Applying Spatial Analysis to Socio-Environmental Interactions

Despite the consensus among scholars and government agencies on the critical need for clean water to improve child and population health, the development of piped systems has not yielded the expected immediate health improvements in most developing countries (Clasen and Cairncross 2004). Recent studies of interventions intended to improve water quality suggest that variation in drinking water quality is partly due the variety of water sources used (Clasen et al. 2006, 2007). While types of water sources, such as wells, pipes, and rivers, explain a much of the variation in water quality, few researchers have assessed how the spatial distribution of these sources also affects quality. This spatial process should be considered given that sociological factors such as development vary across space, and the variation of these factors may explain the spatial distribution of water contamination. Contamination is part of a geographical phenomenon of economic and social disparities across space. If economic development is targeted towards people near a government center, these citizens benefit from economic and social improvements such as piped water distribution systems and knowledge of safe water storage practices. This may lead to a lower chance of people drinking less contaminated water. If, however, poor roads hinder the transport of such benefits to rural communities far from the government center, they continue to suffer the effects of contaminated water; an economic and social disparity creates a health disparity across space.

Despite the association between unsafe water and infant and child mortality, donor groups, governments, and academics in the community health arena have been more focused on malaria and HIV/AIDS. However, the decade 2005-2015 was declared the International Water Decade by the United Nations. The UN alerted policy makers about a “global water crisis,” noting in their 2006 Human Development Report that two million children die each year from diseases related to water-borne illnesses, and millions more women and children spend hours just collecting water, restricting their opportunities to do other things such as receiving more schooling or merchandise items they can sell for a profit (UN 2006). Additionally, water-borne infectious diseases create more poverty and slower economic growth. The International Water Decade’s goal, to be achieved by 2015, was to reduce by half the proportion of people who regularly obtain their drinking water from unhealthy sources or from far away places. The goal also calls for better access to basic sanitation.

The strong and consistent association between unsafe water, hygiene, and infant mortality needs additional exploration. While many previous studies have found evidence that tap water is healthiest and people who have short walks to water sources have cleaner water than those who must take longer walks (Moe et al. 1991), the spatial relationship among water source type, contamination level, and water source location has not been explored at the community level in Africa. That is, extant research has not addressed whether contaminated sources are clustered or whether the spatial distribution is dependent on the water source. With the application of GIS technology and spatial data analysis techniques, we can attempt to answer these spatially contextualized questions. These powerful analytical tools can help policy makers identify sources of contamination that affect the largest number of people. In this study, I use point data obtained from GPS coordinates of 36 communities in the coastal districts of Central Region, Ghana, to examine the spatial nature of water contamination.

Background and Theoretical Model

Unsafe water, sanitation and hygiene are responsible for almost 4% of the global total in disability adjusted life years (DALYs) and 6% of disability among high mortality countries (WHO 2002). This makes water contamination, its sociological correlates, and its spatial pattern, a central concern to scholars and agencies that focus on population health. High mortality is increasingly recognized as a result of the strong and persistent association in developing nations between unsafe water and hygiene, and infant and child mortality arising from diarrheal diseases (Huttley et al. 1997). About 800 million urban dwellers worldwide lack sustainable access to safe drinking water. This helps explain why infant and child mortality rates for poor urban populations can be as high as those for poor rural populations (IIED 2003). Lack of sanitary waste disposal and clean water for drinking, cooking, and washing is responsible for over twelve million deaths per year (Population Reports, 15).

Agriculture remains one of the biggest polluters of water because of fertilizers and pesticides. These contaminants permeate soil and seep into water runoff pathways. High nitrate levels are indicative of contamination by fertilizer that is used for farming. Fertilizer on the ground over time seeps into and permeates soil. The World Health Organization has found that nitrate is a severe and global problem because it deteriorates groundwater quality (WHO 2002). As groundwater travels through soil, it penetrates underwater pools that serve as sources of borehole and well water. Nitrate contamination is spatial in nature because the contaminant, fertilizer, permeates soil and spreads into water runoff (Holton 1996; Manassaram et al. 2006).

Sociological Correlates of Water Contamination

Previous studies on drinking water quality in developing countries have typically considered the influence of community water sources (Clasen et al. 2004; Shier et al. 1996; IIED 2003; Steyn et al. 2004). Water sources in the developing world are comprised of taps/piped distribution, wells, boreholes, and surface water, which includes lakes, streams, and rivers. Interventions to improve water quality include steps to maintain the microbiological quality of safe drinking water, such as piped distribution, because of the risks of water contamination (Clasen 2003). Research demonstrates that pipe-distributed water will have fewer pathogens than surface water which tends to gather in heavily trafficked areas where it is prone to human feces. Diarrhoeal cases have been more prevalent among people retrieving water from untreated surface or stream water while being least prevalent among those retrieving water from a pipe. Additionally, boreholes seem to provide healthy water during the dry season but not during the rainy season (Shier et al. 1996). This is a noteworthy finding given that boreholes have been touted as a better-quality source of drinking water compared to wells and surface water (Moe et al. 1991). Building on this research, I anticipate that levels of contamination from wells and surface water should be higher than water from taps.

The demand for freshwater is increasing as water use per person is rising and countries struggle to manage population growth (Hinrichsen, D. et al. 1998). Most discussions of water quality miss the rural-urban connection, as secure city water supplies often depend on better watershed management in upstream rural areas while wastewater flowing out of cities is usually important for farming downstream (IIED 2003). In Kumasi, Ghana, for instance, there are positive aspects to the use of urban wastewater streams for agricultural production and farmers' livelihoods. This is a spatial process because water initially used in urban areas is reused in a rural area just outside of the city. The water contamination level will be different entering the rural area than it was upon entering the urban area.

Variation across water improvement trials in previous studies has suggested that factors such distance from water sources, as well as community urban-rural status and level of development matter (Jagals et al 1999; Wright et al. 2004). For example, urban places with high population densities may not have access to safe drinking water, leading citizens to travel over space to collect supposedly better-quality water. However, water transported long distances may be of an uncertain quality and safety (Wright et al. 2004). In this process, walking longer distances over space yields unfamiliar water quality because it is farther from home.

Drawing from this literature, urban places with access to safe water sources (i.e. developed urban areas) are expected to have higher-quality water than their rural counterparts, but urban places lacking development will have lower quality water than rural areas without development. Higher levels of contamination are expected in more populated areas because more people generate greater amounts of garbage and, typically in these settings, more people have animals such as goats and chickens roaming in close proximity to human populations. Animal excrement mixes with garbage that eventually reaches drinking water supplies in heavily-trafficked areas with no covers for protection from the surrounding environment.

