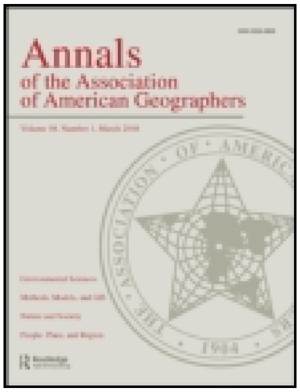

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Connecting the Dots Between Health, Poverty, and Place in Accra, Ghana

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West Africa has a rapidly growing population, an increasing fraction of which lives in urban informal settlements characterized by inadequate infrastructure and relatively high health risks. Little is known, however, about the spatial or health characteristics of cities in this region or about the spatial inequalities in health within them. In this article we show how we have been creating a data-rich field laboratory in Accra, Ghana, to connect the dots between health, poverty, and place in a large city in West Africa. Our overarching goal is to test the hypothesis that satellite imagery, in combination with census and limited survey data, such as that found in demographic and health surveys (DHSs), can provide clues to the spatial distribution of health inequalities in cities where fewer data exist than those we have collected for Accra. To this end, we have created the first digital boundary file of the city, obtained high spatial resolution satellite imagery for two dates, collected data from a longitudinal panel of 3,200 women spatially distributed throughout Accra, and obtained microlevel data from the census. We have also acquired water, sewerage, and elevation layers and then coupled all of these data with extensive field research on the neighborhood structure of Accra. We show that the proportional abundance of vegetation in a neighborhood serves as a key indicator of local levels of health and well-being and that local perceptions of health risk are not always consistent with objective measures. *Key Words: Africa, Ghana, health, neighborhood, remote sensing.*

西非人口迅速增长，居住在城市非正式定居点的人口比例越来越多，这些定居点以基础设施不足和相对高的健康风险为特点。然而，我们既对这一地区的城市空间或健康的特点，也对它们中的空间健康不平等所知甚少。在这篇文章中，我们表明如何在加纳的阿克拉创建数据丰富的野外实验室，在一个西非的大型城市里，把卫生，贫困，和地方之间的节点连接起来。我们的首要目标是测试一个假设，即卫星图像，结合普查和有限的调查数据，如在人口与健康调查 (DHSs) 中所发现的数据，来提供一些城市里健康不平等的空间分布，这些城市比起阿克拉有较少的数据存在。为此，我们已经创建了第一个城市的数字边界文件，获得了两个时次的高空间分辨率卫星图像，从纵向面收集了在空间上分布于整个阿克拉的 3200 位妇女的数据，并从人口普查获得了微观层面的数据。我们还收购了供水，污水和高度数据层，然后把所有这些数据与阿克拉的邻里结构上的广泛的实地研究结合。我们的研究表明，邻里的植被比例丰度可作为地方各级卫生和福祉的关键指标，并且那些健康风险的地方看法并不总是与目标措施一致。*关键词：非洲，加纳，健康，邻里，遥感。*

África Occidental cuenta con una población en rápido crecimiento, una creciente fracción de la cual vive en asentamientos urbanos informales caracterizados por su infraestructura inadecuada y riesgos contra la salud relativamente altos. Sin embargo, muy poco se sabe de las características espaciales o sanitarias de las ciudades de esta región, ni de las desigualdades espaciales en salud existentes en las mismas. En este artículo mostramos lo que estamos haciendo en Accra, Ghana, buscando crear un laboratorio de campo bien surtido de datos, para tratar de unir los puntos entre salud, pobreza y lugar en una ciudad grande del África Occidental. Nuestro principal objetivo es poner a prueba la hipótesis de que las imágenes satelitales, combinadas con datos censales y los limitados datos de campo, como los que se encuentran en los estudios demográficos y de salubridad (DHSs), pueden generar indicios sobre la distribución espacial de desigualdades de la salud en ciudades donde existen menos datos de los que nosotros logramos conseguir para Accra. Con tal propósito, creamos el primer archivo de límites digitales de la ciudad, obtuvimos un conjunto de imágenes satelitales de alta resolución espacial de dos fechas de observación, recogimos datos entre un panel longitudinal de 3.200 mujeres distribuidas espacialmente a través de Accra, y obtuvimos datos del censo a nivel micro. Obtuvimos también datos sobre agua, alcantarillado y

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elevaciones, para luego cotejar toda esta información con un amplio estudio de campo sobre la estructura barrial de Accra. Mostramos que la abundancia proporcional de vegetación en un vecindario sirve de indicador clave de los niveles locales de salud y bienestar y que las percepciones locales sobre riesgos de la salud no son siempre consistentes con las mediciones objetivas. *Palabras clave: África, Ghana, salud, vecindario, percepción remota.*

Sustainable development in Africa, as elsewhere in the world, requires that future population growth be absorbed by cities, because only in or near cities can we anticipate the kind of economic and employment growth needed for people to rise above the poverty level. At the same time, sustainable development requires a healthy population to generate rising levels of economic productivity (Bloom, Canning, and Sevilla 2001; López-Casasnovas, Rivera, and Currais 2005). The health of the urban population thus takes on political and economic significance, yet the literature on health within cities of developing nations is very limited. Our goal is to provide answers to the question of how to move the urban health transition forward in sub-Saharan Africa through an analysis of data for Accra, the capital city of Ghana. Because surveying health patterns within a city is a very expensive process, we test the idea that satellite imagery can be used to help identify places with the worst and best health. If so, we might be able to efficiently model the spatial inequality in health in any city in a developing country. Our work in Accra aims to connect these dots and develop a model that can be used in other cities.

