Geospatial Modelling of Buruli Ulcer Prevalence in Amansie West District, Ghana

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ABSTRACT

Buruli ulcer (BU) is a disease caused by mycobacterium ulcerans (MU). The large number of cases and the complications currently associated with the disease as well as its long-term socio-economic impact could have a substantial effect on the rural economy. Knowledge gaps about the exact mode of transmission and factors that pre-dispose to infection motivated this study. This study employed geographical information systems (GIS) and geostatistics to establish relationship between BU and postulated risk factors in Amansie West District of Ghana. Semivariograms were computed to determine the strength and spatial dependency of the pattern of disease as well as summarize the variation. The risk of developing the disease was estimated by kriging. Ordinary kriging was chosen in the variogram modeling. The BU data sets exhibited a highly positively skewed histogram with possible outlying. The length of spatial autocorrelation (practical range) was much longer than sampling interval (lag size).The kriged map showed that there are large patches of BU disease in the southern part of the study area with few isolated cases in the other parts.. The research revealed that the disease is prevalent in the southern portion of the district which is drained by rivers Oda and Offin. The southern portion is also characterized by intense mining and agricultural activity. The paper concludes that intense human interaction with aquatic environment may be responsible for the high prevalence of BU in the District.

KEY WORDS: Variogram, Kriging, Geographical Information Systems, Spatial Patterns, Buruli ulcer.

1.0 INTRODUCTION

One of the most important pillars of a nation's development is the health status of its citizens. For the past decade, the health status of most Ghanaians has been plagued by many challenges, ranging from inadequate health care facilities, potable water to poor quality environmental management issues. For these reasons, many preventable diseases such as malaria, cholera and many others have been the cause of morbidity and mortality. One of such disease is Buruli ulcer. Buruli ulcer (BU) which has been described by the World Health Organization as one of the neglected tropical diseases is cause by Mycobacterium ulcerans (van der Werf et al., 1999). BU is rated as the third most common mycobacterium infection after Tuberculosis and Leprosy (Josse' et al., 1995). It starts with a painless nodules or papule in the skin and, without appropriate therapy, causes massive skin ulceration, which often results in grossly deforming sequelae (Asiedu and Portaels, 2000). The disease can present as a large area of indurations or a diffuse swelling of the legs and arms. The main form of treatment is wide excision surgery, including amputation of limbs, which requires prolonged hospitalization.

Ghana is the second most endemic country for Buruli ulcer after Cote d'Ivoire globally, (WHO, 2012). The overall National prevalence is 22.7 cases per every 100,000 inhabitants. Amofah et al., (2002), reports that the cases of the disease have been reported in all the ten regions of the country with the Ashanti Region which is the most populous accounting for over 60% of all cases. The most affected district of the Ashanti Region is the Amansie West with a prevalence of 151 cases per 100,000 inhabitants. Buruli ulcer, which is sweeping across Ghana has been described as a cruel disease which silently eats through skin, muscle and bone and, in its worst form, leaves victims with disfiguring and debilitating craters. Buruli Ulcer was first brought to public attention in Ghana in 1993 when severe cases were reported from the Amansie West district of Ashanti Region in August (MOH, 2004). Specifically the most affected town is Tontokorom, although earlier cases have been reported from the Densu and Afram plains, Van der werf et al (1989).

Currently the mode of transmission of Buruli ulcer is not entirely known, though most epidemiological data and some hypothesis have associated the outbreak and emergence of the disease with an aquatic environment (Marsollier et al., 2002). Most investigators have implicated insects, airborne, trauma and human to human as possible modes of transmission. Insects are also suspected to aid the transmission of Buruli ulcer. Most of the work on insects in the transmission of Buruli ulcer had tended to implicate aquatic insects as a possible mode of transmission of the etiologic agen (Nielsen O, et al. 2001). Marsollier et al., (2002) experimentally infected adult water bugs of the family Naucoridae (Naucoris cimicoides) with Mycobacterium ulcerans infected grubs. These insects were then made to bite the tails of mice. They found out that some of the mice tails which were bitten had developed a non-ulcerative inflammatory lesion with oedema at the site of the bite. They provided the strong evidence implicating insects in the transmission of Buruli ulcer. Foci of the disease appears to develop after some form of environmental disturbance such as flooding or the formation of new dams or water storages, sand winning, where excavation have left behind large sheets of stagnant water. Veitch et al (1997) reporting a large outbreak of the disease on Philips Island in Australia associated the source of infection to an irrigation which lay in the midst of the cluster of cases. The number of cases reported from the community reduced after the irrigation site was modified and limited from the public. Scot et al, (2004) noted that cases of Buruli ulcer are associated with tropical wetlands of West and Central Africa and cases have increased rapidly in these areas since the 1980's, particularly after irrigation and dam construction. Travis (1999) also noted that people living near slow-running waters are more likely to contract this disfiguring disease. Portaels et al (1989) reported that re-emergence of the disease in some developing countries may be related to environmental and socio-economic factors like deforestation leading to increased flooding, population expansion without improved agricultural techniques, thus putting more people at a risk of contracting the disease.