The relationship between urban-rural status and water contamination is likely conditioned by the level of development, as demonstrated by the series of arrows linking urban to development to type of water source and the outcome, water contamination (see figure I). Urban-rural status also is anticipated to directly affect water contamination because of population density. If urban areas have more people in closer confinement, not only are more trash receptacles placed, but so are public latrines. These latrines, of which there are many to accommodate the large population, deposit waste (feces and trash) into the ground directly. Even if latrines were replaced with flush toilets, urban areas would have higher water contamination than rural areas because more people generate more trash in urban areas. This trash is regularly littered. The trash may contain chemicals such as soap and detergent which finds its way into drinking water.

More developed communities are expected to have better water quality through indirect positive influences of the specific forms of development. For example, development shapes the types of water sources which, in turn, influence the level of contamination. Yet development also affects the level of contamination indirectly through factors such as chlorine or iodine tablets that more easily reach communities on accessible roads.

In general, levels of development tend to be higher in urban areas than rural areas. Not all urban areas are developed though, and certain indicators of development are more likely to play a role in influencing drinking water contamination. For instance, introducing piped systems into any community should directly reduce the probability of contamination. In this context, development explains the communities' types of water sources, which will explain the variation in the communities' levels of contamination.

A paved road, however, could also indirectly affect water contamination by introducing new products to markets such as chlorine or iodine tablets, which improve water quality. These new products are more likely to show up at markets in more developed communities with paved roads since the trucks that transport them can only travel on paved roads that do not flood. A measure of development that is separate from urban status is needed because certain aspects of development can indirectly affect contamination levels.

The main economic activity of the community might also be correlated with water contamination. Commerce diversifies economies and develops communities by offering technology to a community that cannot generate technology on its own. The influence of commerce is independent of development because people who engage in commerce interact with people from an outside community. Outsiders bring their goods, including health-improving technology, as well as ideas about health and stories of children dying from diarrhea because of a water-borne illness obtained through drinking water. For example, a female is likely to take measures to prevent contaminated water from poisoning her children if she hears a personal story about a child dying from diarrhea from a vendor.

The Spatial Nature of Water Contamination

Spatial autocorrelation is sometimes treated as a statistical nuisance to be corrected in studies of processes that social scientists believe occurs across space. Spatial autocorrelation arises when the arrangement of values in the variables are not randomly distributed across the geographical domain under study. The presence of spatial autocorrelation is a problem in standard statistical modeling because the researcher cannot assume that the observations in the model are independent of one another.[1]

---

[1] Spatial autocorrelation violates assumptions of independence by having values in one area be affected by the value in a nearby area. For instance, if a water source has a high nitrate value, a water source two

Therefore, if we are to understand the distribution of water contamination, we must correct for spatial autocorrelation. One approach is to test whether certain socio-demographic or development factors explain the distribution of contamination through standard regression analysis. A spatial analysis of the residuals of the OLS models help researchers understand the extent to which spatial autocorrelation is a problem. The analysis can also offer suggestions as to whether we can "correct" this by including additional covariates or employing a spatial dependence model.

The spatial relationship between water source type, contamination level, and water source location has not been extensively explored at the community level in Africa. The community health literature has established that one of the best indicators of drinking water contamination is the source from which the water was obtained. The current study accepts this assertion and examines whether contamination is positively spatially autocorrelated among the communities. If contaminated water sources are not clustered geographically, as might be expected given drinking water pathways, what explains the spatial pattern of water contamination? I suggest the spatial nature of contamination is due to the spatially non-random distribution of sociological factors, such as urban status and development that correspond with the spatial distribution of contamination.

Study Setting and Data Collection

Compared to the rest of Africa, Ghana is fairly urbanized, educated, and economically developed. A country of about 240,000 km², Ghana sits on the coast of West Africa. Ghana has progressed through its demographic transition faster than its sub-

---

kilometers away also has a high nitrate value, and this is in part because the nitrate level of the initial water source affects it. If the assumption of independence is violated because of spatial autocorrelation, this calls into question the validity of hypotheses we generate because our test statistic value will be inflated, increasing the chance of a type I error (rejecting the null hypothesis when it is true).

Saharan African counterparts. For example, total fertility rates are 4.1 births per woman and falling, infant mortality rates are 51.4 deaths per 1000 births, and life expectancy at birth is around 56 years (UN 2002). By comparison, sub-Saharan Africa's infant mortality rate is 77.2 deaths per 1000 births. Like some of the other countries in West Africa, coastal parts of Ghana are more educated and economically developed than interior sections. Central Region is one of 10 administrative regions in Ghana and lies on the southern Atlantic coast, about midway between Ghana's eastern border with Togo and western border with Côte d'Ivoire (see figure 2).

The Central Region's unique climate has contributed to ongoing drinking water shortages over the past few decades. The coastal belt of the Central Region through Accra to Togo experiences rainfall totals which are substantially smaller than typical tropical coastal regions. Worldwide coastal areas within the tropical zone experience rainfall totals of 80 inches or more per annum. For instance, Axim, located on the southwest coast of Ghana, receives about 85 inches of rainfall and this increases westwards towards Liberia. In contrast, Cape Coast and Accra have annual rainfall of around 30 inches (Dickson & Benneh 1994). This unusually dry condition along the coast of the Central Region has given rise to acute water shortages for most parts of the year. To offset the water shortages, boreholes and wells have been sunk in some of the rural communities. The water system for Cape Coast, the capital of Central Region, was built in 1927-28 to serve the population of the town which at that time was less than 20,000. The water system has not seen any major expansion since it was built in spite of the increase in population and the expansion of the system to nearby settlements such as Elmina and Saltpond. As a result, the pipe borne water supply in the area is inadequate.

The data for this paper come from water samples collected in Central Region, Ghana, in July of 2006. This data collection was part of a wider project that focuses on water contamination in households and people's perceptions of changes in population and its effects on the environment. In 2004, we conducted a representative survey of the six coastal districts within the Central Region. The survey is based on a two-stage stratified sampling design. We randomly selected six enumeration areas (EA) in each of our three residence strata (rural, semi-urban, and urban) to evenly spread the sample across the strata and, thus, ensure that there is a sufficient sample size in each strata type. Within each of the 18 strata (three stratum in each of the six districts), we selected five EAs using probability proportional to size of the EA. Thus, we initially drew a representative sample of 90 EAs, 54 of which were used in earlier survey work in 2002, and remainder used for this study conducted in 2004. The Ghana Statistical Service (GSS) aided us in this process by providing the list of EAs and population information.

We returned in the summer of 2006 with the goal of collecting water samples from community sources in the 36 communities visited in 2004. Each of these communities had up to four community drinking water sources, all of which were tested. A community drinking water source is either centrally located within the township or just outside the community where residents collect water which they transport to their homes. In certain urban areas, especially Cape Coast, many households do not collect water from community sources because pipes bring water directly into their homes. This was found only in the most economically developed areas of the regional capital city.