The theoretical framework that underpins our work is that urban health and well-being are part of a complex social–ecological–biomedical system, consistent with the view that "the health and well-being of the whole population may be best conceptualized as a 'systems' problem, occurring on a continuum over the human lifespan as well as across a variety of levels of analysis, ranging from the cellular and molecular to individual and interpersonal behaviors, to the community and society and to macro-socioeconomic and global levels" (Mabry et al. 2008, S215). The value of this approach, as Diez Roux (2007, 572) noted, is that "a systems approach focuses on understanding the system functioning so that changes in response to an intervention can be predicted." The health of an urban resident cannot be understood, nor effective interventions implemented, without taking into account the sociocultural and ecologic structure of the city and the economic and health infrastructure in which residents are embedded. Individuals are not simply autonomous biological entities. Rather, the biological characteristics are constantly interacting with the broader environment in a system of feedback loops. Our specific focus within this systems approach is to emphasize that neighborhoods, broadly defined, are important when it comes to the health and well-being of people living in those places (Kawachi and Berkman 2003; Entwisle 2007). Taking it one step further, we hypothesize that when neighborhoods become healthier as a system, not just as a set of individuals, they become environments in which economic productivity and income are more likely to increase, which in turn will accelerate the overall improvement in the health of the people living and working in those environments. As Dunn and Cummins (2007) have noted:

> One of the tantalizing features of research on context and health is that it may lead to more effective interventions to improve health and reduce health disparities. Traditional behaviouralist perspectives, which saw health behaviours and other determinants of health as simple individual attributes, have now been eclipsed by a perspective that emphasizes human behaviour and activity as significantly influenced by contextual factors. It follows from this perspective that 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. (1822)

The local context in a city influences health indirectly by promoting or constraining the knowledge of disease transmission and the ability to access health providers. It also directly affects health through water quality, sewage and waste disposal methods, crowded and dirty homes and yards, indoor air pollution from unhealthy cooking fuels, or lack of refrigeration. Both the direct and indirect contextual influences are related closely to socioeconomic status (SES) and housing quality. Because people of similar SES and similar housing quality tend to live in proximity to one another (although there are exceptions to this pattern), identifying regions of the city by these characteristics provides an important indicator of the population's health and well-being. Our work builds on the idea that neighborhood-level patterns of morbidity and mortality ("health") are importantly influenced by the interaction and feedback between poverty and place and that these patterns can be discerned from the classification of high-resolution satellite imagery.

Connecting People to Places

The 2000 Census of Population and Housing in Ghana was the first geographically detailed census in the nation's history, although none of the maps created for the census had yet been digitized when we began our research. The Ghana Statistical Service (GSS) provided us with a set of paper maps, along with a formal set of boundary definitions (based on physical points of interest in a neighborhood), and we used this information in combination with high-resolution satellite imagery to create a digital boundary file of the 1,731 enumeration areas (EAs) in Accra. We then connected boundaries to the census data, allowing us to characterize each EA on the basis of census-derived data.

EAs in Accra are designed to encompass approximately 1,000 persons and are generally too small in area, population, or both to be considered neighborhoods. In recognition of this fact, GSS created a set of eighty-eight neighborhood boundaries that agglomerated EAs into areas that we call "vernacular" neighborhoods, referring to "neighborhood boundaries that are broadly recognized and agreed to by residents of a given city—in this case Accra, Ghana—even if they may have no premeditated and formal definition. These are the place names, for example, that would be provided to a taxi driver, especially since there is no comprehensive street address system in Accra" (Weeks et al. 2010, 563). These boundaries are not unlike those generated on the basis of local knowledge without access to GSS census data (Songsore et al. 2005; Agyei-Mensah and Owusu 2010) and are similar to what one would find in printed tourist maps of Accra.

