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# The Application of Geographic Information Systems (GIS) to Improving Health Systems in the Upper East Region of Ghana

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## Abstract

Despite the increased use of Geographic Information System (GIS) for health research, the technology is least used in settings where evidence based decision-making is needed most: High mortality settings of Africa where resource constraints impede the provision of essential care. This paper reports on a case study of GIS application in the Upper East Region (UER), one of the poorest regions in Ghana.

**Methods**

Ghana Health Service (GHS) workers were trained to use GPS handheld devices to gather waypoints (coordinates) of all health care facilities and amenities throughout the UER. The waypoints data were then exported to Excel spreadsheets and cleaned of all inconsistencies. The final data was imported into ArcMap 10.2.2 software for data manipulation, display, and analysis.

**Results**

Preventive health issues portrayed by GIS visualization included a substandard access to potable water in one community and health facility deficiencies in the Binduri district. As examples of GIS morbidity surveillance, we map the temporal incidence of cholera in two districts, and evidence of a pattern in the seasonal outbreaks of cerebral spinal meningitis (CSM).

**Conclusion**

Results attest to the feasibility of using GIS to clarify health issues in a severely health service deprived setting, enabling public health authorities to optimize system responses where mostly needed. GIS technology has enabled health officials in the region to visualize the geographic pattern of disease outbreaks in ways that permit the imposition of efficient containment strategies.

**Keywords:** *Geographic Information System (GIS), Ghana Health Service, Upper East Region, health outcomes, health system.*

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# The Application of Geographic Information Systems (GIS) to Improving Health Systems in the Upper East Region of Ghana

There has been a proliferation of research in recent years showing that health, survival, and service access follow geographic patterns and determinants (Dejardin et al., 2014; Schoeps, Gabrysch, Niamba, Sié, & Becher, 2011). Less is known, however, about the application of geographic information system (GIS) to strategize the strengthening and functioning of health systems in severely health deprived settings. Although global attention to health systems strengthening has been catalyzed by a World Health Organization (WHO) report addressing the components of health systems functioning, practical examples of how system functioning can be strengthened by GIS application remain rare. As the above WHO publication noted, a "health system consists of all organizations, people and actions whose primary intent is to promote, restore or maintain health. This includes efforts to influence determinants of health as well as more direct health-improving activities" (WHO, 2007). Thus, all aspects of health care comprise elements of systems, such as global support entities, local governmental organizations, technological and non-technological advancements that contribute to health of individuals worldwide. Despite the widespread consensus that the WHO report has garnered, the framework has been criticized for comprising a "closed system" model that fails to address contextual determinants of system functioning such as regional and district health economic, social, and organizational factors that are profoundly important to effective system functioning. This paper focuses on the need to bring "open systems" criteria into the process of monitoring program functioning, a recommendation that has been central to organizational theory for decades (Katz & Kahn, 1978; Olsen, 1998). To this end, GIS can provide a tool for visualizing the geographic distribution of health service coverage indicators in a rural region of northern Ghana relative to the incidence of acute disease outbreaks.

