA trends of 5q0 between 1979 and 2006 from each method for both years of data are displayed below in Figure 3. Overall, while all 5q0 measures follow a similar trend, there is variation between each measure. The sensitivity of the MAC (Maternal Age Cohort) method to limited data can be seen in the 2003 estimates; particularly the extreme upward trend at year 2001. The 2003 data set has almost 600 fewer women and 1,500 fewer births than the 2008 data. The 2008 MAC estimate appears to coincide with the more stable 2003 and 2008 MAP estimates. The 2003 MAP (Maternal Age Period) trend begins with higher 5q0 estimates than the 2008 trend, but the two converge and follow the same pattern starting around 1997.

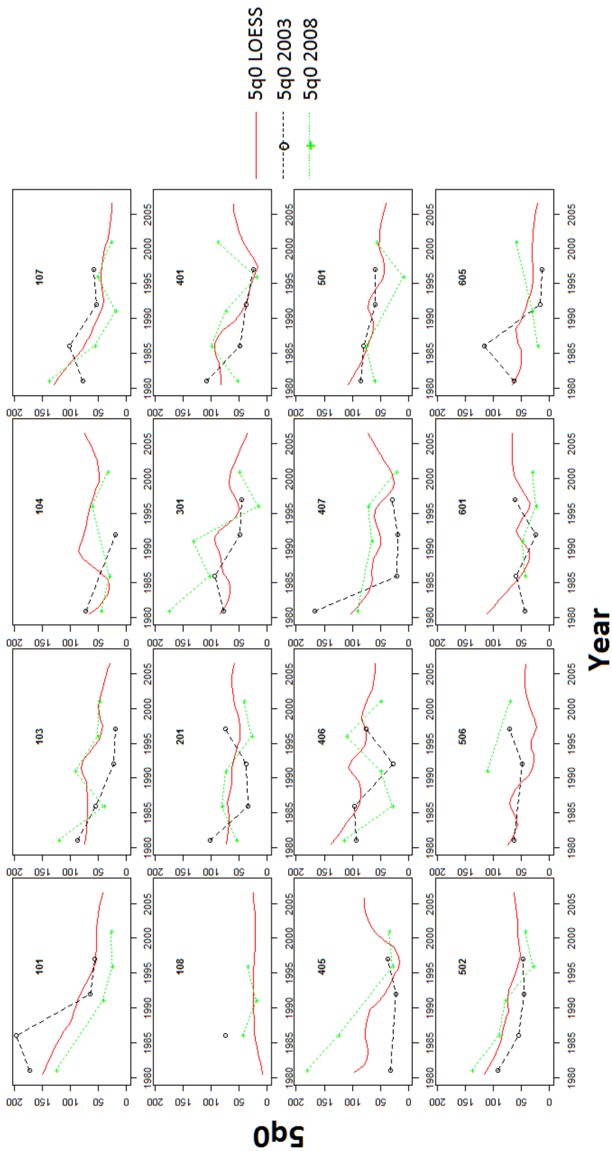
Placing all estimates into a LOESS regression results in the red trend line pictured in Figure 3. The 2001 LOESS 5q0 estimate for Accra is 51.4, almost the same as the 2008 DHS 5q0 measure for the greater Accra region—50.1—but much lower than the Ghana urban rate of 74.7 and country-wide rate of 84.8 (GSS, GHS, and ICF Macro 2009). Both of these measures are higher than the 2008 birth history 5q0 calculation which puts 2001 5q0 at 39.4. While there are differences between the 2003 and 2008 5q0 calculations from the full birth histories, the LOESS trend estimates a higher 5q0 than both starting after 1985. The consistently higher estimates of the MAC, MAP, and combined LOESS are likely a result of country and sub-Saharan DHS trend effects used in the model. These trends are much higher than the sub-region specific measures for the greater Accra region.

Figure 3: AMA trends from 1979 to 2006 of 5q0 for the 2003 and 2008 data sets using MAC (Maternal Age Cohort), MAP (Maternal Age Period), LOESS (regression MAC 2003/2008 and MAP 2003/2008 results), and 2003 and 2008 full birth history calculations



Zone 5q0 LOESS estimates and full birth history 5q0 measures for 2003 and 2008 are displayed in Figure 4. Despite data limitations, all LOESS trend estimates are plausible even in zones with few cases (405 and 506).Visually comparing the LOESS estimates to full birth history data reveals consistency in the measure trends, although several zones show considerable variability of values between years. In contrast to the city-level estimate, the zone LOESS estimates are not higher than the full birth history calculations, and, for most zones, the LOESS estimate falls in between the 2003 and 2008 data. The 5q0 calculations do not allow for comparison of LOESS results in the most recent time period from 2002 to 2006. However, Rajaratnam et al. (2010) demonstrate that standard errors of estimates closest to the year of the survey are not significantly higher than errors of other estimates.