One of the goals of our research has been to conduct fieldwork to validate and reconcile differing neighborhood boundaries. The result of this effort has been a modification of the original GSS vernacular neighborhoods to reflect the perceptions of residents of the local boundaries. We call these the field modified vernacular (FMV) neighborhoods. Most of the difference between the original and FMV neighborhood definitions is that the latter provide a more nuanced and finer gradation, dividing the city into 108 neighborhoods (Rain et al. 2011), as shown in Figure 1. For purposes of this article,

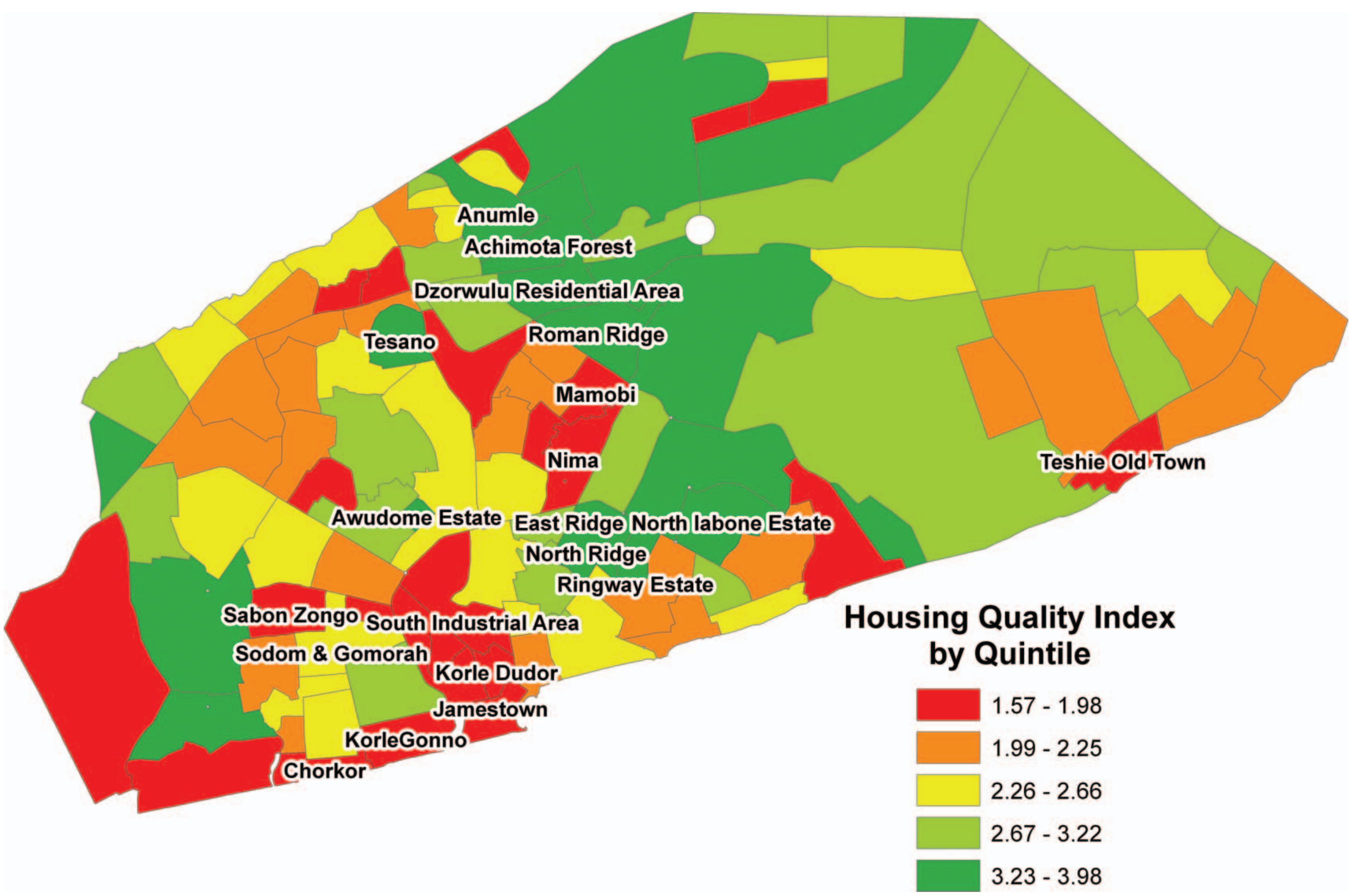

Figure 1. Housing quality index quintiles by field modified vernacular neighborhoods in Accra, Ghana, based on 2000 census data. (Color figure available online.)

we are treating the FMV neighborhoods as the environment in which people live and thus the context in which their health can be evaluated.

Connecting People and Places to the Environment

We first measure the environmental context with an index that combines aspects of the built and social environment, created by running the 2000 census data through a principal components analysis to produce a "housing quality" (HQ) index. The variables included type of floor, whether or not the house has electricity, the 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. We used the first component from the rotated matrix as our index of HQ. It had an eigenvalue of 4.5, which combined characteristics of toilet, liquid waste, source of water, cooking fuel, and type of kitchen facility. Because factor scores are centered on a mean of zero, with a minimum score in this case of –2.22, we added a constant to each score so that the range was from zero, for a house with the lowest quality of housing, to a score slightly above 5 for the highest quality. These scores were then averaged for any given neighborhood definition.