***Background***

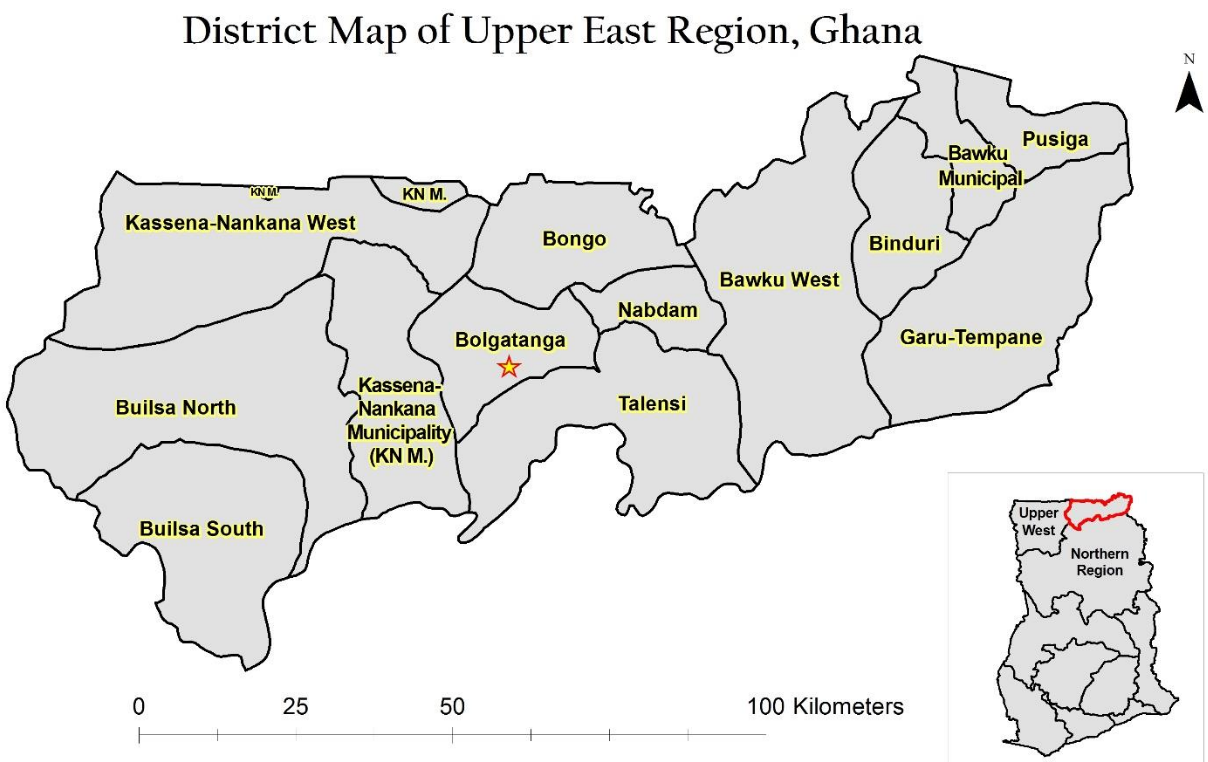
GIS technology provides data that enables managers' to pinpoint exact locations of health problems in a geographical region in ways that guide the imposition of appropriate health interventions. Ever since the invention of the first operational GIS in Canada in 1960 (Kemp, 2008), the technology has been applied to an expanding range of health sector applications. For example, according to (Boulos, 2004), the United Kingdom National Health Service (NHS) and other international countries through GIS application have managed to achieve breakthroughs in targeting and addressing health care issues.

Although GIS technology has been used to study endemic infectious diseases such as malaria (Booman et al., 2000; Martin, Curtis, Fraser, & Sharp, 2002), tuberculosis (Wilkinson & Tanser, 1999), HIV/AIDS (Kalipeni & Zulu, 2008), and other endemic pathogens, it is only rarely discussed as a tool for health systems strengthening.

Beyond epidemic intelligence, GIS technology has the potential for informing health-improvement activities and guiding resource allocation (Bisht & Gairola, 2014). Such examples attest to the potential for GIS to be a routinely applied resource of a national health system. To illustrate this perspective, we piloted an integration of GIS into the health information system of the UER of Ghana, one of the ten such administrative regions in Ghana.

The UER is a Sahelian locality that is bordered by Burkina Faso to the north, the Republic of Togo to the east, the Upper West Region of Ghana to the west, and the Northern Region of Ghana to the south. The region is subdivided into thirteen districts with Bolgatanga as the regional capital (Figure 1). Household economic and health indicators rank among the poorest of all the 10 regions in the country, with about 88.2% population … [living] below poverty line (Ghana Statistical Service, 2014).

**Figure 1- Map of the UER, Ghana**




The UER geographical locality lies entirely within the international region of the Sahel that has experienced Cerebro-Spinal Meningitis (CSM) outbreaks, with the consequence that its population has been targeted for mass vaccinations (Hodgson et al., 2001; Woods et al., 2000). Additionally, the UER is severely health deprived; the top ten causes of death include malaria, anemia, pneumonia, meningitis, tuberculosis, typhoid and AIDS (Ghana Health Service, 2012).