Figure 4: LOESS trend estimates from 1980 to 2006 for each zone. Full birth-history-derived calculations of 5q0 from the 2003 and 2008 data are also shown for comparison



Pearson's correlation results between zone LOESS estimates demonstrate that the zones share similar trends. All zones have positive correlations with each other with the exception of zone 108, which is negatively correlated with all zones due to a gradually increasing 5q0 trend. Zones 501 and 502, directly next to each other in the center of the city, have a trend correlation of .98. Both zone trends are correlated at .95 or higher with zones 101, 107, and 406. All of these zones are neighborhoods with relatively low standards of living where higher child mortality might be expected. However, these zones show consistent declines in child mortality over the years, indicating improvements in child mortality even in the worst neighborhoods of Accra.

Average LOESS zone estimates for five-year intervals are mapped in Figure 5, where 5q0 changes through time can be seen spatially. There is a clear citywide reduction in 5q0 from the late 80s to the late 90s. However, some zones in the eastern half of the city show an increase in the most recent LOESS estimate. In each five-year interval there is considerable variability between the zone estimates. Without confidence intervals, LOESS estimates cannot be compared between zones with any degree of statistical certainty. However, the Figure 5 maps illustrate a relatively wide range of 5q0 estimates between zones. The 1992 to 1996 interval 5q0 estimates range from 23.7 to 83.5 while the 1997 to 2001 estimates range from 21.3 to 77.9, almost identical to the 2002-2006 interval. These are differences in the range of 50 deaths per 1,000 births between zones in Accra.

The slum index, housing quality, and vegetation were scaled from 0 to 1 where zero indicates best outcomes for the slum index and housing quality, but worst outcomes for vegetation (zero indicates the least vegetation). The values were compared to the 1997-2001 time interval of LOESS 5q0 zone estimates since all city data was collected in year 2000. The data are also compared to change in 5q0 from 1992 to 2001. Health facility data were collected in 2008 and were compared to both 1997-2001 and 2002-2006 time intervals. However, there was no relationship between the number of clinics in a zone and the zone's measure of 5q0 (R^2=0.03 for both years). Trendline R^2 values for the remaining measures are shown in Figure 6.

The left image of Figure 6 depicts values from the 1997-2001 time interval, and we see expected relationships of zones with higher slum indexes, worse housing quality, and less vegetation related to higher 5q0 estimates. The highest R^2 score is for the slum index. The right image of Figure 6 shows values for the change in 5q0 from 1992 to 2001. Here the story is more complex. Zones with more slum characteristics and worse housing are associated with improvements in 5q0 rates, while increasing 5q0 is related to better housing quality, lower slum index, and more vegetation. It is important to emphasize that this result is not only a function of the decreasing 5q0 rates in low socio-economic zones like 101, 103, 501, 502, and 406 (Figure 5). At the same time 5q0 appears to be increasing in better off zones such as 405 and 601.

Figure 5: LOESS five-year 5q0 estimates from 1987 to 2006 for zones in Accra

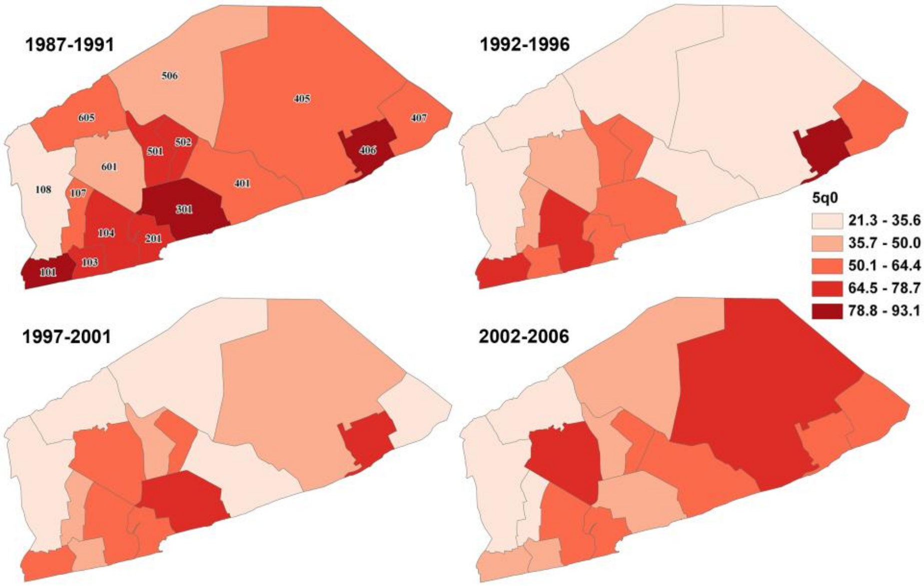
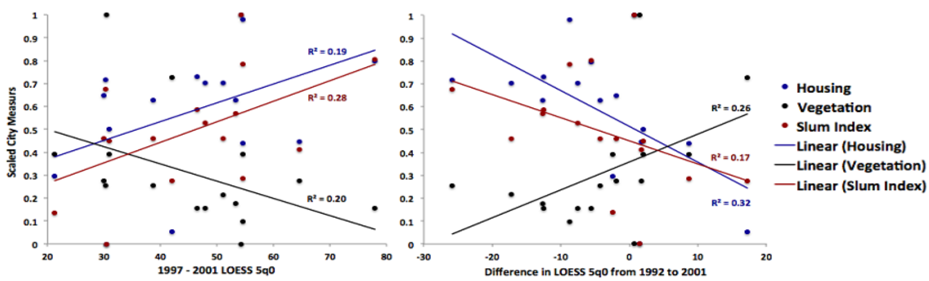