Figure 1 shows the spatial variability in Accra of HQ by FMV neighborhoods, with the color ramp representing the range from the lowest quintile of housing quality (darkest red) to the highest quintile of housing quality (darkest green). The ten neighborhoods with the lowest housing quality (and potentially at higher risk of poor health outcomes) are labeled in Figure 1, as are the neighborhoods with the highest housing quality (potentially at lower risk of poor health outcomes). For example, the five neighborhoods with the lowest HQ are, in order of HQ, Sodom & Gomorrah, Jamestown, Nima, Teshie Old Town, and Mamobi. The five neighborhoods with the highest HQ are, in order, East Ridge, Achimota Forest, Ringway Estate, North Ridge, and Awudome Estate. Of particular note is that some of the neighborhoods with very low HQ are spatially proximate to neighborhoods with high HQ.

Our second measure of the environmental context combines aspects of the natural and built environments. From the imagery we are able to map land cover features such as landscape vegetation and the size and geometry of residential dwellings that serve as proxies for SES and, potentially, health status. We measured land cover and land use change in Accra with georeferenced QuickBird satellite multispectral image data for April 2002 and January 2010. We refined the co-registration of the images and used an empirical line approach to normalize the two dates of imagery radiometrically (Coulter et al. 2011).

The proportion of vegetation cover was estimated for EAs of greater Accra that were imaged in both 2002 and 2010 by summing the number of pixels classified as green vegetation and dividing by the total number of pixels contained within each EA boundary. Difference of proportions for each EA were calculated and used to generate maps of absolute change in green vegetation proportions and percentage change relative to proportions in 2002. A sample of 1,000 visually interpreted pixels for each image date was utilized as reference data for assessing the accuracy of the 2002 and 2010 vegetation maps at the pixel level. Vegetation and nonvegetation pixels were classified with overall, user's, and producer's accuracies in the 93 to 94 percent range. For the entire map extent, the estimate of vegetation change from the reference data is a decrease of 9.3 percent and the semiautomated image change analysis estimates a reduction of 5.7 percent. Due to the difficulty of finding cloud-free imagery at a time near the 2000 census, the high-resolution imagery does not quite cover the entire study site for the year 2002. For the remaining EAs, we calculated vegetation fractions from 15 m spatial resolution ASTER imagery, after determining that there was a very good fit between results from the very high and moderate resolution data (Stoler et al. 2012). Figure 2 shows the results of the vegetation calculations, with each neighborhood in Accra categorized according to the quintile of its percentage of vegetation cover. The patterns were very similar in both years ($r = .90$), despite the substantial vegetation loss throughout the city between 2002 and 2010 due to increased population pressure on the land.

The most revealing difference between Accra residential neighborhoods of varying housing quality and SES is the relative abundance of vegetation cover and the size and density of residential structures (not shown; Weeks et al. 2007; Stow, Lippitt, and Weeks 2010). High-housing-quality areas tend to have a high proportion of landscape vegetation, whereas low-housing-quality areas have little vegetation ($r = .73$). Overall, 49 percent of the neighborhoods were in the same quintile with respect to housing quality and percentage vegetation, and the spatial cooccurrence of these two ways of differentiating environments helps us define the extremes of neighborhood context in Accra. Thus, there are eleven neighborhoods in the first (lowest) housing

