Spatial Analysis of Public Health Data in Ghana: a case study of exploratory spatial analysis of Diarrhoea

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Abstract
Background: Diarrhoea is a public health burden amongst the top five causes of premature death and disability-adjusted life years in the tropical regions. In Ghana, diarrhoea has been identified as the second most common health problems treated in outpatient visits. Evaluations of diarrhea prevention efforts suggested that the best prevention strategies of diarrhoea may vary by location. For this reason, spatial statistical tools such as Geographical Information System (GIS) has been applied expansively in health research to improve public health since 1980s. There are, however, extremely few of such studies in Ghana and there had not been any known nationwide study of the spatial distribution of diarrhoea in Ghana. In this study, we aimed to use exploratory spatial analysis techniques of GIS to assess the spatial epidemiological distribution of diarrhoea in Ghana and to locate the hotspot areas that need further focused public health interventions.
Method: The outpatient department morbidity data of diarrhoea cases over the periods of 2010 to 2014 was obtained from Ghana Health Service and geo-coded using ArcGIS 10.1 according to the 170 administrative districts of Ghana. Incidence rates were estimated and spatially smoothen with Empirical Bayesian Smoothing (EBS) technique to avoid unbiased visual interpretation. The EBS rates were mapped and classified using defined interval classification system. Global Moran's I and the Anselin Local Moran's I were computed with ArcGIS to respectively test for the evidence of space-time variation in the incidence of diarrhoea and to identify areas of relatively high and/or low rates.
Results: This study described the spatial distribution of diarrhoeal infection by assessing the global and local occurrence of the incidence rates of diarrhoea at district levels in Ghana. Mapping the smoothed incidence rates of diarrhoea geo-visually pointed spatial patterns and with generally increasing rates over the years 2010 to 2014. Evaluating the observed non-random spatial patterns, the global Moran's I confirmed significant geographical epidemiological patterns with significant spatial clustering (Moran's $I > 0$, $Z > 1.96$, $p < 0.05$). These spatial patterns were decreasing spatio-temporally from 2010 to 2013 but suddenly increased to the highest clustering in 2014. Cluster-outlier analysis with local Moran's I_i spatio-temporally identified a number of areas with statistically significant measures of relatively high and/or low clustering of rates.
Conclusion: The results of the exploratory spatial analysis disclosed the grave necessity of spatial analysis to improve public health, surveillance and disease prevention strategies in Ghana. The rate of diarrhoea still remains very high in Ghana with significant geographical and temporal variations. This suggests possible inequalities in healthcare services and health intervention programmes and relatively more risk factors in some areas. This study also suggests that diarrhea prevention strategies should be location-specific, while considering the neighbouring locations. The few identified hotspot districts with the most likely endemic clusters of diarrhoea cases need extra health intervention programmes and prioritisation.
Keywords: Spatial epidemiology, diarrhoea, hotspot, spatial analysis, Geographical Information System (GIS), Moran's I, Ghana

BACKGROUND

Diarrhoeal diseases are gastrointestinal infections caused by a wide range of pathogens: rotavirus, *Escherichia coli, Shigella, Campylobacter, Salmonella* and *Vibrio cholerae,* and *Cryptosporidium* [1, 2]. Diarrhoea is a clinical sign which involves having loose or watery stools at least three times per day, or more frequently than normal for an individual. Diarrhoea kills more children than AIDS and malaria combined and is globally the second leading cause of death in children under five years old **[1,3]** and was reported in 2014 Global Burden of Disease study [4] to be amongst the top five causes of premature death and disability-adjusted life years in the tropical region [5].The mechanism of transmission of diarrhoeal diseases clearly indicates that diarrhoea is a disease of poor hygiene and sanitation; transmitted faecal-orally. The pathogens of diarrhoea in human or animal faeces are inadvertently ingested by way of stool to food or water [2].

