2

Evaluating Spatial and Space-Time Clustering of Cholera in Ashanti-Region-Ghana

Frank B Osei[1], Alfred A Duker[2] and Alfred Stein[3]
[1]*Faculty of Public Health and Allied Sciences, Catholic University College of Ghana, Sunyani*
[2]*Department of Geomatic Engineering, Kwame Nkrumah University of Science and Technology, Kumasi*
[3]*Faculty of Geo-Information Science and Earth Observation (ITC), Twente University*
[1,2]*Ghana*
[3]*Netherlands*

1. Introduction

Basic problems in geographical surveillance for a spatially distributed disease data are the identification of areas of exceptionally high prevalence or clusters, test of their statistical significance, and identification of the reasons behind the elevated prevalence of the disease. Knowledge of the location of high risk areas of diseases and factors leading to such elevated risk is essential to better understand human interaction with its environment, especially when the disease transmission is enhanced by environmental or demographic factors. Cluster analysis provides opportunities for environmental epidemiologist to study associations between demographic and environmental exposures and the spatial distribution of diseases (Myaux et al., 1997; Kulldorff and Nagarwalla, 1995; Besag and Newell, 1991; Kulldorff, 2001; Kulldorff et al., 1998).

Cholera is caused by specific strains of the water borne bacterial *Vibrio cholerae* O1 or O139 (*V. cholerae* here after), following ingestion of infective dose through contaminated water or food (Kelly, 2001). The disease has remained as an important cause of mortality and morbidity in the world, especially in developing tropical countries. African countries report approximately 90% of the world wide cholera cases and deaths (WHO, 2001-2006). In most African countries, the synergy of poverty, high population density, poor sanitation, poor housing, and lack of good water supplies enhance exposure to *V. cholerae*. Despite the prevalence and/or fatality and demographic overlap, little has been studied about the spatial and temporal patterns of cholera in Africa. In Ghana, the disease has been a public health problem since its introduction in the 1970s (Pobee and Grant, 1970). Cholera infection is primarily driven by environmental factors (Ali et al., 2002a, 2002b; Huq et al., 2005), and since environmental processes are spatially continuous in nature (Webster et al., 1994), high incidence rates of the disease are expected to cluster together. A previous study carried out in Ashanti Region used Moran's Index for spatial autocorrelation to explore the existence of clusters of cholera. Also in the above study, empirical Bayesians smoothed rates of cholera

(i.e. visual inspection) revealed possible spatial and temporal clustering of cholera for the 5 year period, i.e. from 1997 to 2001 (Osei and Duker, 2008). However, the exact locations of these cluster, as well as the correlations with some demographic and socioeconomic factors were not systematically investigated. The purpose of this study, however, is to investigate spatial and space-time clusters of cholera in Kumasi. Correlation analysis of cholera rates with demographic factors, i.e. sanitation, drinking water and internal migration are also explored to assess the extent to which these factors might explain high rate clusters of cholera.

This study utilizes the *spatial scan statistic* (Kulldorff, 1997) to detect spatial and space-time clusters of cholera. The spatial scan statistic offers several advantages over other clustering methods: (1) it corrects for multiple comparisons, (2) adjusts for the heterogeneous population densities among the different areas in the study, (3) detects and identifies the location of the clusters without prior specification of their suspected location or size thereby overcoming pre-selection bias, (4) and the method allows for adjustment for covariates. Also Kulldorff's spatial scan statistic is both deterministic (i.e., it identifies the locations of clustering) and inferential (i.e., it allows for hypothesis testing and evaluation of significance). The spatial scan statistic has been used to detect and evaluate various disease clusters including cancer (Michelozzi et al., 2002; Viel et al., 2000; Sheehan and DeChelo, 2005; Hjalmars et al., 1996; Turnbull, 1990, Kulldorff et al., 1998), giardiasis (Odoi et al., 2004) tuberculosis (Tiwari et al., 2006), diabetes (Green et al., 2003), Creutzfeldt-Jacob disease (Cousens, 2001), granulocytic elrlichiosis (Chput et al., 2002), and sclerosis (Sabel et al., 2003). The spatial scan statistic, as implemented in SaTScan software (Kulldorff, 2005; Kulldorff, 2006) has the capabilities of detecting purely spatial clusters, temporal clusters, and space-time clusters.