This paper illustrates how GIS application is used to clarify health problems in this context of extreme poverty and health deprivation, as well as demonstrating ways in which GIS can guide the formulation of strategies for mitigating the effects of such problems as a tool for strengthening the UER health system. Finally, it proposes ways that the Ghana Health Service (GHS) can utilize GIS technology among its tools for improving health care.

***Introduction of GIS in the UER***

Before the year 2012, the UER lacked interactive maps portraying the locality of health infrastructure and the incidence of diseases. Consequently, during disease outbreaks both the UER Health Directorate (UERHD) and District Health Management Teams (DHMTs) faced the challenge of pinpointing index cases or tracking disease spread. This information gap delayed response times such as deployment of health care officials to help address and contain outbreaks. The UERHD therefore sought ways to address this problem.

GIS activities initially began in the UER as part of Ghana Essential Health Intervention Programme (GEHIP) work - a collaborative project set-up by Ghana Health Service (GHS), Columbia University, and the University of Ghana School of Public Health (UGSPH) to help improve maternal and child health in Ghana (Awoonor-Williams, Bawah, et al., 2013; Awoonor-Williams, Sory, et al., 2013). GIS technology was introduced by GEHIP to support GHS investigation of the incidence and prevalence of common diseases in the region as well as to effectively identify communities that required health interventions. Since this application of GIS to system monitoring was an innovation in Ghana, there were no templates or previous research designs to emulate when this work was carried out. The development process and monitoring activities extended for a period of one-and-a-half years, from June 2012 to December 2013.

***Methods***

*Data gathered*

Data collected for the GIS project included waypoints (coordinates) of the location of all health facilities and amenities throughout the UER. Waypoints were gathered for all health facilities- hospitals, health centers, clinics and Community-based Health Planning and Services (CHPS) health post locations as well as features of the environment that impact on health, such as water drinking sources- boreholes, wells, stand pipes, dams and rivers-, schools, latrines, drug stores, locations of transport vehicles for pregnant mothers to health care facilities, ambulances, medical tri-cars, and finally settlement areas that define communities according to a central point in each community defined by some key social or geographic landmark, such as the chief's palace or a market place.

*Instruments*

The instruments used were 19 "eTrex Legend H" Global Positioning System (GPS) handheld devices and corresponding training manuals, Minnesota Department of Natural Resources (DNR) GPS 6.0.0.8 software, Microsoft Office Word, Excel, Access, and Power point 2013, GIS Tutorial for Health- 4th Edition textbook, ArcGIS ArcMap 10.2.2 software program and Ghana/UER shapefiles.

*Activities*

A GIS team was constituted to implement all work. Local GHS workers- consisting of disease control and health information officers- from all 13 DHMTs were trained to use the GPS devices to gather data in June 2012. This session lasted two days and involved usage of power point slides to explain the concept of GPS and introduce the devices to the workers. In studying the functions of the GPS devices, GHS workers were taught how to interpret the satellite acquisition page, scroll through the device, and most importantly mark (or collect) and record waypoints.

The GPS device automatically assigned each coordinate with a unique identification number (georeferenced), simplifying the delineation of adjacent recorded locations.

Paper forms columns entitled “Region,” “District name,” “Community name,” “Clinic,” “Health center,” “Borehole,” “Well,” Drugstore,” etc. were provided to workers who were required to write each facility or amenity’s unique identification number on the printed out copies of the page and turn them in with their GPS devices after data collection.

For locations such as hospitals, clinics, health centers, CHPS, communities and schools the workers were taught to first determine their central points and then mark the waypoint. This determination was to be based on (i) personal judgment, or (ii) asking indigenous volunteer workers or (iii) settlers in the locale.

The above initial GIS training and fieldwork activities extended from July 2012 to November 2012 and covered all 13 districts. DNRGPS 6.0.0.8 software was used to retrieve the waypoints from the GPS devices which were then exported into Excel spreadsheets for data cleanup. From Excel, the data was transported into Access which was used to create tables that readily imported into the ArcMap 10.2.2 program for data manipulation and used to generate maps of health care facilities and amenities in the region.