The health statistics of Ghana indicated that diarrhoea accounts for 84 000 deaths annually in Ghana with 25% of these being children under 5 years[6]. In recent years, there has been a decline in mortality rates of diarrhoea but this is not parallel to morbidity rates, especially in developing countries [7,8]. The morbidity of diarrhoea in Ghana remains very high and has been identified as the second most common health problems treated in outpatient visits in Ghana. In the Tamale metropolis of Ghana, diarrhoea accounted for 5.8% and 7.2% of outpatients treatments in 2003 and 2004 respectively [9]. A study conducted by Osam –Tewiah [10] from the Princess Marie Louis Hospital in Accra reported that 29.94% of out-patients visit to the hospital were due to diarrhoea. In 2004, Korle Bu Teaching Hospital (KBTH) Polyclinic reported 4,624 cases and 243 children with acute diarrhoea between November 2005 and January 2006 [8]. Dzotsi *et al* [7] investigated reported diarrhoeal cases at two pilot sites (Korle-Bu Polyclinic and Maamobi General Hospital) in the capital city of Ghana, Accra, following the epidemic outbreak of cholera in 2011. Their study exposed a total of 361 diarrhoeal cases with 5 deaths (4 deaths due to *Vibrio cholerae* and 1 from *Salmonella* infection) between January and June 2012. Cholera has been implicated in most diarrhoea cases in Ghana with the first cholera epidemic in 1970/71. The years thereafter experienced protracted outbreaks of 15,032 cases in 1982(the highest number of cases recorded in a single year); 10,628 cases with 105 deaths in 2011; 9,542 cases with 100 deaths in 2012; 22 cases with no death in 2013; 16,527 cases with 128 deaths as at 14 September 2014. According to WHO, between 1970 and 2012, Ghana recorded 5498 cholera deaths [11,12]. The recent publication of WHO in May 2014 reported diarrhoeal diseases death in Ghana to be 7,589 or 4.05% of total deaths, and the age adjusted death was 29.83 per 100,000 of the population, ranking Ghana as 45th position globally [13].

The location of people can be of great importance in identifying the patterns of diseases in order to uncover the factors governing the space-time epidemiology of diseases [14, 15]. As the principal scientific discipline to understand the causes and consequences of spatial heterogeneity in infections, application of spatial statistical techniques and GIS to improve public health had been acknowledged since 1980s and 1990s [14, 16, 17]. Although the causes of diarrhoea are well understood, evaluations of diarrhea prevention efforts have produced divergent results, suggesting that the best prevention strategies may vary by location and that there is a great need for research on the effectiveness of diarrhea interventions in specific contexts and locations [8]. This is because confounding effects of several environmental factors and cultural practices relate to diarrhoea infection. A good number of studies such as Bessong *et al.,*[18], Dangendorf *et al.,* [19], Chaikaew *et al.,*[20], Osei *et al*, [21], Ruiz-Moreno *et al*, [22], Fernandez *et al*, [23] and many more applied spatial statistical methods to public health and clinical data to uncover the hidden phenomena in the distribution of diarrhoea and risk factors to enhance public health administration and surveillance.

However, there had not been any known nationwide study to evaluate the spatial epidemiology of diarrhoea in Ghana. The only known closely similar study conducted in Ghana was carried out by Appiah *et al*, [24] on the spatio-temporal modeling of malaria incidence in Ghana, spatial statistics of cholera epidemic data by Osei [25] but this one was just in Ashanti region of Ghana and Bayesian spatial analysis of census data for under-five mortality and the environment in Ghana by Arku *et al* [26]. Thus spatial epidemiological studies are actually extremely limited in health researches in Ghana and this limitation was acknowledged by the few Ghanaian authors as well. It is evident in literatures that spatial analysis in health researches is very helpful for optimal public health planning and administration and will be beneficial in addressing the high burden of diarrhoea in Ghana. Hence the aim of this paper was to use the spatial data analysis technique of GIS to assess the spatial epidemiological overview and patterns of diarrhoeal diseases in Ghana. Besides serving as a pre-requisite for further vigorous spatial epidemiological studies of diarrhoea, the study was also intended to indicate that despite the high nationwide burden of diarrhoea cases, there were geographical variations with some areas experiencing relatively elevated burden (hotspots) that need extra public health interventions and priorities. The following spatial epidemiological research questions were hereafter proposed:
Does the incidence of diarrhoeal disease in Ghana form geographical epidemiological patterns?
Are there areas with relatively accumulated rates of Diarrhoea (hotspots)?

MATERIALS AND METHODS

Description of the study area

The Republic of Ghana, centrally located on the West Coast of African, with Accra as the capital city has *latitude and longitude* of 8° 00' N and 2° 00' W respectively. It has a total land area of 238,589 km^2 and bordered by three French-speaking countries: Cote d'Ivoire, Togo and Burkina Faso [27].The Gulf of Guinea and the Atlantic Ocean on the south forms a coastline extending 560 km. With varying temperatures and rainfall, Ghana has average annual temperature of about 26ºC (79ºF) and with two distinct rainy seasons. Annual rainfall ranges from about 1,015 millimetres (40 inches) in the north to about 2,030 millimetres (80 inches) in the southwest [28]. The country consists of ten administrative regions, subdivided into presently 216 districts (but 170 districts for the 2010 census) for effective administration at the local levels. From the 2010 census, the population of

Ghana was 24,658,823 with a population growth rate of 2.4 percent. About 40% of the population are under 15 years of age and close to 50% living in urban areas. The projected population by the Ghana Statistical Service (GSS) as the end of 2014 was 27,043,093. Ghana has several ethnic groups with different socio-cultural practices [27, 29].