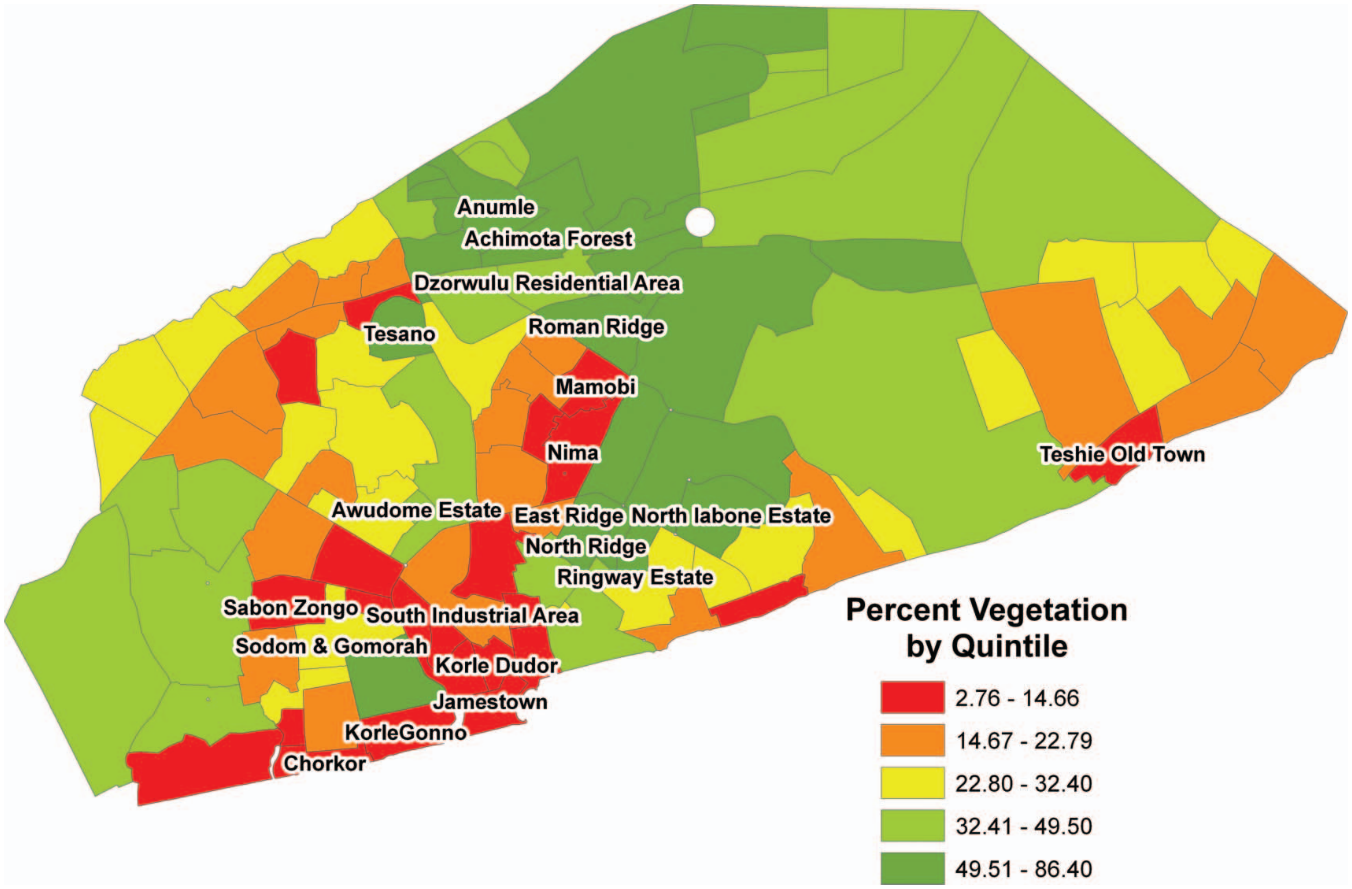

Figure 2. Percentage vegetation quintiles (based on classification of 2010 Quickbird imagery) by field modified vernacular neighborhoods, Accra, Ghana. (Color figure available online.)

quality quintile and also in the first (lowest) vegetation quintile in both 2003 and 2010 (see Figure 3). We hypothesize that these will be the neighborhoods with the poorest health outcomes. There are eleven neighborhoods in the highest quintile with respect to both housing quality and vegetation (both years) and we expect these to have the best health outcomes. It can be seen in Figure 3 that there is clear spatial clustering of the extremes.

Connecting People, Place, Environment, and Health

Do patterns of health follow the expectations raised by the cooccurrence of housing quality and vegetation? To answer that question we turn to the results of in-depth surveys that we conducted in a longitudinal panel of nearly 3,200 women spatially distributed around Accra—the Women's Health Survey of Accra (WHSA). The first round (WHSA–I) was conducted in 2003. A sample of 200 EAs was selected with probabilities proportional to population size. Enumerators then visited those EAs and eligible women (residents of Accra aged eighteen and older) were listed by name and address. Respondents were then selected with probabilities fixed according to the SES of the EA and the age group of the women (older women were progressively oversampled). From the cohort of 3,183 women who completed the household survey in 2003, the first 1,328 women were also asked to participate in a comprehensive medical and laboratory examination. The women interviewed in 2003 consented to be revisited in the future, and this panel of women was reinterviewed between October 2008 and March 2009 (WHSA–II). In WHSA–II there were neither blood tests nor medical examinations, but height, weight, blood pressure, and visual acuity were measured in the home at the end of the household interview.

Tracking women in 2008 and 2009 who had been interviewed in 2003 led to several problems of identification, and different approaches were adopted