2. Methods

2.1 Study area

This study was conducted in Ashanti Region, one of the ten regions in Ghana. The region lies between longitudes 0° 9'W and 2° 15'W, and latitudes 5° 30'N and 7° 27'N. The Ashanti Region is dominated by Ashantis, who constitute 14.8% of all Ghanaians by birth. The Ashantis have a great history of culture of which the influence of the Ashanti Kingdom stretches beyond the borders of Ghana. The region occupies a total land area of 24,389 square kilometers representing 10.2% of the total land area of Ghana. The region has a population density of 148.1 persons per square kilometer, which is about two times higher than the overall population density in Ghana. There are 18 administrative districts in the Ashanti region including Kumasi Metropolis of which the capital is Kumasi, and is the only district which has gained a metropolitan status. The Kumasi Metropolis is the most populous district in the region. The 2000 census recorded the region's population as 3,612,950, representing 19.1 per cent of the country's population. The urban population (51.3%) in the region exceeds that of the rural population (48.7%). In-house pit latrines and public toilets, which may be pit, Kumasi ventilated improved pit (KVIP) or bucket latrines, are the main toilet facilities used in the districts. Water closet (WC) is used by small proportions of households, ranging from 0.5 per cent in Ahafo Ano South to 27.8 per cent in

the Kumasi Metropolis. The proportion of the population with access to potable (pipe-borne) water is relatively low in the districts, including the Kumasi Metropolis. A number of factors, particularly high fertility and internal migration, have accounted for the rapid population growth in the region. About two-thirds of the population in the region was born where they were enumerated; the remaining one third are in-migrants to the region. In 6 of the 18 districts, at least seven out of every ten persons were enumerated in the localities in which they were born, indicating that these districts have less in-migrant than other districts in the region (PHC, 2000).

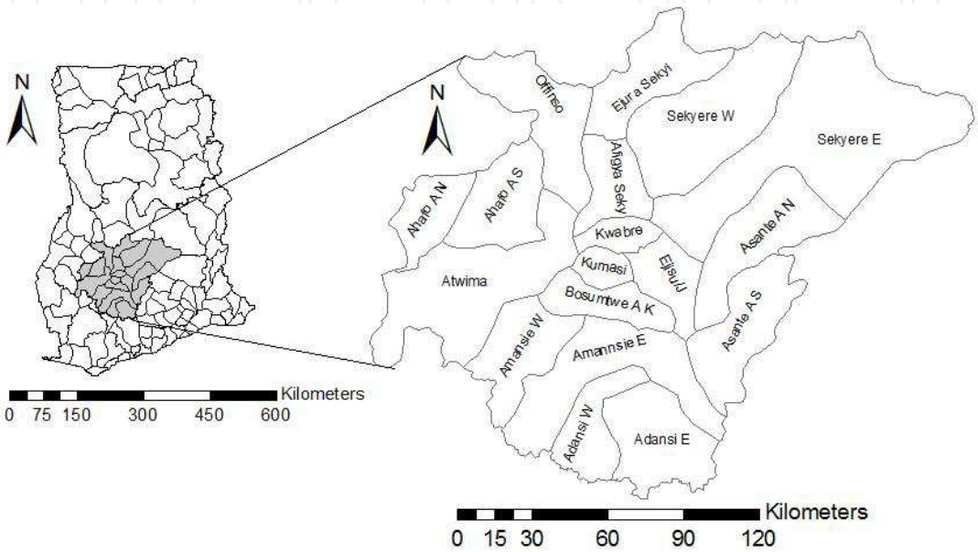

Fig. 1. A map of Ghana showing Ashanti region (in gray color). The figure also shows the spatial distribution of the various districts in Ashanti region

2.2 Data sources

The Ashanti region has a Disease Control Unit (DCU) to which all District Health Directorates (DHD) report suspected outbreaks of various infectious diseases at the end of each year. In this study, all cholera cases used were based on hospital data which were reported to the various DHD. For the detection of statistically significant clusters of cholera, the spatial scan statistic software, SaTScan, developed by Kulldorff, was used. This software requires three main data files to run:

2.2.1 Case file

Case file contains information about cholera cases for specified districts and times. Reported cases of cholera from 1997 to 2001 for each district within the region were retrieved from the DCU. Case definition of cholera was based on the WHO (1993) guidance on formulation of national policy on the control of cholera. According to this guidance, in an area where the disease is not known to be present a case of cholera should be suspected, when a patient, 5 years of age or older develops severe dehydration or dies from acute watery diarrhea, or where an epidemic is occurring, a patient, 5 years of age or older develops acute watery diarrhea, with or without vomiting.

2.2.2 Population file

The population file provides information about the background population at risk for each spatial district. The population database was obtained from the 2000 Population and Housing Census of Ghana conducted by the National Statistical Service (PHC, 2000).

