Post-Optimality Analysis of Siting Plans of Community-Based Health Planning and Services Facilities in the Upper East Region of Ghana

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ABSTRACT

Many rural communities in Ghana face the challenge of access to healthcare due to fewer and often inaccessible available health facilities and which is a national concern. The Community-Based Health Planning and Services (CHPS) facility concept was conceived to help address the problem. In a previous study (Nantomah and Twum, 2017), the authors approached the problem as integer programming and formulated a Maximum Covering Location model for it, to determine optimal locations for siting a few of the CHPS facilities in order to maximize access for the people in as many communities as possible from three selected districts of the Upper East Region of Ghana. In the current work, post–optimality analysis is undertaken to assess how the optimal solutions change with slight changes in selected parameters of the model so as to provide further insight into the nature of the problem. The same data and methodology as in the previous study were used. The results indicate that a number of siting plans that ensure that majority of the people or all the communities are within prescribed service distance of the facilities are possible.

Keywords*: Maximum Coverage; CHPS facilities; Post-optimality; Population*

1. INTRODUCTION

In Ghana, amongst the topmost priority of government is to provide healthcare facilities and quality health care services. The Ghana national health policy (MOH, 2007) indicates that health is intrinsically desirable and a prerequisite for socio-economic development. The Policy seeks to reduce excessive risk and burden of morbidity, mortality and disability, particularly among the poor and the marginalized groups. It also seeks to ensure that people live long, healthy and to reproduce without any increased risk of injury or death and to reduce inequalities in access to health.

In order to achieve universal access to health care services, the Community-Based Health and Planning Services (CHPS) was conceived. The CHP Policy intends to make health care services accessible to the rural folks through siting CHPS facilities within communities which are managed by resident nurses and community volunteers. The siting of the CHPS facilities is capital intensive and also could be in competition with provision of other social interventions and therefore must not be done haphazardly to ensure as many people as possible can access the few facilities that may be provided to ensure value for money. This calls for pragmatic and scientific approach to the problem.

The situation described above belongs to the class of location problems which have been well studied in optimization using integer or mixed integer optimization techniques as the modeling tool. Where the criterion to be optimized is coverage, one of the typical formulations is the Maximum Covering Location model; using integer programming techniques.

Most emergency facility location problems are solved by Covering models (Amponsah, *et al.*, 2011). The main objective of Covering models is to provide coverage to the demand nodes. A demand node is deemed covered only if a facility is available to serve the demand node within a coverage distance which is normally referred to as a "covering" distance. Central to Covering models is the notion of coverage. Toregas, *et al.*,(1971) formulated the Set Covering Location Problem (SCLP) which aims at siting the minimum number of facilities required to "cover" all the demand nodes. The fundamental assumption of the SCLP is that all demand nodes must be covered by a facility. Following the SCLP formulation was the development of the Maximum Covering Location Problem (MCLP) by Church and ReVelle (1974). The MCLP seeks to maximize the population that can be served by a limited number of facilities within a stated service distance or time. Thus, a population is considered covered if it is within a predefined service distance (or time) from at least one of the existing facilities.
Verter and Lapierre (2002) formulated the Capacitated MCLP model that maximizes attendance at preventive health care centres. The earliest formulation which ensured that each population centre was assigned to the closest open facility was solved by Verter and Lapierre (2002) using numerical data from Fulton County, Georgia and the optimal solution recommended the operation of four public health centres to cover 65% of the population. The formulation was improved by ensuring that each population centre is assigned to its closest alternative site, if there is a facility at that site, and this was applied to maximize participation in breast cancer screening centres in Montreal, Quebec. The optimal solution suggested the accreditation of 17 mammography centres, with maximum expected coverage of 50% women in Montreal. Dell'Oimo, *et al.*, (2013) formulated a multi period maximum covering location model to find optimal location of intersection safety cameras for reducing accidents on an urban traffic network, assuming that each camera can be sited at a given intersection and cover a circular detection area. Dell'Oimo, *et al.*, (2013) tested their model with two different scenarios. They first tested their formulation with 15 intersection safety cameras, a covering distance (radius of the intersection safety detection) ranging from 100meters to 300meters and a discrete fixed number of nine time periods. The results showed direct relationship between covering distance and optimal solution (total weighted coverage). They further tested the model using 30 intersection safety cameras and time periods varying from 1 to 9. The results indicated direct relationship between the mean coverage value per time period and the optimal solution. The optimal solution increased from 1577 to 13502 from time periods 1 to 9 and the corresponding mean coverage value per time period also decreased from 1577 to 1500 within the same time periods.