Many authors including Portaels et al., (2001), have reported on the relationship between Buruli ulcer infection and the environment. The works of Barker (1973) indicates that Buruli ulcer incidence is higher amongst users of surface water rather than users of water from deep wells. Mensah-Quainoo, (1998) also reports that high Buruli ulcer incidence tends to cluster along or near surface drainage courses. Several studies have associated increased incidence of Buruli ulcer with environments prone to flooding and development of anaerobic conditions (Reynolds et al., 1999). Lin et al. (2004) have shown that Buruli ulcer prevalence is strongly correlated with environmental risk factors such as ingestion of food or water contaminated with arsenic which may subsequently inhibit the functioning of several sulphydryl- bearing enzymes in the body. Arsenic has the potential to adversely affect the human immune system (Frenkel et al., 2002).

With the exception of the partial study of Smedley et al. (1996) of the Amansie West district, there have been several studies by Duker et al. in 2004 and 2005 on the relationship between arsenic concentrations and the mean Buruli ulcer prevalence in settlements along arsenic-enriched drainage pathways and arsenic-enriched farmland. Again, Asiedu and Etuaful, (1998) have blamed poverty as a major contributing factor to the high prevalence of the disease in the District

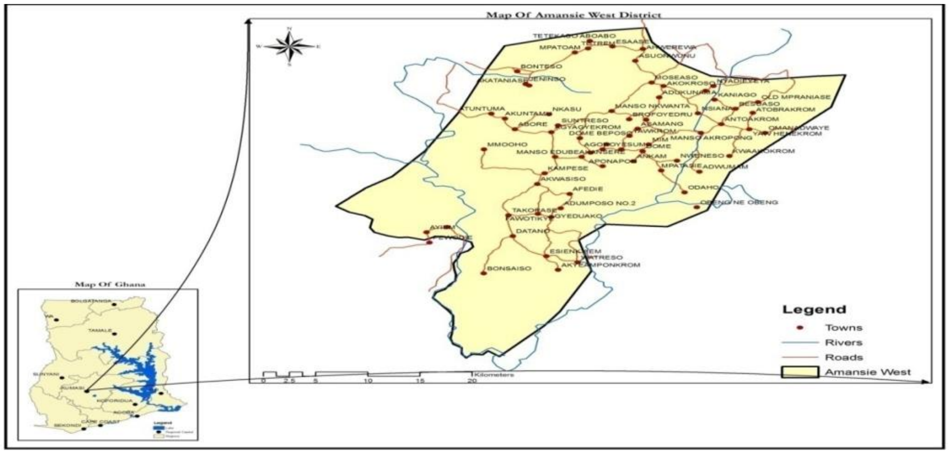
The aim of this paper is to model the spatial distribution of Buruli ulcer in the Amansie West district of Ghana dwelling on existing literature and empirical evidence from the field research. We applied the Poisson kriging to the spatial interpolation of the Buruli ulcer disease in the analysis. The ability of poisson kriging to identify and map environmental factors associated with disease vectors makes it increasingly essential in infectious and vector-borne disease surveillance as illustrated by (Kitron et al., (1994). The challenge of taking into account, the binomial or Poisson nature of count data is attributed to Oliver (1998). Following his studies on risk of childhood cancer in the Midlands of England, developed a method that factors the spatial heterogeneity in the population of children to compute the semivariogram of the "risk of developing cancer" based on the observed mortality rates. Binomial was applied to come out with a map of cancer risk. More vigorous one on binomial kriging was also proposed by (Goovarte, 2005) and this supported the empirical works of Bayes in his geospatial based simulation.). In a similar development, Monetiez et al. (2005) developed Poisson kriging for mapping the relative abundance of species in the presence of spatially animal sightings. Monetiez et al. (2005), compared Poisson kriging with Diggle et al.'s "model-based kriging" which is more or less a Generalized Linear Mixed Model (GLMM) and the results was that Poisson kriging was 500 times faster than GLMM as it does not require more iteration procedure for parameter computation, Gaussian (1998). We believe using Poisson kriging model as a tool in this research will not only add to the existing knowledge on the spatial distribution of the disease, the socio economic effects, causes, stigmatization and coping strategies but will deepen the knowledge base and increase the understanding of the epidemiology of the disease.