2.2.3 Coordinate file

The coordinate file provides information about the spatial location of each district. In this study, the spatial scale of analysis was at the district level. The centroids of the districts were used as the coordinates of the districts.

2.3 Cluster analysis

The spatial scan statistic was used to detect the presence spatial and space-time clusters of cholera. The spatial scan statistic was developed by Kulldorff (1997, 2006) and it is been implemented in the SaTScan software. Spatial scan statistic has a disadvantage of being difficult to incorporate prior knowledge about the size and shape of an outbreak as well as its impact on disease rate (Neill et al., 2005). However, we used this as an advantage to get rid of pre-selection biases of clusters and their locations. Spatial scan statistic method is based on the principle that the number of cholera cases in a geographic area is Poisson-distributed according to a known underlying population at risk (Kulldorff, 2006). For the detection of purely spatial clusters, SaTScan imposes a circular window on the study region which is moved over the region and centered on the centroid of each district. The size of the circular window, which is also the cluster size, is expressed as a percentage of the total population at risk. This varies from 0 to a maximum (not exceeding 100), as specified by the user. The maximum window size should not exceed 50% of the total population because clusters of larger sizes would indicate areas of exceptionally low rates outside the circle rather than an area of exceptionally high rate within the circle. Possible clusters are tested within the window whenever it is centered on the centroid of each district. Whenever the window finds a new case, the software calculates a likelihood function to test for elevated risk within the window in comparison with those outside the window. The likelihood function for any given window W is proportional to:

$$L(\mathrm{W}) = \sup_{W \in \mathbf{W}} \left(\frac{Chol_{(\mathrm{C})}(W)}{Chol_{(\mathrm{E(C)})}(W)} \right)^{Chol_{(\mathrm{C})}(W)} \left(\frac{Chol_{(\mathrm{C})}(\hat{W})}{Chol_{(\mathrm{E(C)})}(\hat{W})} \right)^{Chol_{(\mathrm{C})}(\hat{W})} \times I\left(\frac{Chol_{(\mathrm{C})}(W)}{Chol_{(\mathrm{E(C)})}(W)} > \frac{Chol_{(\mathrm{C})}(\hat{W})}{Chol_{(\mathrm{E(C)})}(\hat{W})} \right) \quad (1)$$

where $\hat{W}$ indicates all the regions outside the window W, and $Chol_{(\mathrm{C})}(\,)$ and $Chol_{(\mathrm{E(C)})}(\,)$ denote the observed and expected number of cases within the specified window, respectively. The window W to be scanned by the spatial scan statistic is included in the set: $\mathbf{W} = \{W_{ik} | 1 \le i \le m, 1 \le k \le K_i\}$, where W_{ik}, $k = 1,...,K_i$, denote the window composed by the (k −1) nearest neighbors to region i. The window W^* that attains the maximum likelihood is defined as the *most likely cluster* (MLC). The indicator function

$I(\ )$ depends on the comparison between $Chol_{(E(C))}$ and $Chol_{(C)}$. $I(\ )$ is 1 when $Chol_{(C)} > Chol_{(E(C))}$, otherwise 0. The test of significance level of clusters is through the Monte Carlo hypothesis testing (Dwass, 1957). In this study, the maximum window size was set as 50% of the total population. The null hypothesis of no cluster was rejected when the simulated *p-value* was less than or equal to 0.05 for most likely clusters and 0.1 for secondary clusters since the latter have conservative *p-values* (Kulldorff, 2006).

A smaller window size (defined as ≤ 25% of the total population) was also used to investigate the possibility of smaller clusters. This varied from ≤ 25% to ≤ 50% with successive increments of 5%. This was meant to check the sensitivity of spatial scan statistic to smaller window sizes when there are larger spatial units and small number of spatial units.

For the detection of space-time clusters, SaTScan imposes a cylindrical window with a circular geographic base and with height corresponding to the time of occurrences. In this way, the base of the cylinder is centered around one of several possible centroids located throughout the study region with the radius varying continuously in size, whereas the height of the cylinder reflects any possible time interval of less than or equal to half the total study period, as well as the whole study period. The window is then moved in space and time so that for each possible geographic location and size, it also visits each possible time interval (Kulldorf et al., 1998). The likelihood ratio test statistic is constructed in the same way as for the purely spatial scan statistic. However, the computational algorithm for calculating the likelihood for each window is in three rather than two dimensions (Kulldorff, 2001). Here, we used a spatial window that could include up to 50% of population at risk and a maximum temporal window of 50%, without including purely spatial clusters. Moreover, most likely clusters for different time lengths (i.e. 1, 2, 3, or 4 year length) were scanned using a temporal cluster size of 90% of the study period and also included purely spatial clusters with temporal size of 100%. The maximum spatial cluster size was set at 50% of population at risk and included purely temporal clusters (spatial cluster size = 100%) as well.