Figure 6: Trendlines of the scaled zone slum index, housing quality, and vegetation as related to 1997-2001 zone 5q0 (left) and change in 5q0 from 1992 to 2001 (right)



5. Discussion

Emerging research increasingly demonstrates large urban differentials of child mortality in the developing world, but there has been almost no research on intra-urban spatial patterns beyond the findings that slums have higher levels of child mortality than non-slum areas. This lack of research is due in part to the limitations of existing data coupled with significant methodological barriers. In this paper, we explored the effectiveness of the new low-cost method developed by Rajaratnam et al. (2010) at the fine spatial scale of urban zones, dividing Accra, Ghana, into 16 such areas. The approach taken in this paper demonstrates considerable potential for effectively estimating small area 5q0 rates and opens up a number of possible paths forward. At the same time the method raises a number of issues for deliberation.

5.1 Spatial data

As previously discussed, the primary issue with measuring intra-urban child mortality is data. A significant conclusion of this study is that, in light of limited spatial data sources, resourcefulness in augmenting and combining existing data can provide the necessary numbers for calculating 5q0 rates at fine spatial scales. Spatial demographers have yet to tackle other methods of enhancing child mortality data, such as utilizing spatial models to assist in deriving missing data. For example, data can be imputed by combining spatially extensive data with substantively intensive sample surveys (Elbers et al. 2003; Hentschel et al. 2000; Wang 2003), or by using spatial models like kriging or Bayesian modeling to fill in neighboring CEB or CD data gaps (Le, Sun and Zidek 1997; Stein 1999). Additionally, rather than 'filling in the gaps' from existing data, future researchers may choose to undertake a spatial sampling scheme that includes respondents selected on the basis of a hierarchy of meaningful geographic boundaries. In the complex urban environment, it may even be of interest to utilize the traditional geographic approach of laying out a sampling grid.

Closely tied to the data is the determination of an appropriate scale of analysis – in other words, how to delineate the data into bounded spaces. Spatial disaggregation of already limited data sets proves to be a balancing act between obtaining a fine enough spatial scale to assess differences within an urban area and ensuring enough data exist in each unit for analysis. In aggregating localities into zones, we utilized an iterative process of first aggregating localities based on satellite imagery and knowledge of the city and then testing to see if our data threshold was met. The focus was to develop geographical aggregations and boundaries that are true to on-the-ground processes rather than arbitrary aggregations that were purely driven by data needs. We set a threshold of 50 births per age cohort in each zone (with the exception of the 18-19 cohort). However, in creating zones that made social and physical sense, some flexibility in meeting this threshold was required. In the future, such a threshold warrants exploration, possibly through a sensitivity analysis of how small numbers of births impact estimates. Zones that did not meet the data threshold in many age cohorts (zones 405 and 506) resulted in estimates that were just as plausible as zones with better data. Lower data requirements may allow for finer spatial disaggregation and more precise knowledge about the spatial variability of child mortality in a city. Such an analysis, while very important, was beyond the scope of this paper.

5.2 Calculating 5q0

In testing the Rajaratnam et al. method at the micro-scale of zones in Accra, we conclude that the method has significant potential. At the city level, the method slightly over-estimated child mortality when compared to calculated 5q0 for both 2003 and 2008 data. However, it was on trend, particularly when compared to the 2008 5q0 calculation. At the zone level, no over-estimation was observed, and LOESS estimates were consistently between the 2003 and 2008 5q0 calculations. Visual comparison of zone 5q0 rates with zone LOESS estimates allows us to conclude that the LOESS estimates are plausible and reflective of calculated 5q0 rates. The robustness of the LOESS performance across all zones, irrespective of data limitations, lends further confidence in the LOESS results.