Data collection

The spatial scale of analysis in this study was the 170 administrative districts of Ghana on which the 2010 census was conducted. The 170 districts and 10 regional administrative boundary maps and shapefile were obtained from Survey and Mapping Divisions (SMD), Accra and the Geomatic department of KNUST. The population data of the 170 districts were obtained from the 2010 census conducted by the GSS for the 2011 to 2014 population projections. The diarrhoeal diseases morbidity data from the outpatient department (OPD) visits within 2010 to 2014 were obtained from Centre for Health Information and Management (CHIM) of Ghana Health Service (GHS). A morbidity case is defined as a visit at an OPD of a health facility and clinically diagnosed of a diarrhoeal disease [24]

Spatial data preparation

The cartographic display of the 170 districts polygons were generated by extracting the coordinates of the digitised boundary map into a National Grid, Ghana Metre-Grid Universal Transverse Mercator (UTM) coordinates system using ArcGIS version 10.1, a GIS software developed by Environmental System Research Institute (ESRI). The diarrhoeal disease incidence rates were estimated from the total number of reported cases of the diarrhoeal disease in each district per unit population at risk of 10,000 people over the periods of 2010 to 2014. The disease rates were geo-coded to the district polygon layers according to the 170 administrative districts to create the geo-relational database for the spatial analysis.

Neighbourhood and Empirical Bayesian smoothing

Neighbourhood is defined as areas (districts) surrounding a given area that are influencing the observation at the target area [30] for which the spatial analysis tool compares the target incidence rate to. The queen polygon contiguity which incorporates both the Rook contiguity (neighbours sharing common edges) and Bishop contiguity (neighbours sharing common corners) relationships into a single measure was used due to the highly irregular shapes and sizes of the districts[31,32]. The crude incidence rates were transformed by Empirical Bayesian smoothing (EBS) technique using GeoDa software (an open access spatial software developed by Luc Anselin).The EBS ensures that mapping and spatial analysis of the rates account for the spatial heterogeneity in the population at risk and the random variables in the rates to avoid unbiased visual interpretation [33,34].The global EBS used the values in all the neighbouring districts to improve the properties of the rate estimate [35] so that the final smoothed rates have a variance stabilising effect through considerable rates adjustment [21,36]

Spatial mapping and Geovisualisation

The EBS annual and cumulative rates were then mapped and classified based on defined interval classification technique in ArcGIS for easy spatial comparison of rates. As an exploratory analysis, mapping and geovisualisation of diarrhoeal disease incidence rates was carried out as the first step in the spatial analysis [37].

Evaluating spatial patterns with spatial autocorrelation

A typical assumption in traditional statistical theory that observations on a single variable are independent (implying no spatial autocorrelation) may not be necessarily true. A spatial autocorrelation (spatial association) measures the correlation of a variable across geographical locations. A global Moran's index I was estimated with ArcGIS spatial statistics tool to evaluate how the incidence rates of diarrhoea autocorrelated among the neighbouring districts in the country [21,31,35]. The spatial autocorrelation in the rates of diarrhoea was measured with the Global Moran's index, I, given under the assumed Gaussian (normal) distributions according to the equation

$$I = \frac{n}{\sum wij} \sum \frac{(R_i - \overline{R})(R_j - \overline{R})}{(R_i - \overline{R})^2}$$

i and j = two areal units (districts); n = number of weights = number of districts

R_i and R_j = smoothed rates estimate for the neighbouring districts i and j; $\overline{R}$ = mean rate

wij= the element in the spatial weight matrix (created with queen polygon contiguity) corresponding to the observation pair i, j, defining the spatial interaction among the districts in the study area. The weights were row-standardized such that each row sums to 1 (Σwij = 1) if districts i and j share a common boundary; otherwise Σwij = 0, for non-neighbouring districts.