2.4 Correlation between cholera and risk factors

Three main risk factors, i.e. sanitation, source of drinking water, and internal migration, were used to explore the extent at which these variables affect cholera prevalence within the study area. These were obtained from the 2000 Population and Housing census of Ghana (PHC, 2000). Four different types of sanitation facilities are used in the study area; WC, Pit latrine, KVIP, bucket or pan. A number of households in the districts have no access to toilet facilities. When a substantial number of households do not have toilet facilities, it is to be expected that inhabitants will defecate in the bush, drains, etc. Bucket or pan is the most unsafe sanitation method because the bucket is open and can attract filth breeding flies. Moreover, faeces have to be transferred to a different bucket when it is full; thus faeces can spread to nearby areas in the course of transfer. In this study, sanitation condition for a district is described as the percentage of the district's share of the region's population who do not have access to toilet facilities, and who use bucket or pan sanitation method. For this, larger values reflect poor or bad sanitation condition, while smaller values reflect good sanitation condition.

Since the natural reservoir of cholera is the aquatic environment, inhabitants who drink from wells, streams, rivers, ponds, dugouts and dams are assumed to be at a higher risk of cholera than those who drink from pipe borne water. Therefore, inhabitants who drink from wells, streams, rivers, ponds, dugouts and dams are classified as inhabitants who do not have access to potable water. The indicator for drinking water for each district was computed as the percentage of the district's share of the region's population who drink from wells, streams, rivers, ponds, dugouts and dams.

Internal migration is one of the important demographic characteristics that accounts for rapid population growth in a place. This variable was computed as a percentage of the district's share of the region's population in the year 2000 that were born outside the district during the time of enumeration.

Global Pearson's correlation coefficient was used to determine the correlation between cholera cumulative incidence rates from 1997 to 2001 and sanitation, drinking water, and internal migration. *P-values* were calculated to serve as a guide to access the significance of all correlation coefficients. Most health planning strategies in Ghana are based on the level of urbanization of a district. In other words, groups of districts with similar urbanization levels are planned together. With this in mind, all districts in the study region were stratified according to the level of urbanization; i.e. *low, medium and high*. Pearson's correlation analyses were repeated for each stratum of districts in order to assess the effects of the risk factors on cholera within each urbanization stratum.

3. Results and analyses

3.1 Purely spatial clusters

No cluster was detected for the years 1997 and 2000 since very few cases were reported for these years. Only most likely significant clusters were detected for the years 1998, 1999, 2001 (Table 1 and Figure 2). These clusters encompassed Kumasi, Bosumtwe AK and Kwabre in 1998 (relative risk $Chol_{(RR)} = 12.25$, $Chol_{(C)} = 733$, $Chol_{(E(C))} = 328.62$), Kumasi in 1999 ($Chol_{(RR)} = 7.42$, $Chol_{(C)} = 1033$, $Chol_{(E(C))} = 421.33$), Kumasi and Kwabre in 2001($Chol_{(RR)} = 15.60$, $Chol_{(C)} = 956$, $Chol_{(E(C))} = 383.32$), and Kumasi and Kwabre from 1998 to 2001($Chol_{(RR)} = 9.70$, $Chol_{(C)} = 2727$, $Chol_{(E(C))} = 1161.47$). No differences were observed between the results of the varying window sizes and the window size of ≤ 50% of the total population. Hence tables for these results are not shown.

3.2 Space-time clusters

While testing whether the purely spatial clusters were long term or temporary i.e. space-time analysis, a statistically significant (p = 0.001) most likely cluster was identified at Kumasi metropolis for the year 1998-1999. This cluster has $Chol_{(RR)} = 5.86$ with $Chol_{(C)} = 1668$ as against $Chol_{(E(C))} = 508.75$ (See Table 2). One statistically significant (P = 0.001) secondary cluster encompassing 3 districts (Ahafo Ano North, Ahafo Ano South, and Atwima) was detected for 1999. For this cluster $Chol_{(RR)} = 1.91$ and $Chol_{(C)} = 179$ as against $Chol_{(E(C))} = 96.34$.