METHODOLOGY

2.1 Study Area

The Amansie West District falls within latitudes 6º 35 and 6º 51 North and Longitudes 1º 40 and 2º 05. It is located in the south-western part of Ashanti Region in the forest zone of Ghana. It shares boundaries with the Amansie East District in the west, Atwima Mponua District in the east, Atwima Nwabiagya District in the north and Amansie Central in the South. The District covers an area of about 1,364 sq. km. and forms about 5.4 percent of the total land area of the Ashanti Region. The District lies entirely in the rainforest belt. It exhibits most semi-deciduous characteristics. The district is very rich in forest resources, such as timber, herbs of medicinal value and fuel wood. It also abounds in different species of tropical hardwood, notably Odum, Mahogany and Sapale. There are four main forest reserves in the district. These are: Oda River Forest Reserve, Apamprama Forest Reserve, Gyeni River Forest Reserve and Jimira Forest Reserve. The dominant soil type in the district is the ochrosols soils that are suitable for a number of crops such as plantain, cocyam, cassava, maize, legumes, oil palm, cocoa, coffee, citrus and pear. The district covers an area of 136,400 square kilometers. The year 2000 population census put the estimated population of the district at 108,273 with a population density of 62.8 persons per square kilometer. The district can be classified as predominantly rural. It has about 310 settlements fairly distributed within the district. Of the 310 settlements, only 19 have populations above 1000 and shows a large proportion constituting small settlement of farming communities.

Figure 1.1 Map of the Amansie West District



Source: field work

2. 2 Data Set and Assumptions

The basic inputs were topographic map data of the study area at a scale of 1:500000. It was obtained from the Survey Department, Accra and was digitized using ArcGIS version 9.2. Initially, the map was geo-referenced by defining the X and Y coordinates of corner points of the map into a War Office Coordinate System. The boundary map of the study area was digitized as a polygon and communities as points. Reported cases of BU cases from 1999 to 2011 obtained from Amansie West District Assembly were entered as attribute of the point feature that is the settlements.

2.3 Geostatistical Analysis of BU

For a given number N=62 of towns, let the number of recorded mortality cases be d(x_α) and the size of the population at risk also be n(x_α), where x_α is the size of the risk entities at α.

Following Oliver et al., 1998, entities are referenced geographically by their centroids with the vector of spatial coordinates $u(x) = (x_{\alpha,} y_{\alpha})$, which explains that the actual spatial support (i.e. size and shape of the towns) is not taken into account in the analysis.

The empirical or observed mortality rates are then expressed as:

$$z(x_{\alpha}) = \frac{d(x_{\alpha})}{n(x_{\alpha})} \tag{1}$$

Given each geographical location $x_{\alpha,}$, can be explained as the realization of a random variables $D(x_{\alpha})$ that in line with a Poisson distribution with one parameter (anticipation of number of count). This means the product of the population size $n(x_{\alpha})$ by the local risk $R(x_{\alpha})$:

$$D(x_{\alpha}) / R(x_{\alpha}) = Poisson(n(x_{\alpha})R(x_{\alpha})) \qquad \alpha = 1, \ldots, N \tag{2}$$

We model the risk variable $R(x_{\alpha})$ as a stationary random field with mean m, variance ${\sigma^2}_R$ and covariance function $C_R(h)$.