Rajagopalan, Saydam and Xiao (2007) applied a multiperiod set covering location model in the field of emergency medical services (EMS). The model aimed at minimizing the number of ambulances that are required to provide predetermined level of coverage, determining their location on different time periods and also considered the fluctuations in the demand patterns by means of a probabilistic approach. The model was solved by a tabu search algorithm using data

from emergency service agency. Curtin, *et al.,* (2007) determined optimal Police Patrol Areas design with Maximal Covering and Backup Covering Location Models. The optimal solutions proposed five best locations that would cover the weighted incidents. Their results showed remarkable improvements (18.9%) in the ability of the police to respond to calls for service. The 18.9% reduction in total distance traveled by police officers to incidents drastically improved response times and reduced cost.

The Backup Covering Location Models ensure that more than one patrol car covers an incident within a service distance. The optimal solutions clustered around the most serious incidents to the neglect of less serious incidents. Amponsah, *et al.*, (2011) used Maximum Expected Covering Location model to determine the locations of seven ambulance emergency medical services in the Kumasi Metropolis. They used Floyd-Warshall algorithm to obtain the distance matrix from all pairs shortest path of the edge distances between all nodes on the graph network and applied genetic algorithm in solving the problem.

As a follow up to the previous work by the authors, a post-optimality analysis of the MCLP model was undertaken in this current work with a view to analyze the range of possibilities of the solution in order to propose a range of alternative siting plans of the CHPS facilities. The methodology and data therefore are the same as in the previous work. In the next section the MCLP model is outlined and the sort of post-optimality analysis undertaken discussed. The results of the analysis using the original data for the previous work in Nantomah and Twum (2017) are presented in the subsequent section. The final section concludes the discussions and makes recommendations for the alternative optimal siting plans for the facilities.

2. The MCLP Model

The problem of optimally siting CHPS facilities is one that seeks to maximize community population coverage within a given service distance given a limited number of CHPS facilities. The Maximum Covering Location model representation of the problem is given by:

$$Maximize \sum_{i\epsilon I} h_i z_i, \qquad \forall i \epsilon I \qquad (1.1)$$

$$Subject\ to: \sum_{j\in N_i} x_j - z_i \geq 0 \qquad \forall i \epsilon I \qquad (1.2)$$

$$\sum_{j\epsilon J} x_j = p, \qquad (1.3)$$

$$x_j \epsilon \{0,1\}, \qquad \forall j \epsilon J \qquad (1.4)$$

$$z_i \epsilon \{0,1\}, \qquad \forall i \qquad (1.5)$$

where:

I = Set of population communities indexed by i

J = Set of potential CHPS facility communities indexed by j.

$d_{ij} = The\ shortest\ distance\ between\ population\ community\ i\ and\ potential\ CHPS\ facility\ community\ j$

$D_c = Distance\ beyond\ which\ population\ community\ i\ is\ not\ covered.$

$N_i = \{j | d_{ij} \leq D_c\}$, *is the set of all potential CHPS facilities that can cover the population in community* i

$h_i = Population\ to\ be\ coveredat\ community\ i$

$p = Fixednumberof\ CHPS\ facilities\ to\ site$

x_j and z_i are the decision variables, given respectively by:

$$x_j = \begin{cases} 1, & if\ \ CHPS\ facility\ is\ sited\ in\ community\ j,\ \ \forall j \in J \\ 0, & otherwise \end{cases}$$

$$z_i = \begin{cases} 1, & If population\ at\ community\ i is covered\ \forall i \in I \\ 0, & otherwise \end{cases}$$

The objective function (1.1) maximizes the number of people covered within the desired service distance. Constraint (1.2) ensures that population at community i cannot be considered covered unless at least one CHPS facility is sited that is able to cover the community. Constraint (1.3) ensures that a fixed number (p) of CHPS facilities are sited; constraints (1.4) and (1.5) reflect the binary nature of the facility siting decisions and community coverage, respectively.

3. Post-optimality Analysis

In view of the fact that the single optimal solution generated for a problem is only tentative or preliminary especially in real problems, there is the need to also undertake further analysis with any given model to assess the stability or sensitivity of the model and the solution it provides (Baker, 2011).Therefore, a sensitivity analysis is undertaken by varying the input values of selected parameters to investigate the model further.