When a sample of water was collected, a GPS reading was taken at the source. Where no community water source existed, a GPS reading was taken near the center of that community. The maps used in this paper are a representation of the communities; the location of community water sources is a proxy for the community location. A clustering of many dots is most likely indicates that a single community had more than one water source.[2] With data on the water source location, we are able to distinguish where the six communities in each district are located relative to one another.

Four different types of water sources are identified in the Ghana study region: pipe or tap water, well water, borehole water, and surface water. Surface water could be from a pond, lake, collected rain water, or river water. Boreholes are deep holes buried 10 to 20 feet into the ground and pump drinking water to the surface. Studies have shown that boreholes provide water that is much more sanitary than well or surface water, but not tap water. During the data collection process we differentiated between the various types of surface water but in this analysis I combine them into a single category to keep the maps more readable and the analysis more parsimonious. Further, descriptive analyses showed no significant differences in contamination levels across surface water sources.[3]

One of the greatest challenges to researchers using GIS is the lack of high quality data for maps or, if available, the high costs of such data. This is particularly true for the developing world and Africa especially. Data on basic infrastructure such as road and rail

---

[2] A number of communities are counted several times when 2004 attributes are linked to 2006 water source data. As a result, the analysis must be weighted by providing a variable based on the number of water sources in a community (between 1-4 water sources). Ghanaian colleagues reported that it was highly unlikely that main water sources changed from 2004 to 2006, so the GPS coordinates taken in 2006 accurately represent 2004 attributes and where communities are located on the map.

[3] The sample of drinking water from each source was collected with a clean ladle and bucket, and placed in a small plastic bottle. Chloroform (.05ml/50ml sample) was added with an eyedropper to preserve the water in the state in which it was collected. The bottles were shipped to the University of Rhode Island Graduate School of Oceanography Lab within one week of collection. The lab tested and analyzed the samples for specific chemicals such as nitrate levels in the water collected. Nitrate is commonly used as a reliable measure for fertilizer contamination or more distant sewage waste.

networks, rivers, elevation, lakes, and large towns are made available through the geocomm website, a leading internet provider of geographic data products and services. This data linked to an electronic map of the boundaries of the regions and districts in Ghana obtained from Dr. John Weeks at UC-San Diego who, in turn, obtained them from the University of Legon in Accra. A file with latitude and longitude coordinates obtained from GPS devices in the field at each water source was attached to the electronic map. GPS devices provide accurate longitude and latitude readings within about 10-50 feet.[4]

The distribution of nitrate was measured in per 100 milliliter of water and is adjusted by the square root due to a heavy right skew in the distribution. For the purposes of interpretation, cut-off values for the nitrate levels reflect an agreement within the scientific community that values above a certain point are much more likely to show unhealthy effects on humans compared to values below that point. This value is 710 micro moles per liter (uM). Values of about 710 uM for nitrate indicate that the water source has high levels of contamination due to fertilizer and/or sewage from distant sources.

Methods

Weighted OLS regression techniques were used in the analyses of water contamination measured in terms of nitrate values. I estimated three sequential models: the first model tests for the influence of water source; the second model examines the association with presence of a year-round access paved road as a proxy for development; and the third model includes urban and commerce (both dichotomous) as the

---

[4] One of our sample sites fell outside our six study districts when placed on a map. Our Ghanaian colleagues found that a disagreement exists within this border community about where the district boundary lies. We follow the Ghanaian government's definition of where the community Sarkwakwa should lie and, therefore, the community is slightly misrepresented on the maps because we moved the community east to fall within the government identified district.

community's main economic activity.[5] A year-round access road is a paved road that is not flooded and remains passable even during the rainy season. We stratified our sample such that one-third of our communities are designated urban, one-third rural, and one-third semi-urban. The definitions of these places were set by the Ghana Statistical Service. In order to simplify the analyses, I consulted with a Ghanaian geographer, Kofi Awusare Asabo, to divide the semi-urban areas such that half were urban and half were rural. This is not truly representative of the population because Ghana is about 41% urban (GSS, 2002). This could mean that the urban variable coefficient over or underestimates the effect of urbanness on water contamination variation.

A weighted model is necessary due to the fact that not all 36 communities had the same number of water sources. This would have implications on the analysis because if more populated places had more water sources and higher levels of development the levels of development would positively bias any coefficients on development. This might lead us to conclude that development matters a lot more to lowering water contamination levels than is actually true. The sample weights are constructed such that a community is weighted half if it has two water sources or one-third if it has three sources.

Before fitting OLS models, I begin the analysis by estimating a Moran's *I* statistic for nitrate. The Moran's *I* is a descriptive spatial statistic that indicates the amount of spatial autocorrelation of a given variable. A statistically significant Moran's *I* suggests that spatial heterogeneity or spatial dependence may be operating in the data.

---

[5] Tests for multicollinearity were conducted because of a strong concern that development in general, year-round road access, and urbanness were strongly correlated. Preliminary analyses used a development index, and although the correlations between variables in the index were never above .50 and there was no evidence of multicollinearity, concern was high enough because of lack of statistical significance during the initial modeling that the index was decomposed and incremental models run. Models of the untransformed dependent variables were also fitted and no significant differences were found.

Spatial dependence exists when the value of nitrate in one community is a function of the value of nitrate in a neighboring community. The existence of spatial dependence may be an artifact of water contamination diffusion and can result in "Galton's problem", where "certain traits in an area are often caused not by the same factors operating independently in each area but by diffusion processes" (O'Loughlin and Anselin 1992, 17). On the other hand, spatial heterogeneity refers to a regional pattern in the data which results in the instability of model parameters across the study area (Anselin 1988). In this case, the slope of any OLS would not be constant when comparing communities across Central Region, but rather adversely impacted by the spatial dependence that is unaccounted for in the model (LeSage 1997; LeSage and Parent 2004). The identification of spatial heterogeneity within the data indicates the presence of geographical variation in water contamination and its incorporation into models explains the place-specific behavior of contamination and water source. Spatial heterogeneity is a large-scale process and emerges when values of the dependent variable differ across space. Spatial heterogeneity assumes that the observed process is heterogeneous across space, and variation independent of location. It also assumes that process is intrinsic to the uniqueness of a place (Anselin 1988).

A spatial weights matrix needs to be calculated to treat the spatial effect, whether it is heterogeneity or dependence. Spatial weights allow the analyst to define who a neighbor is based on the anticipated structure of the spatial process (Anselin 1989). Spatial weights matrices provide patterns of interaction that provide meaningful interpretation of spatial autocorrelation in spatial dependence models. They also offer a framework for studying cross-sectional dependence (Anselin 2002). I used a minimum threshold distance weights matrix which calculates the distance between the communities for two reasons. First, the communities are reflected on the map as points rather than polygons and do not share boundaries as polygon data do (i.e. states bordering states). Second, the minimum threshohold distance guarantees that each community has a neighbor, and thus ensures that each community has a relationship with at least one other community.