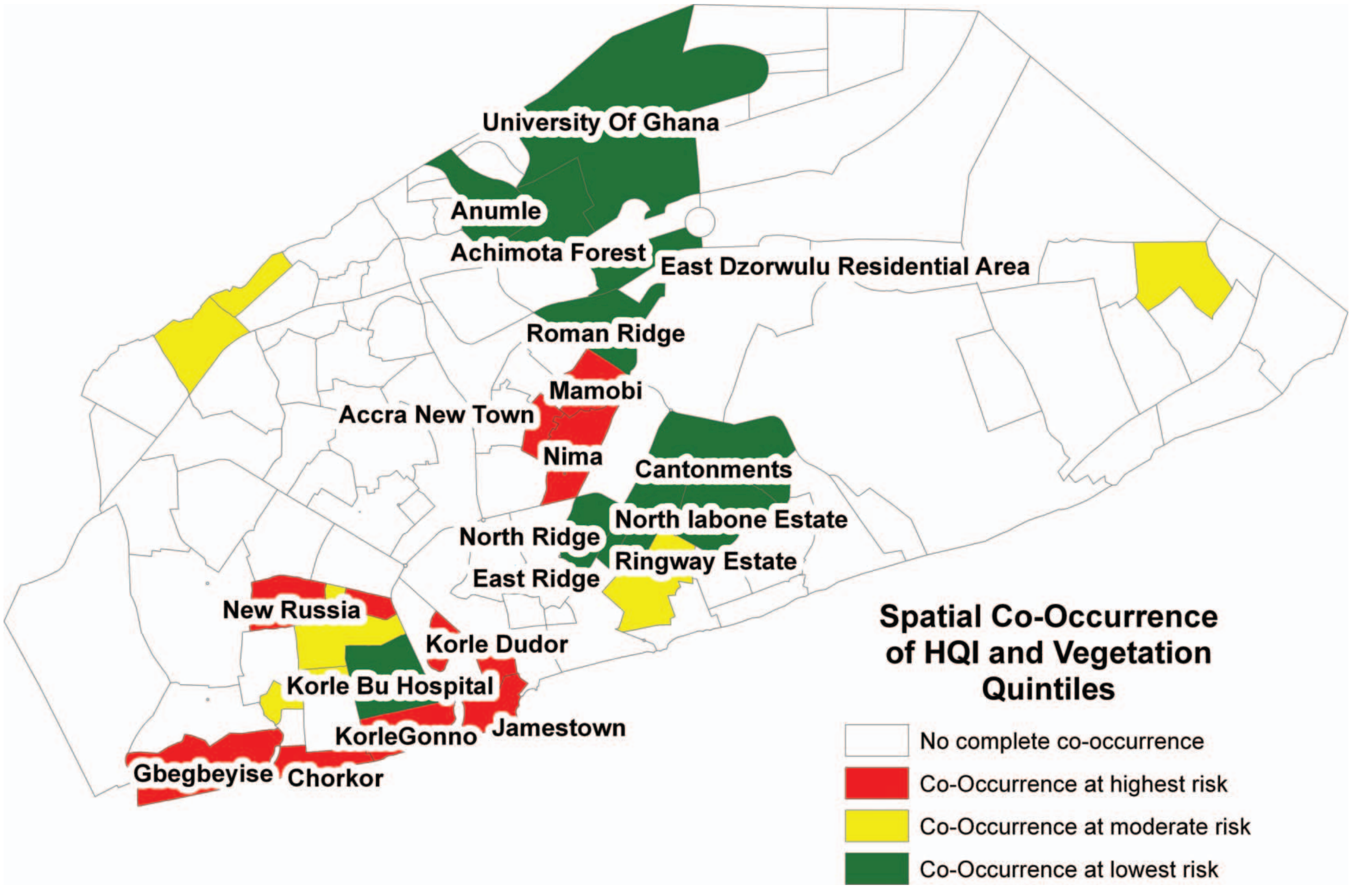

Figure 3. Spatial cooccurrence of housing quality index (HQI) and vegetation quintiles for both 2002 and 2010 by field modified vernacular neighborhood, Accra, Ghana. (Color figure available online.)

depending on the circumstances. An important lesson learned is that tracking individuals is very challenging in a community with a poorly developed system of street addresses and a tendency to use a variety of personal names, depending on the context. Nonetheless, almost two thirds of the originally surveyed women were identified and successfully reinterviewed five to six years after the initial contact. This was aided substantially by a street map we created from a purchased set of CAD data files (tiles) from the Ghana Department of Lands and Surveys that included local detail obtained from digitizing aerial photographs, street names, and elevation detail. These data were combined with our digital boundaries and satellite imagery into a geodatabase from which details could be printed out for sections of the city, thus allowing interviewers to navigate each neighborhood of the city successfully.

Follow-up was also aided immeasurably by the remarkable penetration of mobile phone use. We found that 90 percent of households in the survey own a mobile telephone—a much higher rate than expected, even though Africa has been experiencing the most rapid increase in use of this technology (Tryhorn 2009). For women who were found to have moved within the Accra metropolitan area (AMA), the team made every attempt to locate them in their new residence and interview them as part of the study. For women who were found to have moved outside the AMA, replacements matched by age and EA of residence were identified and asked to join the study. For women who were found to have died, a later study was carried out, in which a verbal autopsy was conducted to ascertain probable cause of death. The number of completed interviews in WHSA–II was 2,814, of which 1,819 were reinterviews of women from WHSA–I and 995 were replacements for women lost to follow-up.