Cluster Area	*Chol*$_{(C)}$	*Chol*$_{(E(C))}$	*Chol*$_{(RR)}$	LLR	*p-value*
Year: 1998					
Kumasi					
Kwabre	733	328.62	12.253	434.73	0.001
Bosumtwe AK					
Year: 1999					
Kumasi	1033	421.23	7.42	592.29	0.001
Year: 2001					
Kumasi					
Kwabre	956	383.32	15.597	673.86	0.001
Year: 1997-2001					
Kumasi					
Kwabre	2727	1161.47	9.699	1618.26	0.001

Table 1. Most likely purely spatial clusters of cholera in Ashanti region, Ghana, detected by retrospective spatial analysis. This Table shows the results of the purely spatial cluster analysis using a spatial window that could include up to 50% of the population at risk in Ashanti region, Ghana, during 1998-2001: LLR (Log Likelihood Ratio)

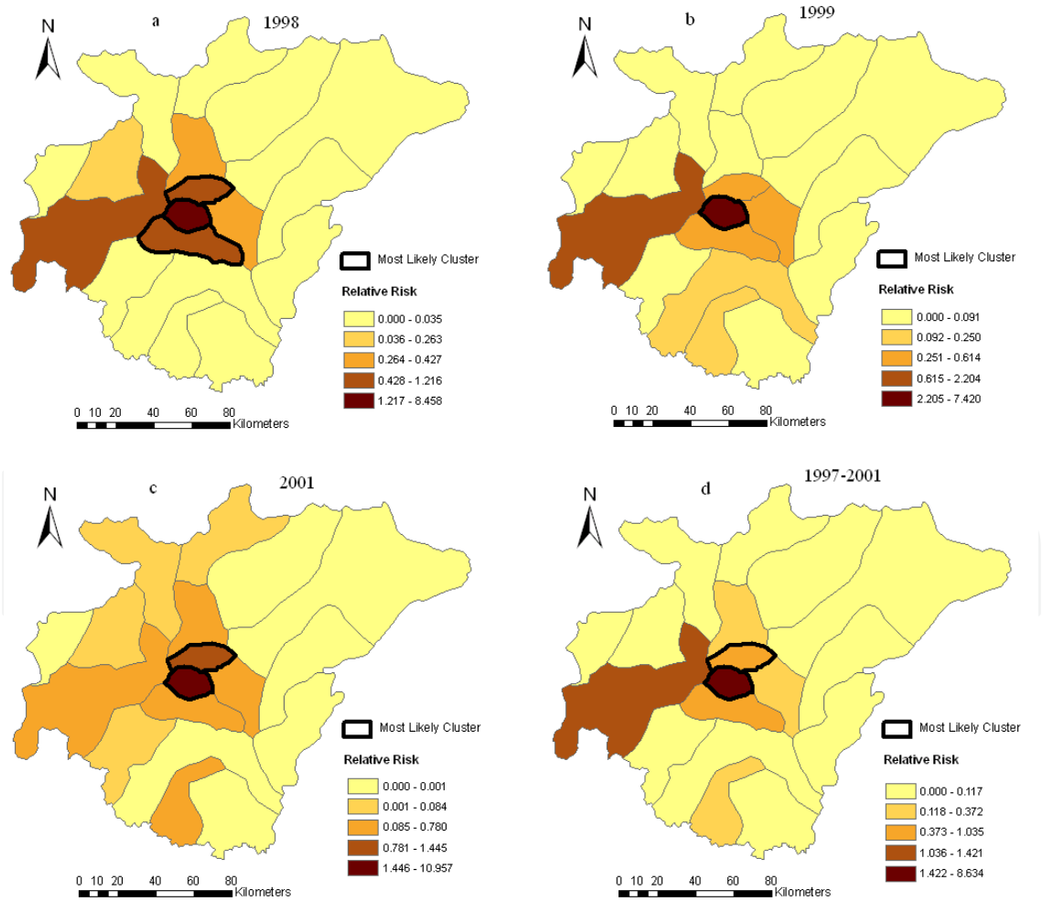

Fig. 2. Locations of the detected clusters of cholera and spatial distribution of the relative risks for 1998(2a), 1999(2b), 2001 (2c), and 1998-2001 (2c)

Cluster Area	Year	$Chol_{(C)}$	$Chol_{(E(C))}$	$Chol_{(RR)}$	LLR	*p-value*
Most Likely Cluster						
1. Kumasi Metro	1998-1999	1688	508.75	5.86	1149.02	0.001
Secondary Cluster						
2. Ahafo Ano North Ahafo Ano South Atwima	1999	179	96.34	1.908	29.34	0.001

Table 2. Significant high rate spatial clusters of cholera in Ashanti region, Ghana, detected by retrospective space-time analysis. This Table shows the results of the space-time cluster analysis using a spatial window that could include up to 50% of the population at risk and a maximum temporal window of 50% without including purely spatial clusters, in Ashanti region, Ghana, during 1998-2001: LLR (Log Likelihood Ratio).