The computed global Moran's *I, z-score* and *p-value* described the degree of spatial concentration or patterns in the disease incidence at 5% significance level for the periods 2010 to 2014. In this analysis *p-value* gives the probability that the observed spatial pattern was generated by some random process. When the *p-value* is very small, it means it is very unlikely (small probability) that the observed spatial pattern is the result of random processes, so the null hypothesis can be rejected. A high *z-score* and small *p-value* for the affected district indicates a spatial clustering of high values [17]. The null hypothesis of no spatial dependency in rates was accepted if Moran's *I* is zero, implying random distribution, otherwise clustering of rates if Moran'I > 0 (positive) or dispersion if Moran's I is negative. The null hypothesis was also rejected if z-test statistics is greater than 1.96 or less than -1.96 at 95% confident level. The magnitude of the *z-score* indicates the intensity of clustering or dispersion [37,38].

Cluster-outlier analysis and Hotspots detection

Global Moran's I detects spatial associations averaged over the entire study area in search for clustering of rates across the study area without specifically identifying the local pockets of mutually similar deviations from the overall mean rate for localised public health intervention and prioritisation. Local forms of the global indexes, which Anselin [38] termed local indicators of spatial association (LISA) enabled distinction to be made among a statistically significant similar clusters of high values (High-High, HH, called hotspot) or low values (Low-Low, LL, called coldspot) and dissimilar outliers of either High-Low, (HL) or Low-High (LH) values. The Anselin Local Moran's I_i in the ArcGIS was performed for the cluster-outlier and hotspot detection of diarrhoea over the periods of 2010 to 2014. The cluster-outlier analysis with local Moran's I_i is an inferential statistic in which the results of the analysis, produced as spatial statistical maps, are interpreted within the context of a null hypothesis of random distribution (no spatial dependency) with the *p-value* [17, 31,37].

RESULTS

Geo-visual spatial exploratory analysis

Smoothing provides a clear spatial picture of the incidence of diarrhoea as presented by the graduated colour quantities, giving visual impression and numerical range of the disease incidence. Identified as the second most common outpatient visits in Ghana, the spatial exploratory incidence maps apparently indicated generally high and non-random geographical patterns of diarrhoeal diseases occurring everywhere (districts) in the country over the study periods. Visual inspection of the incidence maps (**Fig 1**) showed that the highest smoothed incidence of diarrhoea per 10,000 inhabitants was reported in 2012, while the lowest was seen in 2010. From the incidence maps, the increasing spatio-temporal order of annual rates was 2010, 2011, 2013, 2014 and 2012 with a number of pockets of high and/or low diarrhoea affected districts, especially at the northern and south-western parts of the country. Cumulatively, as high as 8,500 to 9,000 cases per 10,000 people were reported in three districts (**Fig 1f**).

Spatial epidemiological patterns and hotspots detection

The results of **Table 1** confirmed the non-random spatial distribution of the incidence of diarrhoea per 10,000 inhabitants observed in the smooth incidence maps. The results showed significant spatial clustering (Moran's I > 0 and Z-score > 1.96 at p< 0.05) for all other years respect to the absolute locations, except in 2013 where there was spatial clustering but not significant. Although the values of Moran's *I* were of small magnitude, the highest Moran's, *I* and *z-score*, suggesting that the likelihood of the epidemiology of diarrhoea resulting from random chance is less than one percent was produced in 2014 and the lowest in 2013. We can deduced that the intensity or accumulation of high rates were decreasing from 2010 to 2013 but suddenly increased significantly in 2014. From the cluster-outlier analysis with local Moran's I_i, the inferential spatial statistical technique detected aggregate of districts with low and/or high incidence rates. The results of the inferential spatial epidemiology, interpreted within the context of a null hypothesis were presented as spatial epidemiological maps (**Fig 2**). In all the years (2010-2014), almost all the districts were experiencing relatively insignificant clustering of diarrhoea with few significant clusters of high rates (hotspots; HH) or low rates (coldspots; LL) and outliers (HL or LH) spreading around the entire study area. The few identified hotspot areas of rapidly worsening rates of diarrhoea during the study period were summarised in **Table 2**. Most of the relatively elevated rates occur in 2014 (9 hotspot locations), followed by 2011 with 8 hotspot locations, 5 hotspots in 2013, 4 hotspots in 2010 but only one in 2012. The cumulative incidence rate also confirmed that the diarrhoea cases clustering all over the study area were locally not significant in most districts but had a number of noticeable hotspots.