The sensitivity analysis for this work is covered under two scenarios. The first considers a fixed service distance at the prescribed figure of 5 kilometers and varied number of CHPS facilities ranging between two (2) and (4) inclusive. The second considers varied service distance between 5 and 8 Kilometers and varied CHPS facilities between two (2) and four (4). The resulting models in respect of the various parameter values and for each district are solved using the Excel Solver.

4. Results and Discussions

4.1 Bongo District

The Bongo District had 35 communities and therefore 35 potential CHPS facility sites. The straight-line distances between pairs of communities when permuted yield a 35×35 symmetric distancematrix. The estimated population of the district was 74,239 (projection on 2010 population & Housing Census figure).The service distance was set to 6 km and the number of CHPS facilities to be sited varied from two to four to observe the behaviour of the model. The

best communities to site the CHPS facilities and the communities expected to be served are recorded in Table 1.

Table 1: Optimal locations of CHPS facilities within 6 km service distance

Best sites (P=2)	**Communities served**	**Population covered**
Asebuga	Bongo, Boko, Adaboya, Beo Kumbusgu, Bogorogo, Akanaba, Akunduo, Asebuga, Beo, Sapuoro, Soe Kabre, Soe Kanseringa, Soe Kuliyawgo, Feo Ashebre, Feo Akunka, Feo Nabisi, Feo Acharaba, Feo Ayelbia, Zoko Gambrongo Azaabisi, Vea, Yorogo, Gowrie, Anafobisi, Beo Dua	57571 (77.5%)
Zoko Goo	Balungu Gantorisi, Namoo, Nayorogo, Towongo, Zoko Gambrongo Abagnabisi, Zoko Kadare, Zoko Tarongo, Zoko Kanga, Zoko Goo Awaa, Zoko Goo, Samboligu	
Best sites (P=3)	**Communities served**	**Population covered**
Asebuga	Bongo, Adaboya, Beo Kumbusgu, Bogorogo, Akanaba, Akunduo, Asebuga, Beo, Sapuoro, Soe Kabre, Soe Kanseringa, Soe Kuliyawgo, Feo Acharaba, Feo Ayelbia, Zoko Kanga, Yorogo, Anafobisi, Beo dua	68912 (92.8%)
Namoo	Boko, Namoo, Feo Ashebre, Feo Akunka, Feo Nabisi, Nayorogo, Towongo, Zoko Kadare, Zoko Goo, Samboligu	
Zoko Tarongo	Balungu Gantorisi, Zoko Gambrongo Abagnabisi, Zoko Tarongo, Zoko Gambrongo Azaabisi, Zoko Goo Awaa, Vea, Gowrie	
Best sites (P=4)	**Communities served**	**Population covered**
Asebuga	Bongo, Adaboya, Beo Kumbusgu, Bogorogo, Akanaba, Akunduo, Asebuga, Beo, Sapuoro, Soe Kabre, Soe Kanseringa, Soe Kuliyawgo, Anafobisi	74239 (100%)
Feo Ashebre	Boko, Namoo, Feo Ashebre, Feo Akunka, Feo Nabisi, Feo Acharaba, Feo Ayelbia	
Zoko Gambrongo Abagnabisi	Balungu Gantorisi, Nayorogo, Towongo, Zoko Gambrongo Abagnabisi, Zoko Kadare, Zoko Tarongo, Zoko Gambrongo Azaabisi, Zoko Kanga, Zoko Goo Awaa, Zoko Goo, Samboligu	
Yorogo	Vea, Yorogo, Gowrie, Beo Dua	

The results show that Asebuga and Zoko Goo are the best communities to site two CHPS facilities. Table 1 displays the communities that the two CHPS facilities could serve and the proportion (77.5%) of the population expected to be covered. Increasing the number of CHPS facilities to be sited to three, yields Asebuga, Namoo and Zoko Tarongo as the best communities to site the

facilities. The proportion of the population covered also increased to 92.8%. Again, when the number of CHPS facilities increased to four, a 100% coverage of the population is achieved. The best communities are Asebuga, Feo Ashebre, Zoko Gambrongo Abagnabisi and Yorogo. In summary, setting the service distance to 6 km can lead to siting two, three and four CHPS facilities to serve 77.5%, 92.8% and 100% of the population respectively.

To further examine the behaviour of the model, the service distance was increased to 7 km and the number of CHPS facilities varied from two to four. With these changes in the parameter values, the corresponding best locations and served communities are recorded in Table 2.