The results of the space-time analysis when modified, i.e. when using a maximum temporal window of 90% (which included purely spatial clusters as well) and a spatial window that could include up to 50% of the population at risk (which included purely temporal clusters also) are shown in Table 3. Most likely statically significant (p = 0.001) cluster of high rates of cholera was again found to exist at the Kumasi Metropolis and Kwabre district for the year 1998-2001. This indicates that Kumasi Metropolis and Kwabre remained statistically significant throughout the year 1998-2001. One statistically significant (p = 0.001) secondary cluster encompassing Ahafo Ano South, Ahafo Ano North and Atwima for the year 1999 was also detected.

Cluster Area	Year	$Chol_{(C)}$	$Chol_{(E(C))}$	$Chol_{(RR)}$	LLR	*p-value*
Most Likely Cluster						
1. Kumasi Metro Kwabre	1998-2001	2727	1161.47	9.699	1618.26	0.001
Secondary Cluster						
2. Ahafo Ano North Ahafo Ano South Atwima	1999	179	96.34	1.91	29.33	0.001

Table 3. Significant high rate spatial clusters of cholera in Ashanti region, Ghana, detected by retrospective space-time analysis. This Table shows the results of the space-time cluster analysis when modified to find 1, 2, 3 or 4-year length clusters using a maximum temporal window of 90%, which included purely spatial clusters as well, and a spatial window of ≤50% of the population at risk, which included purely temporal clusters also, in Ashanti region, Ghana, during 1997-2001: LLR (Log Likelihood Ratio)

3.3 Correlation between cholera and risk factors

Pearson's correlation coefficients and their associated p-values were computed to determine the relationship between cholera cumulative incidence rate and the demographic risk factors (see Table 4). For the whole region, statistically significant relationship was observed for sanitation ($R^2 = 0.55$, $p = 0.001$), drinking water ($R^2 = 0.39$, $p = 0.001$), and internal migration ($R^2 = 0.73$, $p = 0.001$). However, when the analyses were repeated for each strata of urbanization, statistically significant correlations were observed for only the *high* urban

strata (See Table 2). For instance there was a high, but non-significant correlation between cholera and drinking water within the *medium-urban* strata ($R^2 = 0.62$, $p = 0.12$), and no significant correlation between cholera and drinking water within the *low-urban* strata ($R^2 = 0.001$, $p = 0.96$). However, there was a high and significant correlation between cholera and drinking water within the *high-urban* strata ($R^2 = 0.86$, $p = 0.007$).

	Correlation and (*p-value*)		
	Sanitation	Drinking water	Migration
Global	[a]0.55 (0.001)	[a]0.39 (0.001)	[a]0.73 (0.001)
Low urban	[c]0.21 (0.36)	[c]0.04(0.66)	[c]0.001 (0.96)
Moderate urban	[c]0.48 (0.13)	[c]0.62 (0.12)	[c] 0.62 (0.11)
High urban	[b]0.86 (0.007)	[b]0.79 (0.018)	[b]0.89 (0.005)

Table 4. Pearson's correlation coefficients for the relationship between cholera and demographic factors. This Table depicts both the Global Pearson's correlation analyses, and Pearson's correlation analyses for each urbanization strata of districts. The associated *p–values* are shown in brackets. *[a]significant correlations at 0.1% significance level; [b]significant correlations at 5% significance level. [c]not significant*.

4. Discussion

In this study, the purely spatial and space-time scan statistic methods implemented in SaTScan software have been used to analyze cholera cases from 1998 to 2001 in Kumasi, Ghana. These methods identifies whether unusual concentration of disease cases can be explained by chance or statistically significant. The findings of this study reveal several notable points. First, there is the existence of both purely spatial and space-time clusters, not explainable by chance (See Tables 1,2, and 3). Also, the results of both the purely spatial and space-time analysis are somewhat similar. In particular, the purely spatial analysis reported an excess incidence of cholera in Kumasi during the years 1998, 1999, and 2001 (See Table 3.1 and Figure 3.2), and the space-time analysis also reported an excess incidence of cholera from 1999 to 2001 at the same area.