The conditional mean and variance of the rate variable $Z(x)$ are expressed as:

$$E[Z(x_{\alpha}) / R(x_{\alpha})] = R(x_{\alpha}) \tag{3}$$

$$Var[Z(x_{\alpha}) / R(x_{\alpha})] = R(x_{\alpha}) / n(x_{\alpha}) \tag{4}$$

Poisson kriging

The risk over a certain settlement with centroid x_{α} is computed as the following linear combination of K neighbouring observed rates:

$$\hat{r}pk(x_s) = \sum_{i=1}^{K} \lambda i(x_s) z(x_i) \tag{5}$$

The weights $\lambda_i(x_\alpha)$ are obtained in order to minimize the mean square error of prediction under the constraint that the estimator is unbiased. These weights are the solution of the following system of linear equations, Poisson Kriging system:

$$\sum_{i=1}^{K}\lambda_j(u_\alpha)\left[C_R(u_i-u_j)+\delta_{ij}\frac{m^*}{n(u_i)}\right]+\mu(u_i-u\alpha) \qquad (6)$$

$$\sum_{i=1}^{K}\lambda_j(u_\alpha)=1$$

$\delta_{ij}=1$ $\delta_{ij}=1$ if $x_i=x_j$ and 0 otherwise m^* is the population-weighted mean of the rates. The term $\mu(x_\alpha)$ is a Lagrange parameter that comes from the minimization of the estimation variance subject to the unbiasedess constraint on the estimator. The addition of the term, $m^*/n(x_i)$, for a zero distance explains for variability obtain from population size, leading to smaller weights for less reliable data. This term exactly represents the difference between the variance of the risk and rate variables. We employed kriging to filter the noise from the observed rates aggregated to the town level, but not to estimate the risk within the settlement itself.

The prediction variance based on Poisson kriging is estimated using the traditional formula for the ordinary kriging variance:

$$\sigma^2 pk = C_R(0)-\sum_{i=1}^{K}\lambda_i(x_i)C_R(x_i-x_\alpha)-\mu(x_\alpha) \qquad (7)$$

The estimation of kriging weights and kriging variance (Equation (6) and (7)) needs knowledge of the covariance of the unknown risk, $C_R(h)$ or equivalently its semivariogram $\gamma_R(h)=C_R(0)-C_R(h)$. The semivariogram of the risk is estimated as (Monestiez et al, 2005):

$$\hat{\gamma}_R(h) = \frac{1}{2\sum_{n=1}^{N(h)} \frac{n(x_\alpha)n(x_\alpha+h)}{n(x_\alpha)+n(x_\alpha+h)}} \sum_{\alpha=1}^{N(h)} \left\{ \frac{n(x_\alpha)n(x_\alpha+h)}{n(x_\alpha)+n(x_\alpha+h)} [z(x_\alpha)-z(x_\alpha+h)]^2 - m^* \right\} \quad (8)$$

where the different pairs $[z(x_\alpha)-z(x_\alpha+h)]$ are weighted by the corresponding population sizes to homogenize their variance.

Weighting scheme is applied to the least-square fitting of a semivariogram model to experimental values.This is to ensure that the selected model is the one that reduces the weighted sum of squares of differences between the experimental and model curves. The L is the number of classes of distance.

$$wss = \sum_{l=1}^{L} w(h_l)[\gamma(h_l) - \gamma(h_l)]^2 \quad (9)$$

3.0 RESULTS

The amount of error (nugget effect) the C_0 in the semivariogram (see Table 3.1) of BU disease is zero (54.18), sill (C_0+C_1) is 763.35 and a major range of 349723.711 metres (Table 1)

Model	**Cubic**
Partial Sill (C_0 +C_1)	763.35
Nugget (C_0)	54.18
Lag size	14282
Number of lag	12
Major range	349723.711
Angle tolerance	45°
Angle direction	0 °

Table 3.1: Best fitted semivariogram model parameter of BU data

Figure 3.1 which is cubic semivariogram model shows the radius at which autocorrelation is experienced

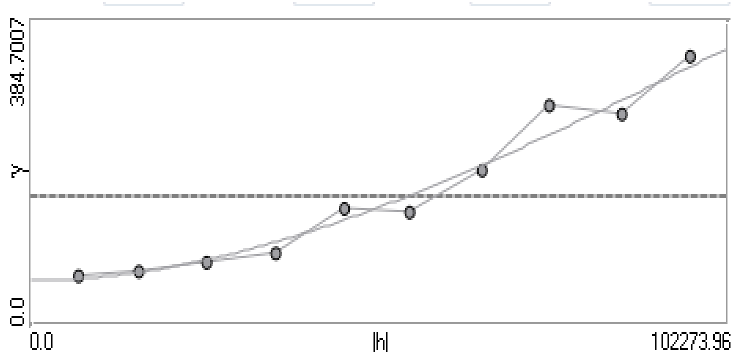


Figure 3.1: Cubic semivariogram model

The spatial dependence of the cubic model which is estimated to be the ratio of (C_0) to (C_0+C_1) is 7%. This indicates that the range of spatial autocorrelation is very strong for all plots.