Table 2: Optimal locations of CHPS facilities within 7 km service distance

Best sites (P=2)	**Communities served**	**Population covered**
Balungu Gantorisi	Bongo, Balungu Gantorisi, Boko, Akunduo, Namoo, Feo Ashebre, Feo Nabisi, Feo Ayelbia, Nayorogo, Towongo, Zoko Gambrongo Abagnabisi, Zoko Kadare, Zoko Tarongo, Zoko Gambrongo Azaabisi, Zoko Kanga, Zoko Goo Awaa, Zoko Goo, Vea, Yorogo, Samboligu, Gowrie, Anafobisi	64277(86.6 %)
Akanaba	Adaboya, Beo Kumbusgu, Bogorogo, Asebuga, Beo, Sapuoro, Soe Kabre, Soe Kanseringa, Soe Kuliyawgo, Feo Akunka, Feo Acharaba, Beo Dua	
Best sites (P=3)	**Communities served**	**Population covered**
Akanaba	Bongo, Adaboya, Beo Kumbusgu, Bogorogo, Akanaba, Akunduo, Asebuga, Beo, Sapuoro, Soe Kabre, Soe Kanseringa, Soe Kuliyawgo, Feo Akunka, Feo Ayelbia, Yorogo, Anafobisi, Beo Dua	71815(96.7 %)
Namoo	Balungu Gantorisi, Boko, Namoo, Feo Ashebre, Feo Nabisi, Nayorogo, Towongo, Zoko Kadare, Zoko Goo, Samboligu	
Zoko Tarongo	Zoko Gambrongo Abagnabisi, Zoko Tarongo, Zoko Gambrongo Azaabisi, Zoko Kanga, Zoko Goo Awaa, Vea, Gowrie	
Best sites (P=4)	**Communities served**	**Population covered**
Bongo	Bongo, Balungu Gantorisi, Bogorogo, Akanaba, Akunduo, Asebuga, Beo, Soe Kabre, Feo Akunka, Nayorogo, Vea, Gowrie, Anafobisi, Beo Dua	74239(100 %)
Sapuoro	Adaboya, Beo Kumbusgu, Sapuoro	
Feo Acharaba	Boko, Soe Kanseringa, Soe Kuliyawgo, Feo Ashebre, Feo Nabisi, Feo Acharaba, Feo Ayelbia, Nayorogo	

Zoko Goo	Namoo, Towongo, Zoko Gambrongo Abagnabisi, Zoko Kadare, Zoko Tarongo, Zoko Gambrongo Azaabisi, Zoko Kanga, Zoko Goo Awaa, Zoko Goo, Samboligu	

The results in Table 2 indicate the best communities to site two CHPS facilities as Balungu Gantorisi and Akanaba. These would cover 86.6% of the population. Increasing the number to three will increase the population coverage to 96.7%. The best communities to site the three are Akanaba, Namoo and Zoko Tarongo. The results show (see Table 2) that siting four CHPS facility will ensure 100% coverage of the population and the best communities are Bongo, Sapuoro, Feo Acharaba and Zoko Goo. Each could serve at least three communities.

Further sensitivity analysis was conducted by increasing the service distance to 8 km, while varying the number of CHPS facilities to be sited from two to three. The results are displayed in Table 3.

Table 3 Optimal locations of CHPS facilities within 8 km service distance

Best sites (P=2)	**Communities served**	**Population covered**
Nayorogo	Balungu Gantorisi, Boko, Namoo, Feo Nabisi, Feo Ayelbia, Nayorogo, Towongo, Zoko Gambrongo Abagnabisi, Zoko Kadare, Zoko Tarongo, Zoko Gambrongo Azaabisi, Zoko Kanga, Zoko Goo Awaa, Zoko Goo, Yorogo, Samboligu, Gowrie	
Anafobisi	Bongo, Adaboya, Beo Kumbusgu, Bogorogo, Akanaba, Akunduo, Asebuga, Beo, Sapuoro, Soe Kabre, Soe Kanseringa, Soe Kuliyawgo, Feo Ashebre, Feo Akunka, Feo Acharaba, Yorogo, Anafobisi, Beo Dua	72273(97.4%)
Best sites (P=3)	**Communities served**	**Population covered**
Beo Kumbusgu	Adaboya, Beo Kumbusgu, Bogorogo, Akanaba, Asebuga, Beo, Sapuoro, Soe Kabre, Yorogo, Anafobisi, Beo Dua	
Feo Ayelbia	Soe Kanseringa, Soe Kuliyawgo, Feo Ashebre, Feo Akunka, Feo Nabisi, Feo Acharaba, Feo Ayelbia	74239 (100%)
Nayorogo	Bongo, Balungu Gantorisi, Boko, Akunduo, Namoo, Nayorogo, Towongo, Zoko Gambrongo Abagnabisi, Zoko Kadare, Zoko Tarongo, Zoko Gambrongo Azaabisi, Zoko Kanga, Zoko Goo Awaa, Zoko Goo, Vea, Samboligu, Gowrie	