Second, the excess incidence of cholera mainly existed at Kumasi Metropolis throughout the period under study. Specifically, the purely spatial analysis reported excess incidence of cholera at Kumasi in 1998, 1999, and 2001. While testing whether the purely spatial clusters were long term or temporary, the space-time analysis also reported excess incidence of cholera at Kumasi Metropolis from the year 1999 to 2001. When the space-time analysis was modified to detect 1, 2, 3, 4, or 5 year length clusters, the space-time most likely cluster at Kumasi Metropolis became a purely spatial cluster (i.e. existed for 1997 to 2001, see Table 3). This indicates a sustained transmission of cholera at Kumasi Metropolis from 1997 through to 2001. Two main reasons may explain these patterns. (1) *Demographic status*: Kumasi is the most urbanized and highly commercialized district in Ashanti region, and therefore there is always a high daily influx of traders and civil workers from neighboring districts to Kumasi Metropolis. Such a high daily influx strain existing sanitation systems, thereby putting people at increased risk of cholera transmission. The rural poor also often migrate to city centers with the hope of a better life. However, due to the high cost of housing, such

migrants settle at slummy and/or squatter areas where environmental sanitation is poor. This largely explains the high *northern population* (inhabitants from the northern sector of Ghana; which is the most deprived sector) within Kumasi Metropolis. (2) *Geographic location*: Kumasi Metropolis is the central nodal district of Ghana, and therefore, all road networks linking the northern sector and the southern sector of Ghana pass through Kumasi. There is the high probability of stoppage and transit by travelers, resulting in a high daily population increase and overcrowding at city centers.

Third, the findings of the space-time analysis clearly depict the statistical power of the scan statistic for detecting recently emerging clusters. The space-time analysis detected an important cluster during the year 1999 that would otherwise not be detected by a purely spatial analysis. This cluster encompassed areas surrounding Ahafo Ano North, Ahafo Ano South, and Atwima districts (See Tables 2 and 3).

Fourth, both the purely spatial and space-time cluster analysis detected no cluster during the years 1997 and 2000. This is somewhat consistent with both the overall global and national cholera trends. Although officially notified cases do not reflect the overall burden of the diseases, cholera cases reported to WHO in 1996 was 4.4 times higher than cases in 1997 (a decrease of 77% from 1996 to 1997), and cases in 1998 was 9 times higher than cases in 1997(an increase of 80.3% from 1997 to 1998). Compared to 1999, the year 2000 saw 46% global reduction in the total number of cases, and about 65% reduction in the total number of cases reported in Ghana. After a massive outbreak in Ghana from 1998 to 1999, health officials and policy makers implemented several measures to curb the menace. Notable among these measures were effective waste collection and disposal (including solid waste, sewage, industrial and clinical waste), cleansing of public areas, food hygiene, hygiene education and related programs. Consequently, the reduced number of cholera cases in the year 2000.

When the maximum window size was varied from ≤ 25% to ≤ 50% of the total population, the same results were obtained as with the window size of ≤ 50% of the total population. This clearly shows that for large geographical scales with fewer spatial units, spatial scan statistic will likely not be sensitive to varying window size. Chen et al. (2008) clearly demonstrated the sensitivity of the spatial scan statistic to the issues of varying window sizes (SaTScan scaling issues) through a geo-visual analytic technique. Their study was partly a quest to determine an optimal setting for SaTScan scaling parameters due to the confusing and even misleading results which are possible if the parameter choices are made arbitrarily. However, their data was across larger spatial geographical area with larger number of spatial units; giving SaTScan much flexibility on the varying window sizes. Contrary to our data used, there were only 18 spatial units; a number probably too small for spatial scan statistic. Therefore the interpretation of our findings should fall within the framework of the above limitation.

The findings of the correlations analysis suggest that cholera is high when majority of the people do not have access to good sanitation facilities; do not have access to potable water; and when internal migration is high. When the correlation analyses were repeated for each strata of urbanization, statistically significant correlations were observed for only the *high-urban* strata. Considering drinking water for instance, there was no significant correlation within the *low-urban* strata and the *medium-urban* strata, but a high significant correlation was observed within the *high-urban* strata (See Table 4). This implies that drinking water, sanitation and

internal migration affect only *high-urban* communities in the study area. This is consistent with the findings of the cluster analysis. Both the purely spatial and space-time analysis identified Kumasi Metropolis and Kwabre district as significant high rate clusters of cholera, which are also amongst the most urbanized and overcrowded areas in Ashanti Region.