The second training and fieldwork sessions were held in December 2012 to serve as a refresher course as well as a mechanism for training new GHS workers on how to gather, retrieve and enter waypoints into Excel spreadsheets. A final training session took place in December 2013 where the workers were ultimately taught how to transport data from Excel spreadsheets, into Access and finally into the ArcMap 10.2.2 program and manipulate the data to generate health care related maps for their various districts and communities. The GIS workbook- GIS Tutorial for Health 4th edition was used to achieve this aim. The ultimate aim of all conducted training was to make the UER GHS workers self-sufficient and competent so they could gather their own data and create maps without supervision.

***Results***

GIS-based portrayal of data highlighted health problems within the region identified several health related problems that would have otherwise been overlooked. These issues included a potable water problem, evidence of a cholera outbreak, and deficiencies in the location of a health care facility. Furthermore, recurrent monitoring enabled regional authorities to detect a temporal pattern in the outbreaks of cerebral spinal meningitis (CSM) in the UER. We review each of these examples, in turn.

*Improving water drinking in Shia-Tindongo*

Shia-Tindongo is a community located in the Talensi district. Residents of Shia-Tindongo faced a water drinking problem, but due to lack of transportation and poor communication systems were unable to report their situation to appropriate health officers. Accordingly, residents had to walk many miles to obtain water from the next village which was almost impossible during the raining season and posed an inconvenience. As a result, Shia-Tindongo residents constructed their own water source which was determined to be unsafe by a GHS worker. The residents’ main water source was a hand-dug well which was extremely shallow and without appropriate covering (Figure 2).

**Figure 2 – Shia-Tindongo Community's Water Source**

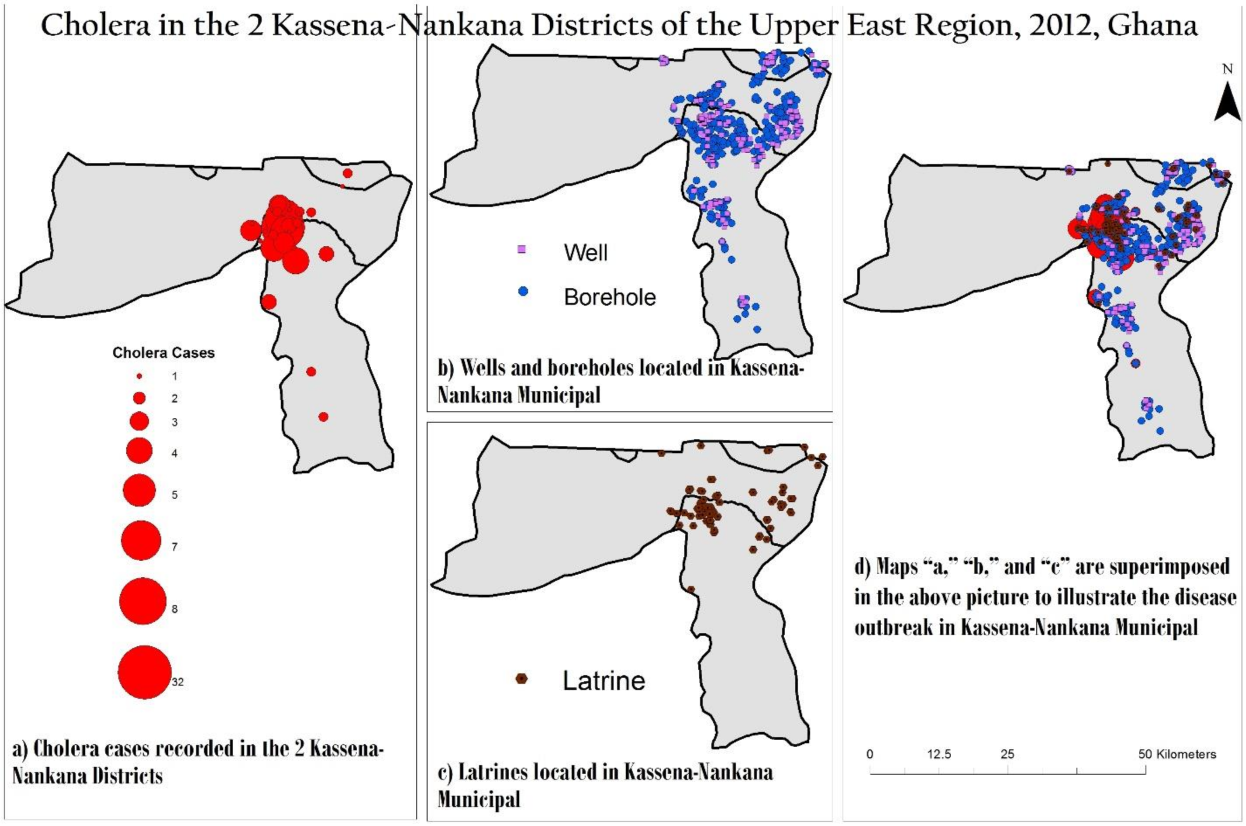
The shallowness and lack of an approipriate cover could allow for contamination from runoff or dirty draining water which could easily pollute the water source. Further, the water source could contribute to malaria prevalence since it presented as a form of stagnant water. The above situation was therefore reported to the Regional Director of Health Services who then worked to secure funding to build a borehole for the people of Shia-Tindongo. Thus, the GIS work brought to limelight an issue that otherwise might have been unresolved for years.