RESULTS

The Distribution of Water Sources

Figure 3 represents the distribution of water sources by type. Cape Coast, the capital, and Winneba, the second regional city, are identified. There are three notable aspects about the distribution of water source type. First, the distribution suggests that urban areas do not necessarily have more water improvements than rural areas. For example, Winneba lacks pipe water access while more rural interior communities, especially north of Cape Coast, have such improvements. Winneba only has surface water and well sources of drinking water.

Second, improvements appear disproportionately distributed around the capital city. Cape Coast and many of the surrounding communities have access to tap water whereas the far higher percentage of communities that are near Winneba have access to wells and surface water. There are historical reasons for why improvements fall disproportionately close to the capital. Cape Coast was the capital of the Gold Coast (the former colonial name for Ghana) until 1877. The pipe-borne water supply was introduced to the town in 1928 with the building of a dam across the Kakum River. The pipes were meant to serve the population in and around Cape Coast. In contrast, Winneba's old pipe system broke down decades ago and it now obtains water from a dam thirty kilometers away. The water in Winneba has a greater risk of being exposed to natural and human contaminants because it must travel many kilometers in the open.

The third noteworthy pattern is that borehole water sources tend to be located inland and in more hilly communities. In comparison, surface water and well sources are found both on the coast and inland. This may be significant for water contamination because rivers and streams, types of surface water, near the coast have traveled great distances from hillier inland communities and are prone to contamination because it travels through several communities that use and, in a sense, pollute the water. Bathing is one use that can pollute the water since soap deposited upstream affects the contamination levels of all downstream communities.

Exploratory Data Analysis

Although the original sampling design called for one-third of our communities to be urban, one-third rural, and one-third semi-urban, previous studies have found a meaningful difference in water quality according to an urban-rural dichotomy. Semi-urban places where equally divided between rural and urban areas as discussed earlier.

Table 1 illustrates the characteristics of the study communities. A plurality of the communities receive drinking water from a tap. However, nearly half retrieve their drinking water from either wells or surface water sources, indicating overall poor water infrastructure. On the other hand, transportation infrastructure is well-developed; 87% of the communities have access to a paved road that did not flood during the rainy season. The great majority of the communities' economies depend on farm-like activities. Since many communities are coastal, communities that do not focus exclusively on farming also depend on fishing and raising livestock.

Figure 4 demonstrates that communities in the Central Region that are high in nitrate are near other communities that are high in the respective contaminant. The Moran statistic for nitrate levels, reported in Figure 4, is 0.21 which indicates some positive spatial autocorrelation and suggests that a community's nitrate value is similar to the value of nitrate levels in a neighboring community. Further, the Moran's *I* is statistically significant ($p < .05$) which suggests that the nitrate levels are non-randomly distributed across the Central Region. The upper right quadrant of the corresponding Moran's scatter plot displays communities with high levels of nitrate that are near other communities with high nitrate levels. The clustering of many observations in the lower left quadrant indicates that most communities have low levels of nitrate and are near other communities with low nitrate levels. The few communities in the "high-high" upper-right quadrant are located only in the far eastern part of the region. Winneba, the set of points which is highlighted and the furthest left of the highlighted points, is the main city in this area. Her proximity is geographically closer to Accra than Cape Coast, but as discussed earlier, the city is poor and underdeveloped. The positive and significant Moran's statistic motivates an analysis of sociological factors that might explain the spatial distribution of nitrate contamination.

Multivariate Analysis: Water Sources Dichotomous (Nitrate: Tap vs. Else)

After determining an appropriate weights matrix, I ran the incremental models using Stata. On the final models (those with all independent variables), the residuals were saved and analyzed using GeoDa. Specifically, I calculated a Moran's *I* on the residuals for nitrate. If the residuals are not spatially autocorrelated, this indicates that the original spatial autocorrelation observed in the dependent variable is explained by the covariates and suggests that spatial heterogeneity, not spatial dependence, characterizes the process of water contamination in the Central Region of Ghana.

Piped tap water is the only water source from which we collected water and do not expect to find nitrate contamination because of the protection pipes provide from contamination elements such as fertilizer and animal and human waste. Table 2 shows the results of the OLS regression of nitrate levels. Nitrate is significantly lower among communities with tap sources compared to communities with all other water sources. Other socioeconomic variables are significant as shown in model 3. Development, measured as the presence of a year-round road, is negatively associated with nitrate levels. While this variable is only marginally significant, the size of the coefficient is substantial. For example, all else constant, a community having tap water and a year-round road would have very little nitrate, if any at all. However, all else constant, a community having just tap water, the nitrate value would be over fourteen times the amount.

Urban areas have marginally significant higher nitrate levels than rural areas. This result is not surprising given that sewage and waste are more prevalent in areas where there are more people (urban areas are characteristic of this). The association is nearly opposite to the one found between tap water. In fact, the results show that the associated benefit tap water has on reducing nitrate would be eliminated if the tap is in an urban area. However, significance on urban is marginal. One explanation is that the sample was evenly divided between rural, urban, and peri-urban communities. The interaction between water infrastructure and urban, model 4, is not significant. This suggests that whether a community has a tap is not conditioned by urban status. Therefore, I would not emphasize the importance of urban areas in determining higher nitrate levels in communities in model three. Instead, the focus should be on water sources.

Finally, communities that specialize in commerce have significantly lower nitrate levels than agricultural communities. This result is highly significant and consistent with expectations; fertilizer used in agricultural production is a source of nitrate contamination. Only 5.4% of the communities listed commerce as a main economic activity; most of the communities are engaging in agriculture and are at a higher risk of nitrate contamination. Results suggest economic and social community development that comes from expanding an economy beyond farming could benefit community health. A larger sample is needed, though, to accurately assess any such benefits.

A Moran's *I* for the residuals of the OLS analysis of nitrate was calculated and reported in Figure 5. This statistic is compared to the value reported for the dependent variable estimated in the exploratory spatial data analysis (Figure. 4). The original Moran's *I* for nitrate was 0.21 ($p<.05$ with 999 permutations). In contrast, the Moran's *I* for in the residuals decreased to 0.17 (p-value=.05 with 999 permutations). The figure illustrates areas where nitrate is being over-predicted and under-predicted; communities where nitrate is being over predicted are highlighted in yellow. The over-predicted communities fall in the upper-right quadrant while the under-predicted fall in the lower-left. The map shows that there are more over-predicted communities than under-predicted communities, and the over-predicted communities tend to be in the eastern third of the study area where I originally suspected higher nitrate levels would exist.