DISCUSSION

This study applied spatial statistical techniques to public health data to geographically explore the incidence of reporting diarrhoeal diseases at the health facilities in Ghana. As a foundational spatial analysis, this study disclosed the existence of spatial and temporal characteristics of diarrhoea transmission in Ghana, allowing the quantification of the level of diarrhoea clustering in the country. Literatures affirmed that the spatial analysis of epidemiological, clinical and public health data in investigating a broad spectrum of diseases was beneficial to health management and remains one of the most important public health interest since the 1980s[17]. To the best of our knowledge, this is the first attempt to employ spatial analysis to spatially investigate the geographic variation of the endemic diarrhoea nationwide. The results of this study also demonstrated that GIS mapping and other spatial statistical techniques are capable quickly displaying large information and generating thematic maps to identify and highlight diarrhoea risk prone areas for public health administration in Ghana.

The geovisualisation of the incidence rates of diarrhoea was used as the first step in obtaining an initial overview of the distribution and possible spatial epidemiological patterns in the rates of diarrhoea as a broader component approach of exploratory spatial analysis. The geo-visual maps showed and suggested high incidence rates and geographical diversities in the incidence of diarrhoea over the study periods across the study area with highest rates in 2012. The observed geo-visual annual patterns, statistically confirmed with the positive Global Moran's I implies spatial epidemiological dependency patterns in the spread of diarrhoeal diseases throughout the country as reported elsewhere [18,19,20,21,22,23,24]. We can therefore deduced that adjacent districts tend to have almost similar diarrhoea distribution of high or low rates. The implication is that some locations were heavily infected and also any health intervention to address diarrhoea at one place should also consider the close-connected neighbouring areas because social interactions and population mobility are unavoidable. Temporally, the positive Moran's I and z-score values (Table 1) indicating accumulation of cases in some particular areas in the country had the clustering intensity decreasing from 2010 to 2013 but increased greatly in 2014. This could suggest that although the incidence increases, the general prevention and control measures seemed to be improving in most places but suddenly worsened in 2014. The local Moran's I_i cluster-outlier analysis also confirmed spatial association of diarrhoea at district levels with significant high/low rates but not in clear spatial trend in most districts during the study period. This could be due to several factors such as an unabated transmission, differences in behavioural changes induced by the presence of the disease could also alter the observed spatial patterns. This result suggests that the ideal conditions for establishments and maintenance of transmission are found in these places and that the pattern of diarrhoea occurrence is not static and disease may occasionally spread to other districts of the country [17]. However, the identification of the few hotspot areas should be considered by the public health practitioners for target prioritisation of health interventions, and resources allocation to prevent further deterioration [39] and future control strategies. This is imperative because in addition to possible more conducive prevailing risk factors in the hotspot locations, the observed spatial clustering could also be due to lack of equity in health and social intervention programmes, overcrowding, access to health services and environmental factors [17,21]. Understanding the spatial patterns is therefore useful for effective health planning and resource allocation [40].

CONCLUSION

Spatial epidemiology can play a key role to redefine public health data for strategic healthcare management with reference to where and when the cases are occurring and to identify the nature of transmission to aid in optimizing resources and health intervention. The results of this study showed that the annual incidence of diarrhoea is still very high in every district of Ghana and with high likelihood of a district becoming infested when other boundary districts are infected. The spatial epidemiology provides health authorities with more easily understandable platform to identify focal areas at greater risks of diarrhoea to optimise public health prioritisation and specific interventions rather than relying on annual incidence rates alone (which cannot clearly identify hotspots) without integrating the spatio-temporal components for extensive epidemiological assessment. The few identified hotspot districts with the most likely endemic clusters of diarrhoea cases need extra health intervention programmes and prioritisation. In a broader perspective, since visuals are easily understood, incorporating spatial epidemiology in presenting routine public health data especially in the tropical regions (with low literacy level) will effectively and efficiently communicate health information to the general public to enhance community participation in prevention of diseases of public health concern such as diarrhoea.

Further Studies

This exploratory spatial analysis sets the pace and suggests further vigorous spatio-temporal studies to investigate the risk factors underlying the spatial distribution of diarrhoeal diseases in Ghana for exact and geographically suitable risk-reduction programmes. With an up-to-date base street map and proper address system, analysis at smaller groups or village levels will be of great relevance for community health planning and other public health administrations in Ghana.

Limitations

Possibility of under-reporting of diarrhoea cases could affect the results of the study. Spatial statistical techniques attempt to address different sizes and shapes of districts but the likelihood of spatial error cannot be overlooked. Results of spatial analyses should therefore be interpreted circumspectly. Despite these limitations, the study showed that GIS and spatial statistical techniques may provide an opportunity to clarify and quantify epidemic, endemic and emerging diseases of public health concern.