The results indicate that with the service distance of 8 km, the best communities for siting two CHPS facilities are Nayorogo and Anafobisi. When so sited could cover 94.7% of the population. A 100% coverage of the population can be achieved by siting a CHPS facility each in Beo Kumbusgu, Feo Ayelbia and Nayorogo.

In summary, when the service distance is set to 6 km, the model sites two, three and four CHPS facilities to cover 77.5%, 92.8% and 100% of the population respectively (see Table 1). The model

also sites two, three and four CHPS facilities to cover 86.5%, 96.7% and 100% of the population respectively (see Table 2) with a service distance of 7 km. Similarly, when the service distance is set to 8 km, the model sites two and three CHPS facilities to cover 97.4% and 100% of the population respectively (see Table 3). The results indicate that an increase in service distance corresponds with least number of CHPS facilities to be sited to attain 100% coverage of the population.

4.2 Builsa North District

The Builsa North District had 30 communities and so 30 potential CHPS facility sites. The distances between pairs of communities when permuted yield a 30×30 symmetric distance matrix. The estimated population of the district was 62,639 (projection on 2010 population & Housing Census figure).The service distance was set to 6 km and the number of CHPS facilities to be sited varied between 7 and 8, to observe the behaviour of the model. The results indicate best communities to site them and the communities they could serve as displayed in Table 4.

The results show that Chuchulliga Azuguyeri Nawasa, Sandema Balansa, Sandema Bilinsa, Kadema Changsa, Wiaga Tandem Tankangsa, Longsa, Sunyensi Zungdem and Kologu Amodalg communities are the best locations for siting seven CHPS facilities that could yield a maximum of nearly 100% population coverage. When the number of CHPS facilities is increased to eight, 100% coverage of the population is achieved and the best communities to site them are Chuchulliga Azuguyeri Nawasa, Sandema Balansa, Sandema Bilinsa Tankungsa, Kadema Changsa, Wiaga Tandem Tankangsa, Longsa, Sunyensi Zungdem and Kologu Amodalg. Each CHPS facility could serve at least one community.

Table 4: Optimal locations of CHPS facilities within 6 km service distance

Best sites (p=7)	Communities served	Population covered
Chuchulliga Azuguyeri Nawasa	Chuchulliga Namonsa Adabissa, Chuchilliga Azuguyeri Yipala, Chuchilliga Azuguyeri Nawasa, Chuchulliga Namonsa Jaata, Chuchilliga Azuguyeri Teedem, Nauwalise, Kologu Amodalg	61978(98.9%)
Sandema Balansa	Sandema Abiliyeri, Sandema Kandem, Sandema Balansa, Sandema Suwarensa, Sinyensi Yikpien	
Sandema Bilinsa	Sandema Nyansa, Sandema Fiisa, Sandema Kobdem, Sandema Bilinsa, Sandema Korri, Sandema Longsa	
Kadema Changsa	Kadema Changsa	
Wiaga Tandem Tankangsa	Kadema Banyangsa, Kadema Gaddem, Kadema Gobsa, Wiaga Tandem Tankangsa	
Longsa	Wiaga Yisobsa, Wiaga Yemonsa, Wiaga Senyansa, Longsa, Farensa	
Sunyensi Zungdem	Sinyensi Akpiokyeri, Sunyensi Zungdem	

Best sites (P=8)	Communities served	Population covered
Chuchulliga Azuguyeri Nawasa	Chuchulliga Namonsa Adabissa, Chuchulliga Azuguyeri Yipala, Chuchulliga Central/ Chuchulliga Azuguyeri Nawasa, Chuchulliga Namonsa Jaata, Chuchulliga Azuguyeri Teedem, Nauwalise	62639(100%)
Sandema Balansa	Sandema Kandem, Sandema Balansa, Sandema Suwarensa, Sinyensi Yikpien.	
Sandema Bilinsa Tankungsa	Sandema Abiliyeri, Sandema Nyansa, Sandema Fiisa, Sandema Kobdem, Sandema Bilinsa Tankungsa, Sandema Korri, Sandema Longsa.	
Kadema Changsa	Kadema Changsa	
Wiaga Tandem Tankangsa	Kadema Banyangsa, Kadema Gaddem, Kadema Gobsa, Wiaga Tandem Tankangsa	
Longsa	Wiaga Yisobsa, Wiaga Yemonsa,, Wiaga Senyansa , Longsa, Farensa	
Sunyensi Zungdem	Sunyensi Akpiokyeri, Sunyensi Zungdem	
Kologu Amodalg	Kologu Amodalg	