Since the Moran's *I* was not significantly reduced and marginally significant, it is necessary to search for the reasons for the remaining spatial autocorrelation. To do this, I examined the Moran's *I* on the residuals of incremental models run where an independent variable was added each time. Table 3 shows my findings. A significant change is found when the development indicator, the presence of a year-round working road, is inserted into the model. Namely, the Moran's *I* of the residuals falls to .14 and this is insignificant at p<.10. By observing the Moran's *I* of the residuals of the other models, I find a virtually non-significant Moran's *I* and the reduction of the Moran's *I* in terms of value and significance means that the distribution of the covariates correspond to the distribution of nitrate contamination. Therefore, the best fitting model is the one with water infrastructure and development because the AIC score is the lowest, these independent variables are significant, and the Moran's *I* is insignificant.

Discussion and Conclusion

Access to safe water and sanitary infrastructure was moderate in the study in the Central Region of Ghana. This is similar to some other areas in developing nations and to other regions in Ghana (Boadi and Kuitunen 2005a, 2005b, 2005c, Keraita et al 2003, Ghana Stat. Service 2002). Use of tap water for water consumption characterized 34% of the communities, lower than the 40% reported in a study in the Accra metropolitan area (Boadi and Kuitunen 2005a), and right around the 32% estimated from a child health study of Accra households (Boadi and Kuitunen 2005b).

The combination of poor water quality and low levels of infrastructure for safe water and sanitation suggest substantial risk from water-borne infectious diseases in this region. Given that 23% of childhood communicable diseases can be attributed to unsafe water and sanitation (WHO 2002), urgent attention is needed to extend safe water systems, provide direct investments for sanitary facilities and conduct household level health education campaigns about water and sanitation (Soares et al 2002).

Water sources exert powerful direct influences on water safety and quality in the absence of interventions to improve water quality (Shier et al. 1996; Steyn et al. 2004). Piped water from private or public systems generally has fewer pathogens than surface or well water, which are affected by drainage of human, animal and other wastes, particularly when sanitary waste disposal systems are lacking or poorly maintained. In the OLS model, water from taps are strongly associated with lower nitrate levels.

Exploratory spatial data analysis suggests communities in the far eastern part of the region have higher levels of nitrate and this may be a spatial process. Nitrate contamination in one water source does imply that other nearby sources are contaminated with nitrate. OLS results point out that water sources are most adept at explaining water contamination. This analysis cannot provide concrete evidence that urban status, which may directly or indirectly affect water contamination, affects water contamination. However, the residual analysis showed that water source type, development, and commerce correspond to the spatial distribution of nitrate contamination. In other words, these variables explain the spatial context of nitrate in this region. The residual analysis shows that spatial heterogeneity characterizes the process of water contamination in the Central Region of Ghana. In this case, spatial heterogeneity represents a large-scale process that emerged when values of nitrate differ across space.

Poor water quality found in this area of Ghana can be improved with development, especially the expansion of piped water systems. This could play a large role in reducing the risk of childhood diarrhea and other water-borne infectious diseases. Political and economic policies favoring expansion of piped water systems must be continued and strengthened. In addition, household and neighborhood health education research and training programs about water and sanitation must be linked to water system expansion in order to fully realize the potential public health benefits of safer water.

Given that various populations can be affected in different ways, policy makers should be aware that the provision of clean water through municipal systems has not yet yielded the expected health improvements and there is a need for continued construction of water systems to provide a high quality of water to both rural and urban communities. This paper presents a rare opportunity to examine spatial relationships of water contamination in Africa, a continent where collecting such data is rare. I have sought to explore the spatial link of community drinking water sources with the hope of being informative to policy analysts. The results show that improving water deliverance systems and community transportation access is key to bringing safer water to residents, and we must not forget the many residents who live away from the administrative capital. In fact, it might be especially pertinent to pay attention to the dynamics of cities that have high densities but have been ignored in the distribution of wealth since bad water affects more people in those cases.

Figure 1:

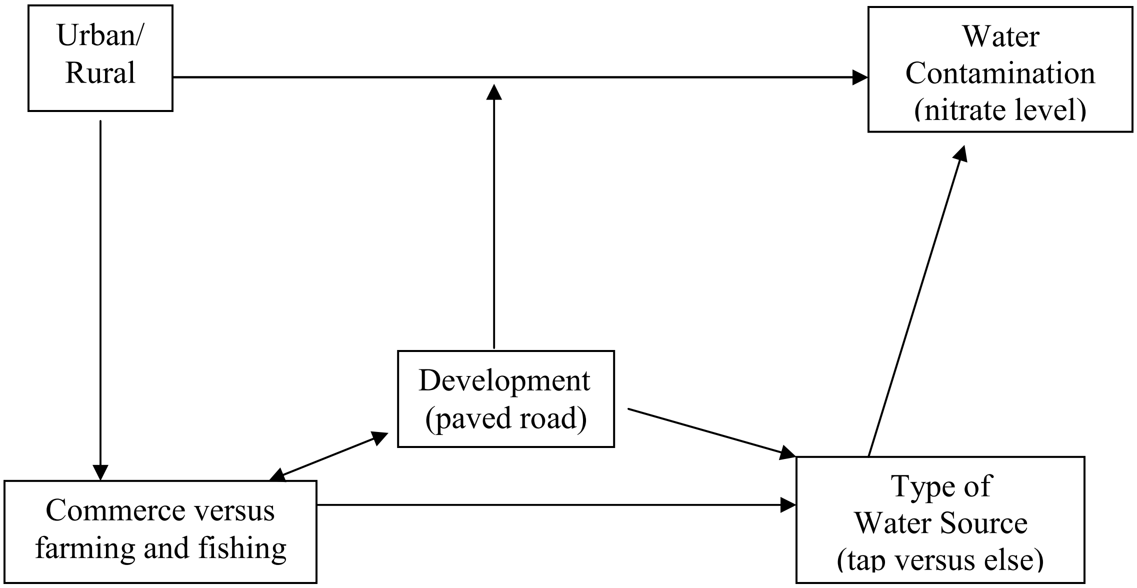

Figure 2: Study Area

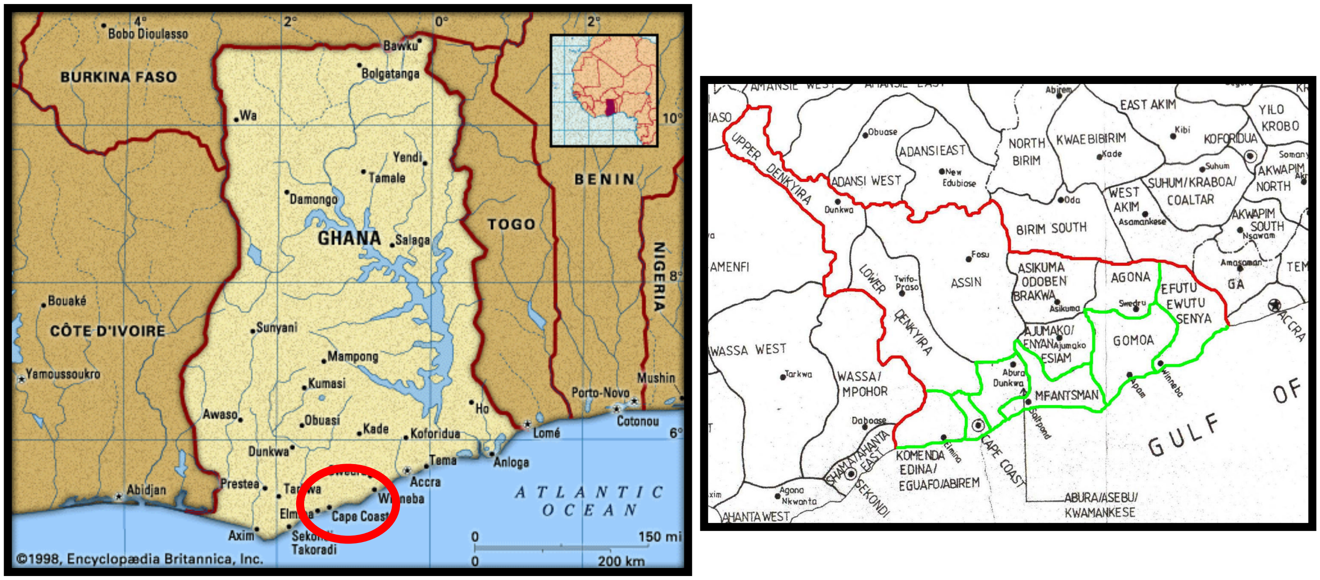

Figure 3:

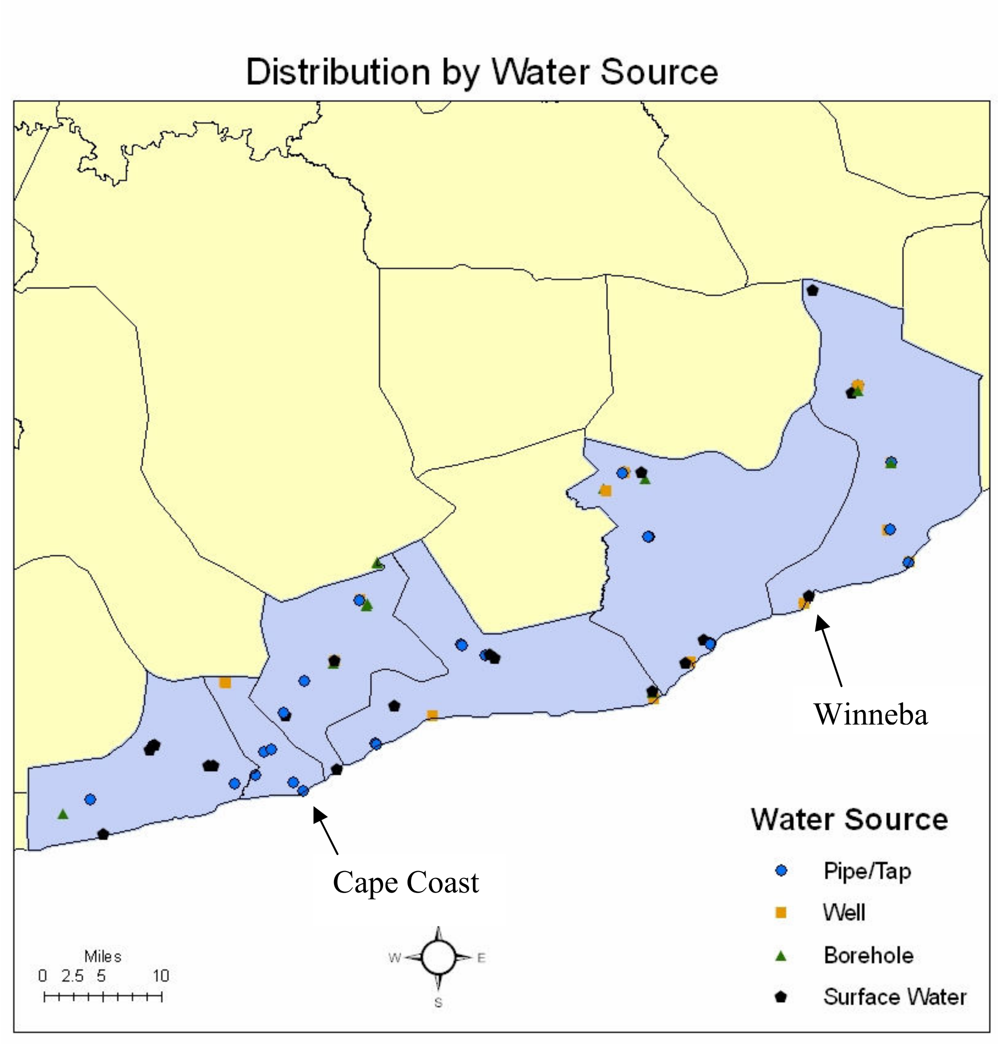
Distribution by Water Source
Winneba
Cape Coast
Water Source
● Pipe/Tap
■ Well
▲ Borehole
⬟ Surface Water
Miles
0 2.5 5 10
W
E
S

Figure 4:

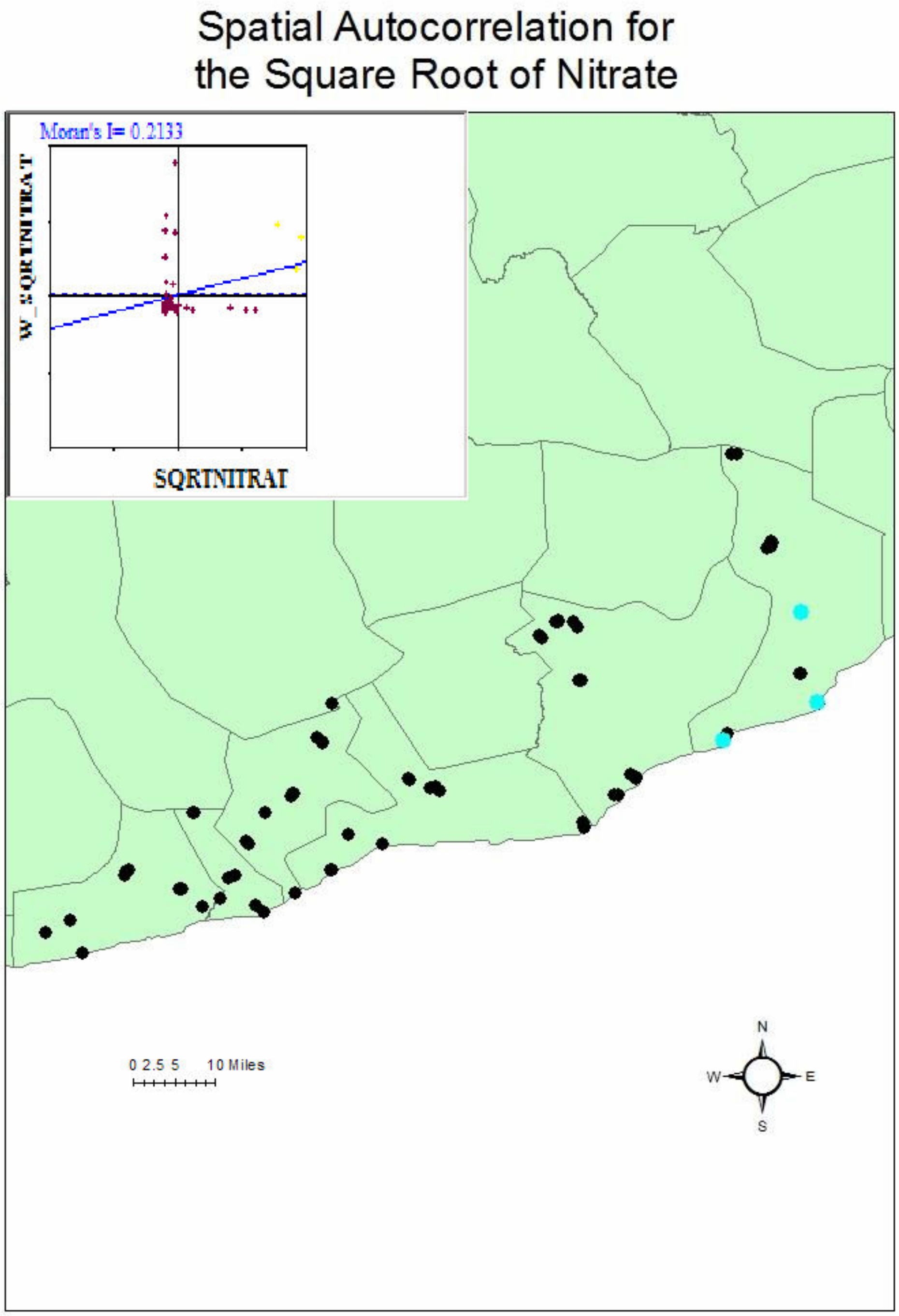
Spatial Autocorrelation for
the Square Root of Nitrate
Moran's I= 0.2133
W_SQRTNITRAT
SQRTNITRAT
0 2.5 5 10 Miles
N
W
E
S

Figure 5:

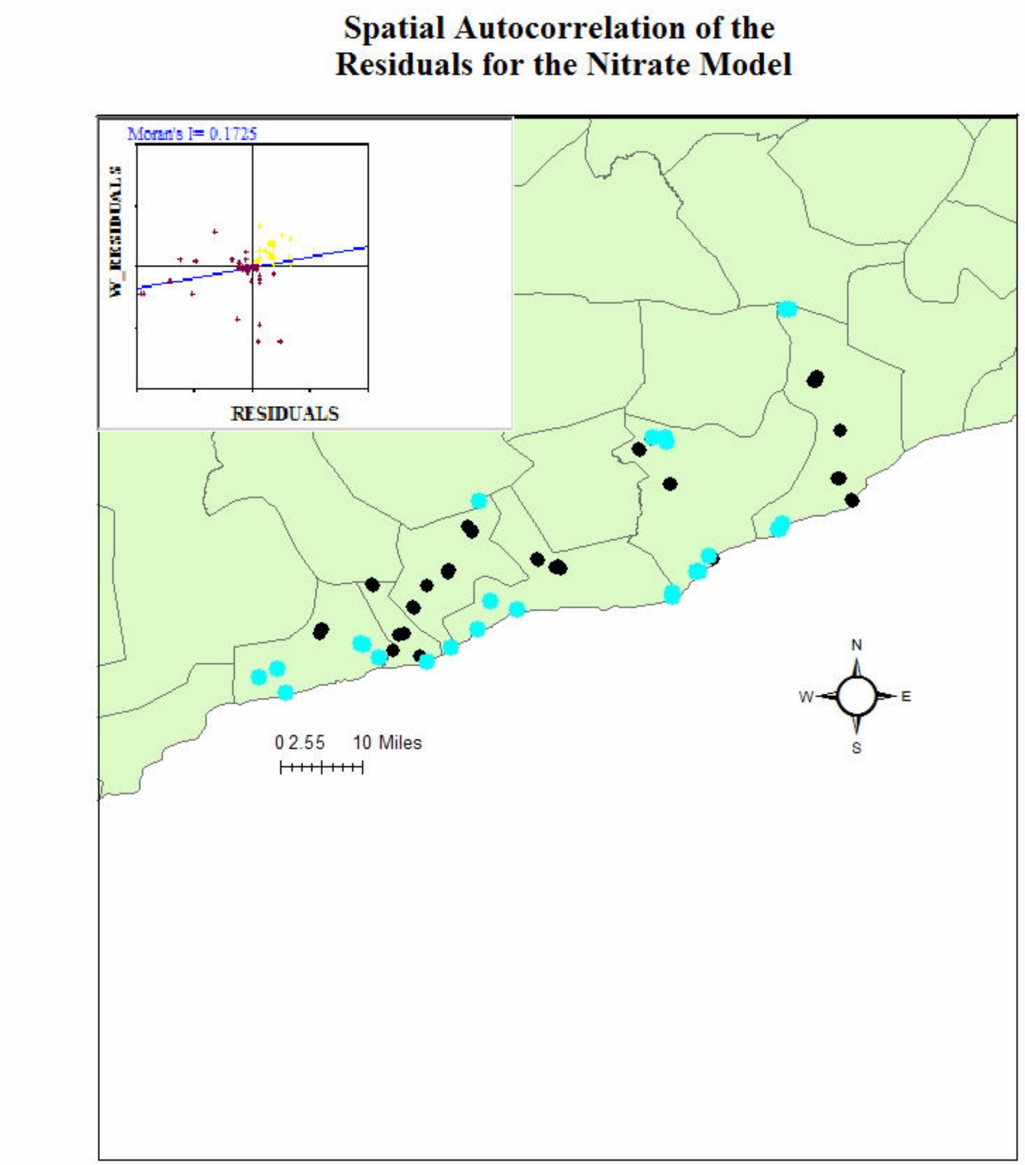
Spatial Autocorrelation of the
Residuals for the Nitrate Model
Moran's I= 0.1725
W_RESIDUALS
RESIDUALS
0 2.55 10 Miles
N
W
E
S

Table 1: Univariate Statistics

Square Root of Nitrate	Mean: 6.90
	Median: 1.11
Percent Above Threshold	9.5%
Square Root of Ammonia	Mean: 1.20
	Median: .54
Percent Above Threshold	13.5%
Water Source Type	
Tap	33.8%
Well	20.2%
Borehole	17.6%
Surface Water	28.4%
Urban	50.0%
Presence of a Year-Round Access Road	86.5%
Commerce is Main Economic Activity	5.4%
Number of Water Sources in Community	
1	17.6%
2	29.7%
3	36.5%
4	16.2%