Abbreviations

CHIM: Centre for Health Information and Management, EBS: Empirical Bayesian smoothing, ESRI: Environmental System Research Institute, GIS: Geographical Information System, GSS: Ghana Statistical Service, GHS: Ghana Health Service, GDHS: Ghana Demographic and Health Survey, GBD: Global Burden of Disease study, HH: clusters of High-High values (hotspots), HL: outliers of High-Low values, KNUST: Kwame Nkrumah University of Science and Technology, LH: outliers of Low-High values, LL: clusters of Low-Low values (coldspots), LISA: Local Indicator of Spatial Autocorrelation/Association; MOH: Ministry of Health;

PHC: Population and Housing Census SMD: Survey and Mapping Divisions, UTM: Universal Transverse Mercator, WHO: World Health Organisation.

Ethical consideration

An informed written consent was sought out from the Ghana Statistical Service, Ghana Health Service and Survey and Mapping Division, Accra. Ethical approval is not applicable since the research involved aggregated data with no direct contact or data on human subject(s).

Competing Interests

The authors have no competing interest to declare.

Authors' contributions

SDN designed the study, performed the methodology and compiled the manuscript
FBO: Corrected and reviewed the manuscript in each step
DNN participated in data collection and contributed to literature review
TA participated in data collection and data processing
RMP critically revised the manuscript for its public health relevance

Consent to publish

All authors read and approved the final manuscript to be published in this journal and accept the conditions of submission and the Copyright and License Agreement.

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APPENDIX

Tables

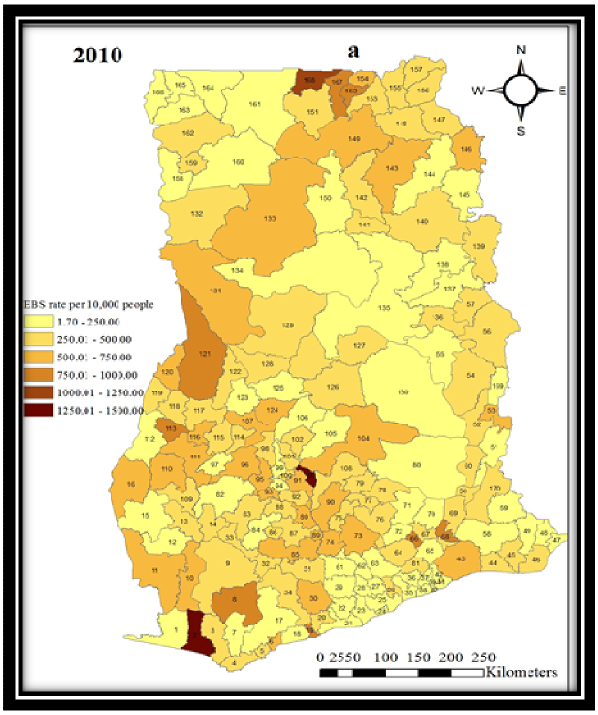
Table1. The Global spatial autocorrelation of diarrhoea incidence rates

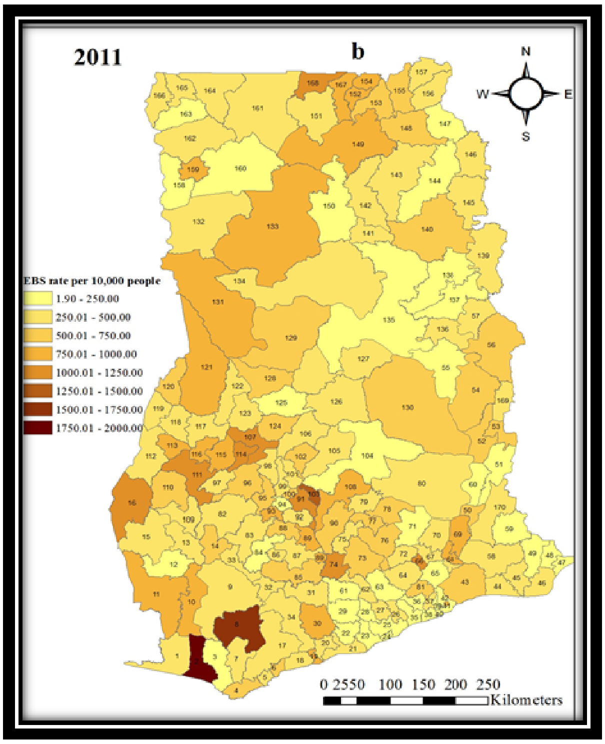
Year	Moran's I	P-value	Z-score	Spatial Pattern
2010	0.1442	0.0016	3.1472	Significant clustering
2011	0.1327	0.0038	2.8951	Significant clustering
2012	0.0913	0.0250	2.2411	Significant clustering
2013	0.0868	0.0534	1.9320	Insignificant clustering
2014	0.1486	0.0012	3.2293	Significant clustering
2010-2014	0.1177	0.0099	2.5777	Significant clustering