Cholera primarily attack individuals with insufficient knowledge of and inappropriate attitudes towards hygienic practices, and who live in dwellings that lack access to safe drinking water supply and to adequate facilities for sanitation, sewerage disposal and treatment (Glass and Black, 1992). Majority of the region's population who do not have access to good sanitation systems, and drink from rivers, streams and ponds are people living in most urbanized and densely populated districts. For instance, Kumasi metropolis's share of the region's population who do not have access to potable water is close to 13%, a value 2.3 times higher than the mean percentage.

Fecal contamination of rivers is a major water quality issue in many fast growing cities like the Kumasi Metropolis where population growth far exceeds the rate of development of wastewater collection and treatment. The water bodies near densely populated areas may have high fecal concentrations due to defecation and sanitation practices of the people. Ali et al. (2002a) has asserted that fecal contamination of surface water in densely populated area is higher than a sparsely populated area. Although Kumasi Metropolis and other urbanized districts are served with potable water, this water does not flow throughout the year. At certain times no water flow for a period of a week or two. Residents are therefore compelled to exploit nearby streams, rivers and ponds. If such water bodies are contaminated and is used for drinking or cooking, there is the likelihood of infection.

After several decades of research into cholera, the risk factors which contribute to its transmission have not changed. The spatial and temporal patterns that the disease displays, however, are not the same from one outbreak area to another. Although several of the findings of this research are more confirmatory, it draws the attention of health officials and policymakers about the area where there has been sustained transmission of the disease over the years. The study also provides very useful information to health officials and policymaker about the spatial and temporal patterns of cholera in Ghana. For example, this study clearly shows that there has been a sustained transmission of cholera in Kumasi during the period under study. The findings of this study will also have important implications for public health officials since control strategies would vary depending on the most important risk factors in most important districts. With the important high rate cluster locations and risk factors identified, optimal efforts can be taken at appropriate districts to prevent and control cholera. There is no doubt that the fecal oral route of cholera transmission should be of primary concern because of its importance in the development of secondary cases and in subsequent spread of the disease. It should therefore be the concern of health officials and policymakers to provide better sanitation systems to prevent fecal contamination of water bodies within *high-urban* districts. Moreover, potable (pipe-borne) water supply in urban and densely populated districts should be expanded and improved to prevent cholera outbreaks.

5. Conclusion

This study has shown the presence of both spatial and space-time hotspots of cholera in Ashanti region, suggesting that there has been sustained transmission of cholera within

these hotspots. The study has also shown that drinking water, sanitation and internal migration are important risk factors of cholera in Ashanti region; however, these predictors do not have a significant impact in cholera transmission in low urban communities. This study has also demonstrated that using available health data, GIS and spatial scan statistic can provide public health officials in Ghana with new knowledge about the prevalence rate and hotspots of a disease. This new knowledge will help them to come out with optimal strategies to prevent and contain diseases outbreak. Of the three risk factors studied, the effect of internal migration on cholera is comparatively high. Measures to reduce internal migration can reduce pressure on sanitation and water supply systems. Since the studied risk factors could not explain cholera prevalence in low urban areas, a more detailed research needs to be carried out at individual levels to thoroughly understand the epidemiology of cholera in the study area.

6. Acknowledgements

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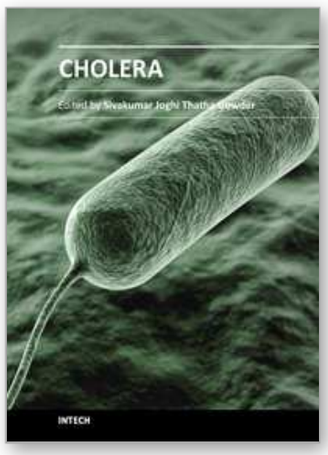

Cholera

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Cholera, a problem in Third World countries, is a complicated diarrheal disease caused by the bacterium Vibrio cholerae. The latest outbreak in Haiti and surrounding areas in 2010 illustrated that cholera remains a serious threat to public health and safety. With advancements in research, cholera can be prevented and effectively treated. Irrespective of "Military" or "Monetary" power, with one's "Own Power", we can defeat this disease. The book "Cholera" is a valuable resource of power (knowledge) not only for cholera researchers but for anyone interested in promoting the health of people. Experts from different parts of the world have contributed to this important work thereby generating this power. Key features include the history of cholera, geographical distribution of the disease, mode of transmission, Vibrio cholerae activities, characterization of cholera toxin, cholera antagonists and preventive measures.

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