*Cholera in the Kassena-Nankanas*

Before GIS introduction in the UER, Disease Control officers in DHMTs manually marked the location of cases during disease outbreaks on hand drawn maps. However, the hand drawn maps were often inaccurate, resulting in inaccurate siting of cases. Moreover, accurate counting of cases in a particular household or community once there was a spike in incidence rate was a frequent problem. Furthemore, it was difficult to keep records of disease outbreaks over a period of time as many hand drawn maps were required to precisely show an outbreak from the index case, to prevalence, how many people received treatment, etc. Introduction of GIS tecnology helped to address the above problems as well as raise important questions in such circumstances.

The 2012 cholera outbreak in Kassena-Nankana East and West districts illustrates how GIS is improving tracking of disease outbreaks in the UER and consequently improving the response to future epidemics. In Figure 3, the map labelled "d" displays a superimposing of wells, latrines and boreholes to show that more reported cholera cases occurred where most of these amenities existed. This map was impossible to create before the 2012 GIS work. However, its production raised questions concerning possible human waste drainage into water sources. The possibility of having such a map helps the District Directors as well as the Regional Director of Health Services readily visualize health problems in the region, find ways to investigate them, discover solutions and be better prepared in case similar disease outbreaks occur in the future.

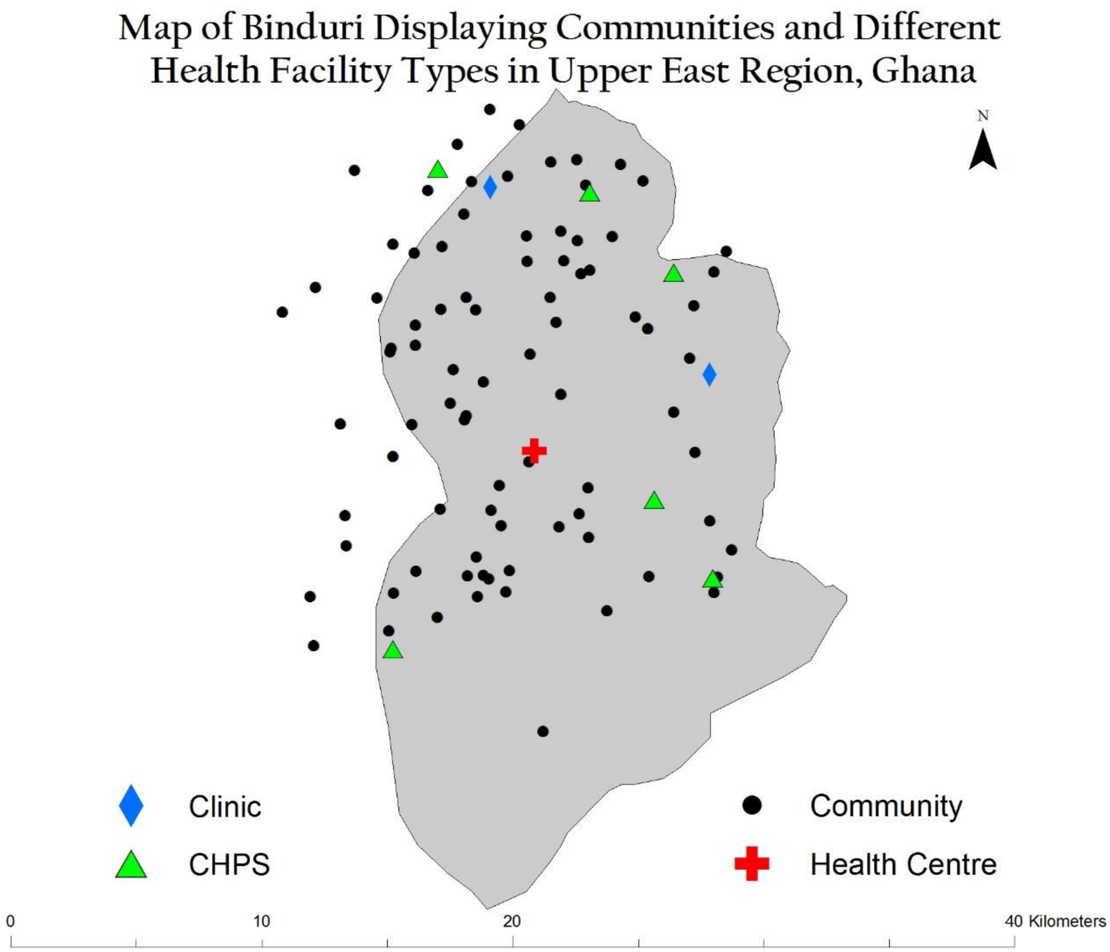
**Figure 3- Cholera in UER**




*Locating a community health facility: The Binduri Case*

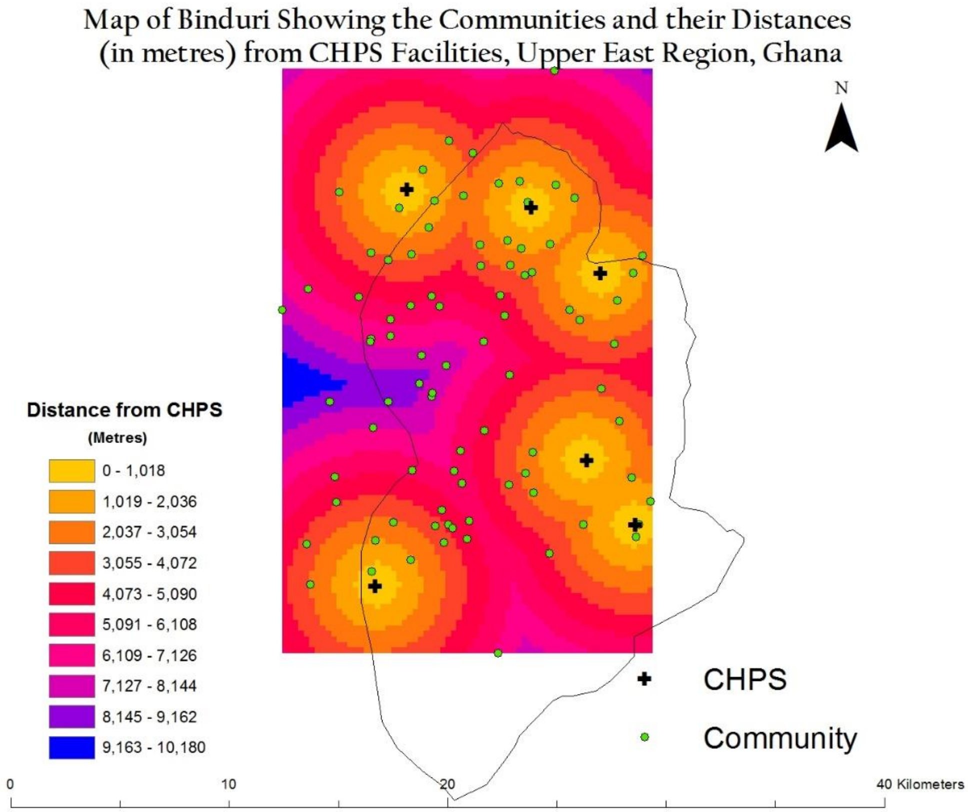
GIS was used in the UER to optimize the location of community facilities. In September 2013 the District Director of Binduri, was tasked with proposing suitable locations to site new CHPS health facilities. The main aim was to site the CHPS at strategic points in order to cater to more residents and reduce travel distances especially during emergencies. To solve this issue, the GIS team gathered the waypoints of all health facilities and communities located in the district. The information was then mapped and displayed in Figure 4 below:

**Figure 4- Binduri Health Facilities Map**




As Figure 4 shows, the map provided immediate information on visualization of Binduri District communities that lacked accessible health facilities. To augment this information, the Spatial Analyst tool, Euclidean Distance, was used to calculate the distance from each community to the nearest health facility. An example of the generated map is displayed in Figure 5.

**Figure 5- Euclidean Distance of Binduri Health Facilities**

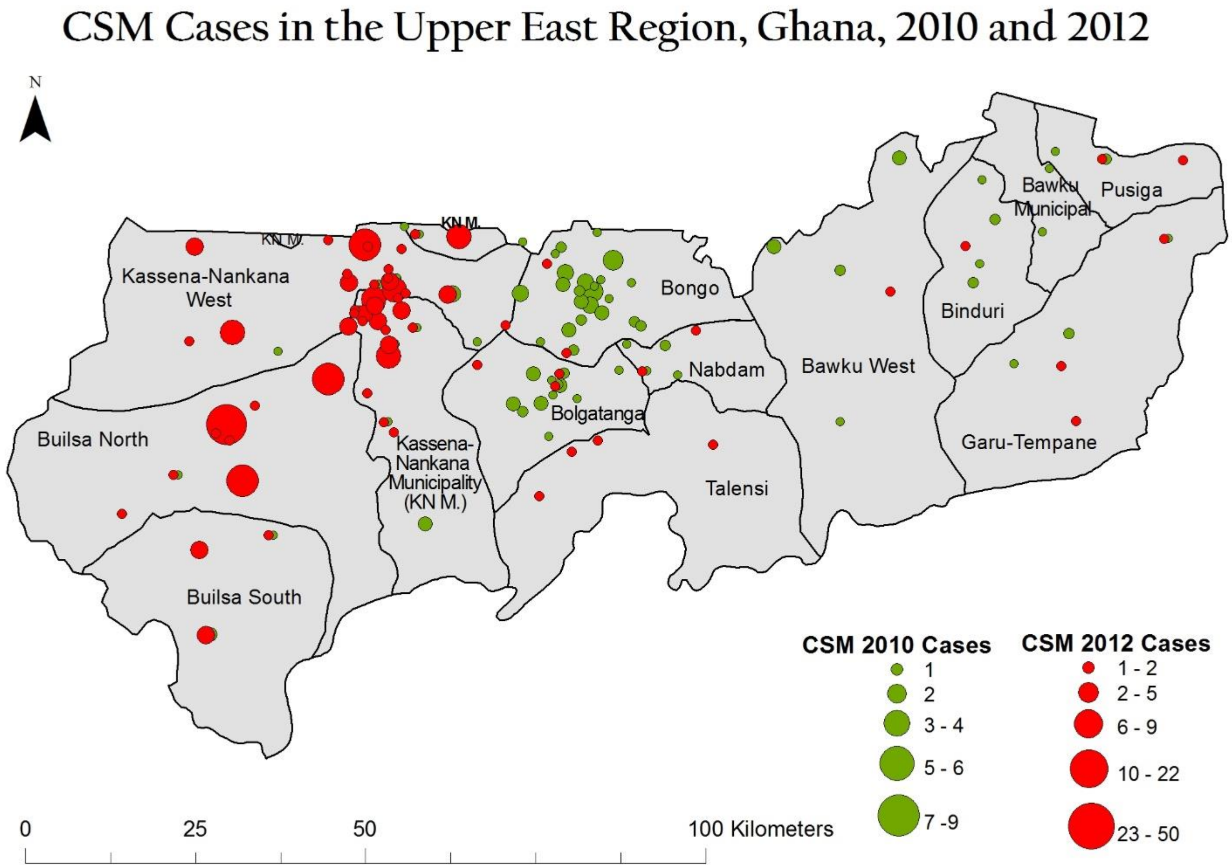



Distances generated by ArcMap 10.2.2 were transported into MS-Excel Spreadsheets and shared with the DHMT to inform their priorities for the construction of new CHPS facilities. Maps, in turn, were used in exchanges with local, political and development authorities to advocate for the allocation of development revenue for CHPS startup costs. These presentations have proved to be useful for justifying development investment in future health care facilities in the UER.