Table 2. Hotspot locations of diarrhoea

Year	District codes
2010	91,103,167,168
2011	89,91,103,107,108,114,115,116
2012	8
2013	113,116,121,131,154
2014	57, 111,113,115,116,117,120,121,131
2010-2014	8,113,115,116,121,131,154

Figures





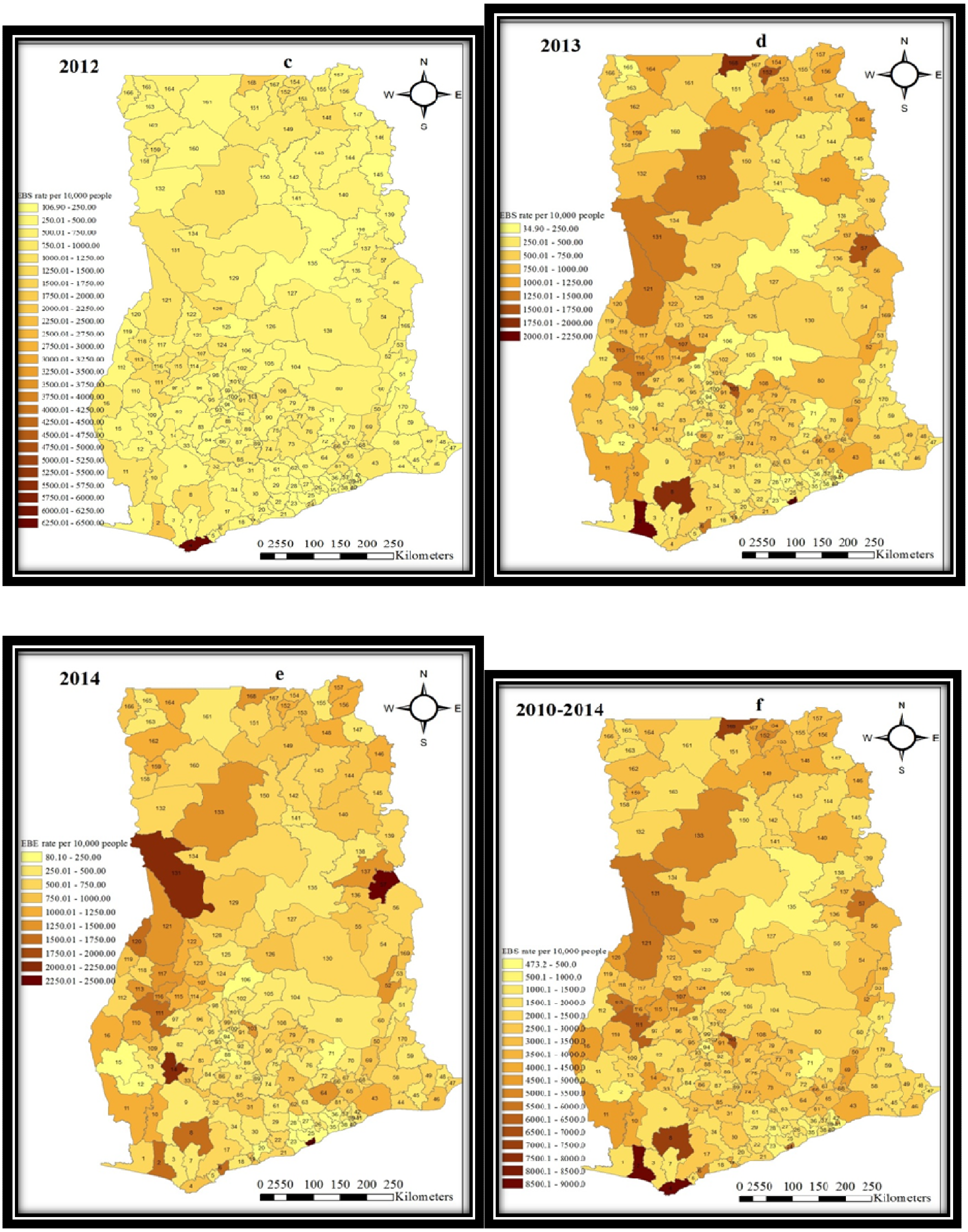


Figure 1. Map showing annual smoothed incidence of Diarrhoea for 2010(2a), 2011(1b), 2012(1c), 2013(1d), 2014(1e) and 2010–2014(1f).