In analyzing neighborhoods as health contexts, building on our systems approach, we recognize that in a city with relatively high mortality such as Accra, the biggest differences in health will be found especially at the youngest and oldest ages. These are the ages for which we can anticipate the strongest interaction

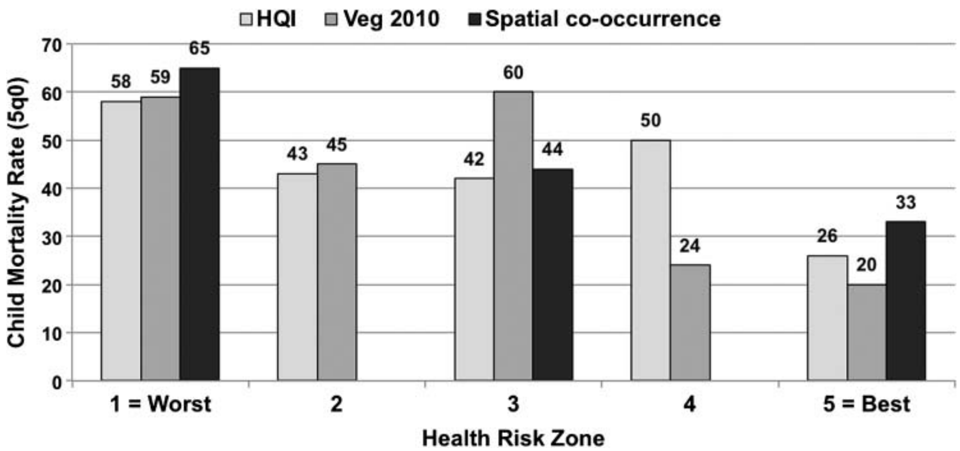

Figure 4. Measures of child mortality (5q0) by risk zones in Accra, Ghana. HQI = housing quality index.

between neighborhood environment and health, as the very young and old are apt to be the least mobile, so the neighborhood of residence will be the single most important ecological contextual factor. Among younger and middle-aged adults who are in the labor force, place of residence will represent one of several different ecological contexts that might impact health (Kwan et al. 2008; Matthews 2008).

One of the most widely used measures of child health is the probability that children will survive from birth to their fifth birthday (5q0). There are a variety of ways to model this in the absence of detailed pregnancy histories or complete vital statistics, drawing on two key questions asked of women in many surveys: (1) number of children ever born and (2) number of those who have died. It turns out that the ratio of children dead to children born at different ages of motherhood provides a close approximation to 5q0 (Rajaratnam et al. 2010). For women who have ever had a live birth, we calculate whether or not any of their children have died to date. We do this calculation by age group of women and then calculate age-standardized proportions of women who have lost a child, using the Accra 2000 census population as the standard. We calibrated this measure at the regional level in Ghana, using data from the 2003 Demographic and Health Survey. The adjusted R^2 between 5q0 and the age-adjusted proportion of women who have lost at least one child was 0.88. We employed the regression equation from these data to convert proportions who had a lost a child into the predicted child mortality rates (5q0; formulas are available from the authors on request).

We then used the data from the pregnancy histories of women interviewed in WHSA–II to calculate the proportion of women with a live birth who had lost at least one child in each of the health-risk zones shown in Figures 1 through 3. Figure 4 shows that the child mortality rates are more than twice as high in the lowest quintile of housing quality compared to the highest quintile (58 compared to 26). All of the intermediate housing quality quintiles have childhood death rates that are between those extremes. The quintiles based on the 2010 vegetation classification also show a clear differentiation in child mortality between the highest and lowest quintiles although the middle (third) quintile is out of order with respect to child mortality. Our interpretation of this anomaly is that several of the neighborhoods in this risk zone are at the periphery of the city and are occupied by migrants to the city who have above-average mortality but are living in an area that has been settled recently enough that it has not yet been completely devegetated. Finally, it can be seen that the zones created by the spatial cooccurrence of quintiles based on housing quality in 2000 and vegetation in 2003 and 2010 had a clear spread, in which child mortality was almost exactly twice the level (65) in the highest risk area compared to the lowest risk area (33), with the moderate risk area falling between those extremes (44) in terms of child mortality.

We now turn to the other end of the age structure and ask whether there is a relationship between the health of older women (age fifty-five and older) and the risk zones in which they live. Keep in mind that we have, by definition, interviewed survivors, so we can anticipate differences less dramatic than for childhood mortality. Some parts of the city might have higher survival rates from given diseases and conditions, but we have no data to measure this. Rather, we focus on the relative conditions of the women interviewed. For the sake of brevity we have focused on one example, and Figure 5 shows the percentage of women reporting that their health is only fair or poor by risk zone quintiles.