*Cerebro-Spinal Meningitis (CSM) and the UER*

Cerebro-Spinal Meningitis (CSM) is hyper-endemic in the Sahelian "meningitis belt" (Besancenot, Boko, & Oke, 1997; Dukić et al., 2012; Molesworth et al., 2002) extending across eighteen sub-Saharan African countries. Sahelian northern Ghana has experienced CSM outbreaks occurring in regular 10 year cycles (Lamelas et al., 2014; Owusu et al., 2012) the most recent of which occurred in 2010 and 2012. CSM outbreaks can be addressed, however, if emergency vaccination campaigns are launched without delay (Woods et al., 2000). GIS enabled the UER Regional Health Administration to map the reported cases of CSM recorded over 2010 and 2012 epidemic years in the UER. Figure 6 portrays the results of this investigation.

**Figure 6- CSM in UER**




Between the years 2010 and 2012 the CSM incidence shifted westward. For example, in 2010 most cases were recorded in Bongo, but in 2012 the preponderance of incidence shifted to Kassena-Nankana West and Builsa North. The cause of this shift is unknown, but speculation concerns the association of the force of the epidemic with the direction of prevailing trade winds. Studies have revealed the strength of the northeasterly trade winds that blow over eastern, western and parts of northern Africa between Latitudes $0^0$ and $30^0$ N. Gyan et al., (2005) in their study concluded that there was an association between pediatric admissions in the Caribbean Island Trinidad and African dust clouds carried by the easterly trade winds. Additionally, in Prospero's (1999) work he discussed the discovery of African mineral dust in southeastern United States which was attributed to the northeasterly trade wind flow from the continent. Such research reveal the strength of the northeasterly trade winds lending support to the hypothesis that the westward movement of CSM is related to wind and climatic conditions. Figure 5 invites policy deliberations on ways to use GIS to prioritize immunization campaigns at the outset of CSM epidemics.

### *Conclusion*

This paper discussed GIS and its beneficial aspects not only to the UER GHS workers but to the population that they serve. In severely resource constrained settings, such as the circumstances of the UER in Ghana, GIS can contribute information for improving the geographic prioritization of preventive and ambulatory health care delivery. The technology helped direct attention to the water needs of the Shia-Tindongo community, demonstrated new ways to improve disease tracking, provided precise locations for new health facilities and highlighted features of the temporal pattern of CSM incidence in the African meningitis belt.

Ghana is in the process of extending the application of GIS to practical health system programming and research. With GIS as a routine tool for regional and district managers to apply, health professionals could visualize service needs, manpower coverage gaps, and facility visitation patterns based on age, sex, or social characteristics of populations served. In particular, GIS in Ghana could facilitate decision-making in times of disease outbreaks crisis, contributing directly to the resilience of health systems (Kruk, Myers, Varpilah, & Dahn, 2015). In 2014, there was a widespread cholera outbreak in the nation and according to WHO Regional Office for Africa (2014), “cumulatively, 14,411 cases including 127 deaths … [were] reported from 74 districts in 8 out of the 10 regions in the country.” In such cases GIS technology could be used to visualize the spread of the epidemic and pinpoint localities where the disease burdens is elevated by an outbreak, guiding action needed to contain their spread.

Ghana as a developing country is full of health problems such as malaria, typhoid fever, pneumonia, cholera, CSM, etc. Such diseases can be more efficiently dealt with if health officials have visual maps of the country showing where many of these illnesses usually originate. If disease origins can be linked to particular parts of the country through usage of interactive maps, then the appropriate health workers can be deployed. GIS technology can further help to show the places where more health facilities are needed thereby improving the efficiency and effectiveness of primary health care throughout the nation.

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