Due to the limitations of intra-urban child mortality data, we believe that the Rajaratnam et al. method is particularly suited for exploring spatial patterns of 5q0. The method offers considerable flexibility by utilizing summary rather than full birth histories. It offers choices for developing measures that can use a combination of data including children ever born, children dead, mother’s age, and time since first birth. Furthermore, the application of the LOESS regression allows multiple time points and data sets to be fed into the analysis. This is of particular interest to researchers with discrepant data sources that cannot be joined together. Surveys could be calibrated or weighted to each other before spatial disaggregation, and 5q0 measures could be calculated for each individual survey and then fed into LOESS. We believe this is the best method currently available for small area 5q0 estimates.

There are multiple future steps to be taken to improve local estimates and achieve statistical confidence in obtained estimates. The MAC, MAP, and LOESS methods all draw on country-specific random effects and regional frequency distributions of births and deaths from DHS surveys. Differences between urban and rural rates are often large, and the inclusion of rural data in random effects and frequency distributions may pull LOESS results upward. As the DHS is designed to be representative at the urban and rural levels for almost all countries it is administered in, rural data could be excluded in calculating random effects and frequency distributions. This would effectively tailor MAC, MAP, and LOESS to be urban-specific and, presumably, to be more accurate in intra-urban estimates.

The next step in testing the Rajaratnam et al. method will be to calculate confidence intervals and perform a more robust estimate validation. Confidence intervals will provide certainty in the possible range of 5q0 estimates, and will allow for comparison of zones to determine if differences in 5q0 rates are statistically different within the city. This is a key step in understanding how child mortality might be influenced by differences in places. Further validation will be performed when the 2010 Ghana Census data are released, which includes CEB and CD for each female respondent, and will provide cases in the hundreds of thousands.

5.3 Context and child mortality

Comparison of the LOESS estimates to measures of environmental and social conditions in the zones yielded expected results in the 1997-2001 time period but surprising results for the 1991 to 2001 trend. The significance of wealth differentials for child mortality found in other studies leads to a natural assumption that neighborhoods with more slum-like conditions and poorer housing quality may be the best targets for health interventions. In Accra, we do see a correlation between poorer environmental conditions and worse 5q0 estimates across all zones for the 1997-2001 period. However when examining the trend over time, we actually see improving child mortality rates in lower SES areas with concurrent deterioration in specific higher SES areas. While the number of clinics in a zone had no trendline relationship to 5q0 or change in 5q0, the results for the other variables may be indicative of the effectiveness of past and ongoing interventions that reach out to perceived worst slums. At the same time, women in zones 405 and 601, areas that are not perceived to be bad areas of the city, may not be getting the care they need. Antai and Moradi (2010) point out that focusing interventions on the most disadvantaged urban neighborhoods will exclude women who may benefit from such interventions and are living in neighborhoods that do not obviously qualify.

The spatial analysis helps to tease out the areas in the city that are doing well, as well as areas that may be falling behind. Future research may focus on conducting a multi-level analysis of the zones to better understand how individual and area-level effects are impacting child mortality. Another area of potential research, and a significant consideration for the results presented here, are the effects of migration.

Accra faces significant rural to urban migration as well as movement within the city as women relocate to neighborhoods for economic or personal reasons. Migration may impact the location of a woman's residence at the time of survey as compared to the location of a woman at the time of losing a child. Furthermore, women in certain zones may be more likely to have migrated than others. Understanding the impacts of migration on small area child mortality estimates may be a fruitful area of study for spatial demography.

An in-depth analysis of variance resulting from migration was beyond the scope of this study; however, our data do provide information pertaining to a woman's residential location in years past. As a basic assessment of a woman's duration of residence at the place she was surveyed, we calculated the mean number of years that a woman (aged 18-49) has lived at her current house of residence for each zone using the 2008 WHSA and HAWS data sets. Values ranged from 6 (zone 506) to 17 (zone 401). Other than zone 506, only two other zones had average values below ten years – zones 201 and 101. These data cannot tell us if a woman moved within her neighborhood, from a different neighborhood with similar or different characteristics, or from a different town altogether. But, as most zones have an average residential period of at least ten years, we can have some assurance that migration isn't severely impacting LOESS estimates.

5.4 Incorporating spatial analysis into child mortality studies

The analysis presented here tested the Rajaratnam et al. method for urban zones in Accra, Ghana. We conclude that the method has significant potential for small area child mortality estimates and offers considerable flexibility to researchers grappling with limited data resources. This study also demonstrates the need for examining intra-urban child mortality: zones in Accra exhibit considerable variation in 5q0 rates with differences as high as 50 deaths per 1,000 births between zones. This finding underscores that child mortality is a complex demographic event that varies significantly even within a city. Understanding child mortality and how it is affected by other demographic events such as migration, the health transition, and changing family structure might best be done in the urban environment where these processes are rapidly playing out in close spatial proximities. The Rajaratnam et al. method provides an important first step to the possibility of disaggregating child mortality estimates for urban areas.

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