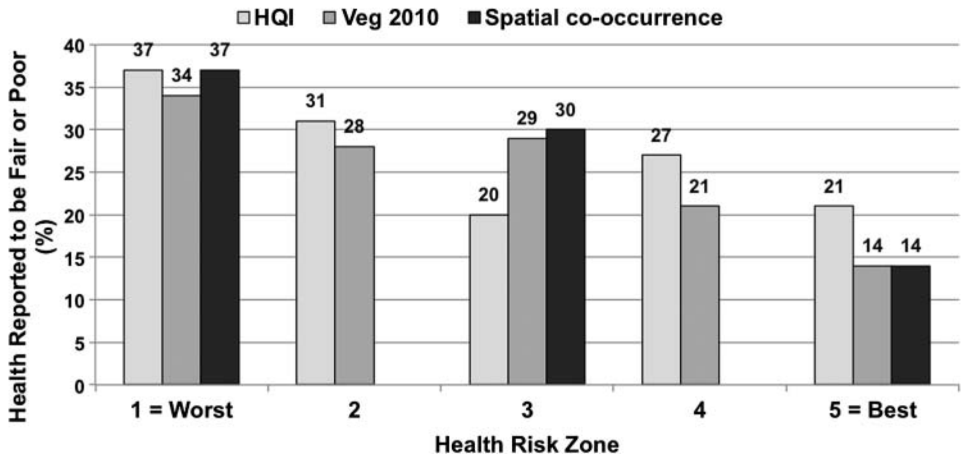

Figure 5. Percentage of women 55+ who report that their health is fair or poor by risk zones in Accra, Ghana. HQI = housing quality index.

Consistent with our expectations, the percentages are clearly highest in the higher risk neighborhoods and lowest in the lower risk neighborhoods, regardless of whether we measure risk in terms of housing quality, vegetation, or the cooccurrence of the two.

Connecting with the People About Their Health

During the summer of 2010, the research team conducted a series of focus groups in an SES-stratified selection of ten neighborhoods within the AMA. To arrange each focus group, our facilitators at the University of Ghana contacted the assemblyperson or local chief for each neighborhood and then worked through community groups to organize participants. Focus groups of eight to fifteen persons were conducted at a variety of venues (including a church, a bar, and a private residence), with discussions lasting between one and two and one half hours.

We know from the WHSA–II that people living in high-risk zones were least likely to understand the exact cause of malaria, although the self-report data suggest that they were not more likely to have ever had malaria. Across all focus groups, however, participants perceived malaria as the number one health issue in their neighborhoods. As one Nima neighborhood resident stated, "The problem here is malaria." Nima is one of the poorest neighborhoods in Accra, but residents in every focus group regardless of neighborhood SES expressed the same perception that malaria was their neighborhood's primary health concern. Participants in focus groups seemed to blame most fevers on malaria from the mosquitoes that breed in trash-choked gutters near their homes. Even if this is not the type of place in which the *Anopheles gambiae* mosquito that carries the malaria parasite typically breeds, the residents understood a connection between their environment and health when it comes to malaria. Other diseases like typhoid, diarrhea, respiratory issues, and even chronic diseases like stress and diabetes, however, were not so readily connected to the environment. Participants in Nima were also aware that people are more likely to get sick during the rainy season when the gutters are overflowing from all of the trash being thrown in them, but there were no specific diseases attributed to this problem.

Focus groups also revealed a contrast between neighborhoods where residents felt a strong sense of personal responsibility for their own health and others where people expressed that they felt more susceptible to their environment. For instance, in the relatively wealthy Cantonments neighborhood, where the majority of residents are government and embassy workers, focus group participants expressed that "it is your individual house that is the cause, not the environment," and that environmental elements did not have a significant impact on residents' health. One participant stated, "The air is clean, there are trees all around." In contrast, in the relatively poorer Sabon Zongo and Jamestown neighborhoods, focus group participants mentioned the collection of environmental factors that they felt impacted their health, such as low water quality, reliance on public latrines, and poor solid waste management. Participants in Sabon Zongo noted that nearby neighborhoods where people are neater, cleaner, and better educated about health and hygiene were also healthier. These comments are consistent with our view of health as a system. People saw themselves as being at risk of disease because of the combination of personal habits and environmental context, but some of the neighborhood residents also understood that they could be empowered to make changes in the environment that would ultimately benefit not only their health but the health of their neighbors as well.

Connecting the Dots

Through the use of a vast array of geospatial techniques, surveys, focus groups, and extensive fieldwork, we have been connecting dots showing that if cities are conceptualized as places with different zones of health that transcend the local residents, we are able to use proxy data such as housing quality and vegetation indexes from satellite imagery to identify places within the city that are likely to have the worst and the best health outcomes among people living there. More than one in five (22 percent) of Accra's population live in the highest risk neighborhoods (the first quintile on both the HQ index and vegetation), whereas only 3 percent live in the lowest risk neighborhoods (the fifth quintile on both HQ index and vegetation). The burden of health is thus heavily and disproportionately borne by lower income neighborhoods. Some of them have active nongovernmental organizations working to empower local residents to improve their lives, including their health, but most neighborhoods do not. Harpham (2009) has suggested that something akin to street-level advocacy might be appropriate in the Global South to create the kind of social movement for health in that part of the world that has successfully brought health improvement to the policy table in developed countries. In Accra and other sub-Saharan African cities, the systems approach suggests that the most efficient way to improve health is to improve the environment, at the same time teaching people more effectively how to protect themselves from disease and other health hazards.

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