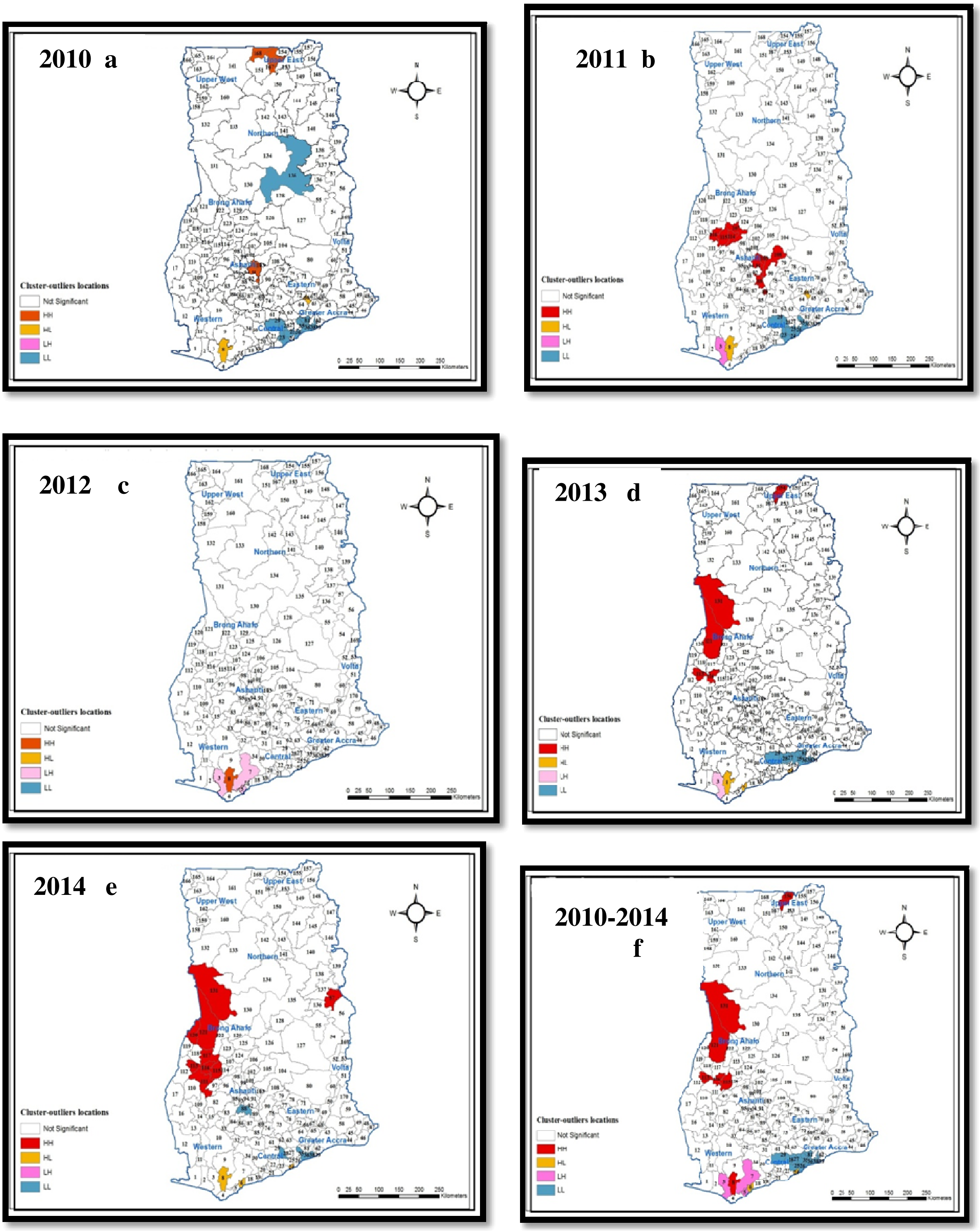


Figure 2. Cluster-outlier spatial statistical maps of Diarrhoea rates for 2010(2a), 2011(2b), 2012(2c), 2013(2d), 2014(2e) and 2010–2014(2f).