In figure 3.2, the spatial dependence as is evident in the semivariogram in figure 3.1 comes up. This is because there are both large or deep and small or light patches. The areas closer to major rivers generally appear to have large risk whereas the risk is small in central part where major settlements are found. The southern and north part of the district have the largest frequencies and apparent risk. However, the risk is higher in the southern portion and especially closer to the confluence of the two rivers, the Offin and Oda Rivers. Unfortunately, this area has very poor social infrastructure especially good drinking water and health facilities in addition to artisenal mining activities.

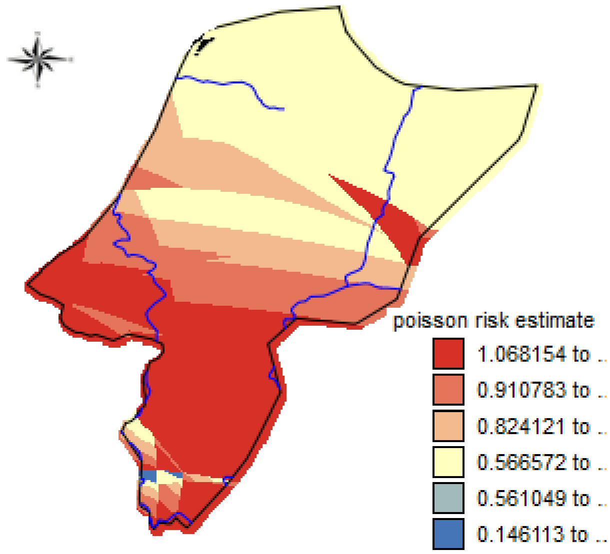


Figure 3.2 Map of the estimated risk of BU disease in Amansie West by Ordinary kriging

Mean:	0.6078
Root-Mean- Square:	13.09
Average- Standard Error:	22.59
Mean Standardized:	-0.0533
Root-Mean- Square Standardized:	0.8123

Table 3.2 Summary statistics of the prediction model

The value of mean prediction error (0.6078) is relatively small,this may indicate that the predicted values are unbiased. Similar information is provided by the mean standardized prediction error (-0.0533). The average standard error (22.59) is greater than the root-mean-square of predicted-errors (13.09). This indicates that the model slightly over-estimates the variability of BU cases. The root-mean square prediction error (or kriging standard deviation) is a measure of the error that occurs when predicting data from point observations and provides the means for deriving confidence intervals for the predictions. Finally, the root-mean-square standardized (0.8123) prediction error is small closer to one, and thus corresponds to a good estimate .

4.0 DISCUSIONS

Table 3.1 shows a major range of 349723.711 meters (349.724 km). This shows the rate at which the disease is spread over a very large area of the District. Normally, smaller range indicates that the phenomenon under study has a very smaller or range of spatial distribution. This major range, by implications, means that the disease has very wide spread in the district or there is a wide spatial distribution of the disease in the district. This is also confirmed by Cubic semivariogram model, figure 3.1. The result of 7% as indicated in figure 3.1 shows that the phenomenon being studied (Buruli ulcer) seems to indicate that there was autocorrelation between samples. Of all the models, the cubic semivariogram model gives better spatial autocorrelation and less nugget variance. This also confirms the major range in table 3.1.

The results of the study has once again brought to the fore the nexus between the environment and human health. The results of the study indicates that Buruli ulcer endemicity in the Amansie West district is associted with aquactic environments that have been disturbed either through mining or irrigation. This is evidenced by the colourization of the risk map, figure 3.2. The Northern and Central portion of the risk map (figure 3.2) which is not drained by the two major rivers showed light yellow colours whereas the southern part of the map which is drained by the two major rivers showed thick red colours. These findings confirms the studies of Duker et al., (2005) which found that BU prevalence is influence by arsenic through arsenic bioaccumulation in food crops and subsequent bioaccumulation in human tissues. Their research revealed that most farmlands are situated close to the two major streams or rivers and food crops are mainly cultivated on flood plains because they are level, fertile and easy to irrigate during dry periods. The flood plains themselves comprise mainly recent sediments transported down streams and rivers and deposited on the adjacent land during flood events. If the suspended load includes arsenic bearing minerals, these too are deposited on the flood plains during flood events. However, the high arsenic locations are more restricted in spatial extent and therefore influence only part of the agricultural land and food crop consumption. More importantly, high arsenic might be a measure or reflection of more general contamination (e.g., from mining), which has rendered land unsuitable for agriculture. James et al (2003) in Benin also identified three risk areas according to origin of patients reporting at hospitals with Buruli ulcer and noted that most of them were coming from Laguna areas of coastal Benin, marshy inland areas where market crops and rice are cultivated, and river valleys areas. Carbine et al (2003) also noted that water sources are associated with high incidence rates of the disease, Darie (2003), reported the strong association of the disease to an aquatic ecosystem.