Table 2: OLS Regression Predicting the Square Root of Nitrate

Independent Variable	Model 1	Model 2	Model 3	Model 4
Constant	9.72***	23.60**	20.31**	19.55**
Water Infrastructure	-7.07**	-6.25**	-6.36**	-2.44
Year Road Present		-15.83	-15.46*	-15.83*
Urban			6.62*	8.75
Commerce			-8.63**	-8.29**
Water Infrastructure x Urban				-7.24
R-Square	0.04	0.13	0.17	0.18
N	74	74	74	74
AIC Score	616.36	612.43	611.52	611.89

***p<.01 **p<.05 *p<.10

note: Water Infrastructure means tap vs. everything else

Table 3: Analysis of OLS Residuals

Model	Moran's I	p-value (999 permutations)
Original MI on Nitrate Levels	0.21	0.04
Water Infrastructure (WI)	0.22	0.02
WI and Development (Dev)	0.14	0.10
WI, Dev, Urban	0.17	0.05
WI, Dev, Urban, Commerce	0.17	0.04
WI, Dev, Urban, Commerce, Interaction	0.20	0.03

References

Anselin, Luc. 1988. *Spatial Econometrics: Methods and Models*. (Dordrecht: Kluwer Academic Publishers), pp. 2-15.

Anselin, Luc. 1989. "What is Special About Spatial Data? Alternative Perspectives on Spatial Data Analysis." *NCGIA Technical Paper 89-4*.

Anselin, Luc. 2002. "Under the Hood: Issues in the Specification and Interpretation of Spatial Regression Models." *Agricultural Economics* 27 , 247-267.

Boadi KO, Kuitunen, M. 2005a. Childhood Diarrhoeal Morbidity in the Accra Metropolitan Area, Ghana: Socio-Economic, Environmental and Behavioral Risk Determinants. Journal of Health and Population in Developing Countries 7 (1):1-13.

Boadi KO, Kuitunen M. 2005b. Environment, wealth inequality and the burden of disease in the Accra metropolitan area, Ghana. Int J Environ Health Res 15 (3): 193-206.

Boadi KO, Kuitunen M. 2005c. Environmental and health impacts of household solid waste handling and disposal practices in thrid world cities: the case of the Accra Metropolitan Area, Ghana. J Environ Health 68 (4): 32-6.

Clasen T, Bastable A. 2003. Faecal contamination of drinking water during collection and household storage: the need to extend protection to the point of use. *J Water Health*. Sep;1(3):109-15.

Clasen TF, Cairncross S. 2004. "Editorial: Household water management: refining the dominant paradigm." *Tropical Medicine and International Health* 9(2):187-191.

Clasen T, Roberts I, Rabie T, Schmidt WP, Cairncross S. 2006. "Interventions to improve water quality for preventing diarrhoea." Cochrane Database Syst Rev. Jul 19;3:CD004794.

Clasen T, Schmidt WP, Rabie T, Roberts I, Cairncross S. 2007. "Interventions to improve water quality for preventing diarrhoea: systematic review and meta-analysis." BMJ. 2007 Mar 12 (Epub).

Dickson KB, Benneh G. 1994. A New Geography of Ghana. London: Longman.

Ghana Statistical Service 2002. 2000 Population and Housing Census: Summary Report of Final Results. Accra, Ghana.

Hinrichsen, D., Robey, B., and Upadhyay, U.D. "Solutions for a Water-Short World." *Population Reports* Series M, No. 14. Baltimore, Johns Hopkins University School of Public Health, Population Information Program, September 1998.

Holton, Conard. 1996. "Nitrate Elimination." *Environmental Health Perspectives* 104 (1): 36-38.

Huttly SR, Morris SS, Pisani V. 1997. Prevention of Diarrhoea in Young Children in Developing Countries. Bulletin World Health Organization. 75(2):163-74.

International Institute for Environment and Development (IIED). 2003. "Water and Sanitation: What will deliver the improvements required for urban areas?" *Environmental and Urbanization Brief-8*, 1-5.

Jagals P, Bokako TC, Grabow W. 1999. Changing Consumer Water-Patterns and their Effect on Microbiological Water Quality As a Result of an Engineering Intervention. Water SA 25 (3): 297-300.

Keraita B, Drechsel P, Amoah P. 2003. "Influence of urban wastewater on stream water quality and agriculture in and around Kumasi, Ghana." *Environment & Urbanization* 15 (2): 171-178.

LeSage, James P. 1997. "Bayesian Estimation of Spatial Autoregressive Models." *International Regional Science Review* 20, 113-129.

LeSage, James P. and Parent, Oliver. 2004. "Bayesian Model Averaging for Spatial Econometric Models." www.spatialeconometrics.com.

Manassaram, Deana M., Backer, Lorraine C., Moll, Deborah M. 2006. "A Review of Nitrates in Drinking Water: Maternal Exposure and Adverse Reproductive and Developmental Outcomes." *Environmental Health Perspectives* 114 (3):320-327.

Moe CL, Sobsey MD, Samsa GP, Mesolo V. 1991. Bacterial Indicators of Risk of Diarrhoeal Disease from Drinking-Water in the Philippines. Bulletin of the World Health Organization 69 (3): 305-317.

O'Loughlin, John, Colin Flint, and Luc Anselin. 1994. "The Geography of the Nazi Vote: Context, Confession, and Class in the Reichstag Election of 1930." *Annals of the Association of American Geographers* 84(3):351-380.

Shier RP, Dollimore N, Ross DA, Binka FN, Quigley M, Smith PG. 1996. Drinking Water Source, Mortality and Diarrhoea Morbidity Among Young Children in Northern Ghana. Tropical Medicine and International Health 1 (3): 334-341.

Soares LC, Griesinger MO, Dachs JN, Bittner MA, Tavares S. 2002. Inequities in access to and use of drinking water services in Latin America and the Caribbean. Rev Panam Salud Publica 11 (506): 386-396.

Steyn M, Jagals P, Genthe B. 2004. Assessment of Microbial Infection Risks Posed by Ingestion of Water during Domestic Water Use and Full-Contact Recreation in a mid-Southern African Region. Water Science and Technology 50 (1): 301-308.

United Nations. 2006. Human Development Report 2006. New York: United Nations Development Programme.

World Health Organization. 2002. World Health Report 2002: Reducing Risks, Promoting Healthy Life. Geneva: World Health Organization.

Wright J, Gundry S, Conroy R. 2004. Household Drinking Water in Developing Countries: A Systematic Review of Microbiological Contamination between Source and Point-of Use. Tropical Medicine and International Health 9 (1): 106-117.