The study also reveals that the risk of Buruli ulcer is higher in settlement located in the southern part of the District, close to the Offin and the Oda Rivers, (figure 3.2). These are areas where intense artisanal mining activities are prevalent though the artisanal mining activities are close to River Offin than that of Oda. Mining, which is the second contributor to the District economy, was observed to be an activity which dates back to the pre-colonial era. The sector currently employs about 22 per cent of the labour force in the District, mainly the male population who are found in both large scale and small scale mining activities. Artisanal and small-scale mining is a significant sector that provides a livelihood for the local community and produces a sizeable proportion of the world's extractive commodities, but it is also associated with serious negative social, environmental, and security consequences (Williams et al., 1996; Ogola et al., 2002). Even as Artisanal and small-scale mining has potential to contribute positively to social and economic development and can provide much-needed income in fragile rural economies, the sector is closely linked to human health and poverty. Further, the mining activity has been widely identified as a source of finance for violent conflicts that have victimized foreign investors and caused severe social and economic disruptions. While conflict associated with extractives has brought attention, mostly negative, to the mining sector as a whole, the link between Mycobacterium ulcerans - the bacteria that causes Buruli ulcer and artisanal small-scale mining remains largely unknown to, and misunderstood by, health officers and even would-be stakeholders (Amofah et al., 1993). The only established fact is that the mining activities pre-disposes the community members to the disease causing organisms but the origin of the organism to the environment could not be established by this research. The problem has therefore been how to strike a balance between livelihood and Buruli ulcer infections. The usefulness of these rivers/streams to the District is limited due to the level of pollution from various sources most especially through mining activities as observed in the District. The pollution of the water bodies in the District poses a great threat to the health of communities that use the rivers as sources of drinking water and other domestic purposes (Smith et al., 2000).

Apart from the artisanal mining near the water bodies, another factor that is believed to have contributed to the disease especially around the southern portion of the district is deforestation due to increased basic agriculture activities in the area as a result of human interaction with the environment. Thus the recent marked increase of prevalence rate in the endemic areas is attributed to environmental changes taking place at an alarming. Supporting this hypothesis, Aseidu and Portals (1998) revealed that in Benin, the ratio of infection was 100 per 100,000 people in communities with environmental changes where as in those areas without environmental changes, the ratio is about 20 per 100,000 people. A similar situation prevails in the most endemic areas in Amansie West district. The Amansei West Districts is home to the Datano-Essienkyiem Forest Reserve and the Apiaprama Forest Reserves. These forest reserves are located between Tontokrom and Watreso. These forest reserves are fast being depleted because of the intense agriculture activity through felling of trees and tilling of the land. These physical activities on the natural environment have the potential of leading to the spread of the disease.

The prevalence of Buruli ulcer corresponds to the quality of the natural environment as well as the socio-economic quality of life. Apart from the physical damage that it inflicts on the physical body, it drains the scarce resources that could be used to improve the socio-economic conditions the District. Buruli ulcer is often regarded as a strange disease, in that the causes are speculative. Thus while some attribute the cause to marshy soils, vegetation, poor personal hygiene and poverty, others believe it is caused by supernatural factors such as witchcraft or through curses for the gods.

The geostatistical analysis applied in this research has led to an optimal estimation and mapping of incidence rates of BU infection and environmental factors that contributes to the disease; mainly due to the level of spatial dependence. It has also shown that the risk is higher in settlement close to the Offin and the Oda Rivers where artisanal mining and farming is prevalent. The prediction map made based on kriging interpolation and kriging standard deviation provides useful information for risk assessment and decision support.

Health and well being of humans cannot be separated from the natural environment. Human health and environmental issues have become a major concern in the world and have received considerable political recognition. Having identified the link between the disease prevalence and the physical environment, this paper concludes that any intervention strategies should consider striking balance between livelihoods and environmental change if it is to succeed.

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