Next, the service distance was increased to 7 km and the number of CHPS facilities varied between 6 and 7, and the results are in Table 5. The results indicate that the best communities to site six CHPS facilities are Chuchilliga Namonsa Jaata, Sandema Bilinsa Tankungsa, Kadema Gaddem, Kadema Changsa, Farensa and Sinyensi Yikpien. These could serve 98.9% of the population. Increasing the number of CHPS facilities to seven, yields 100% coverage of the population. In this case, the best communities to site them are Chuchulliga Namonsa Jaata, Sandema Kobdem, Kadema Banyangsa, Kadema Changsa, Farensa, Sinyensi Yikpien and Kologu Amodalg.

Table 5: Optimal locations of CHPS facilities within 7 km service distance

Best sites (p=6)	Communities served	Population covered
Chuchulliga Namonsa Jaata	Chuchulliga Namonsa Adabissa, Chuchulliga Azuguyeri Yipala, Chuchulliga Azuguyeri Teedem, Nauwalise, Chuchulliga Namonsa Jaata	61976(98.9%)
Sandema Bilinsa Tankungsa	Chuchulliga Azuguyeri Teedem, Sandema Fiisa ,Sandema Kobdem, Sandema Bilinsa Tankungsa, Sandema Korri, Sandema Longsa	
Kadema Gaddem	Kadema Banyangsa, Kadema Gaddem, Kadema Gobsa, Wiaga Tandem Tankangsa, Wiaga Senyansa	
Kadema Changsa	Kadema Changsa	

Farensa	Sandema Abiliyeri, Sandema Nyansa, Sandema Balansa, Sandema Suwarensa, Wiaga Yisobsa, Wiaga Yemonsa, Longsa, Farensa, Sinyensi Central	
Sinyensi Yikpien	Sandema Kandem, Sunyensi Zungdem, Sinyensi Yikpien	
Best sites (P=7)	**Communities served**	**Population covered**
Chuchulliga Namonsa Jaata	Chuchulliga Namonsa Adabissa, Chuchulliga Azuguyeri Yipala, Chuchulliga Azuguyeri Nawasa, Chuchulliga Namonsa Jaata, Chuchulliga Azuguyeri Teedem, Nauwalise.	62639 (100%)
Sandema Kobdem	Sandema Fiisa, Sandema Kobdem, Sandema Bilinsa Tankungsa, Sandema Korri, Sandema Longsa,	
Kadema Banyangsa	Kadema Banyangsa, Kadema Gobsa, Wiaga Tandem Tankangsa, Wiaga Senyansa.	
Kadema Changsa	Kadema Changsa	
Farensa	Sandema Abiliyeri, Sandema Nyansa, Sandema Suwarensa, Wiaga Yisobsa, Wiaga Yemonsa, Longsa, Farensa, Sinyensi Akpiokyeri	
Sinyensi Yikpien	Sandema Kandem, Sandema Balansa, Sunyensi Zungdem, Sinyensi Yikpien	
Kologu Amodalg	Kologu Amodalg	

In conclusion, when the service distance was set to 6 km, the model sites seven and eight CHPS facilities to cover 98.9% and 100% of the population respectively (see4). Similarly, when the service distance was set to 7 km, the model sites six and seven CHPS facilities to cover 98,9% and 100% of the population respectively (see Table 5).

4.3 Talensi District

The Talensi had 26 communities and thus 26 potential CHPS facility sites. The distances between pairs of communities when permuted yield a 26×26 symmetric distance matrix. The estimated population of the district was 134,157 (projection on 2010 population & Housing Census figure).

The service distance was set to 6 km and the number of CHPS facilities varied between 5 and 6. In this case, the results are presented in Table 6. The best communities are Tongo Baare, Shiega Winduri, Gorogu, Dushe and Kalboka. The five CHPS facilities would cover 99.2% of the population. Increasing the number of CHPS facilities to six leads to 100% coverage of the population and the best communities are Tongo Baare, Shiega Winduri, Gorogu, Pelungo, Kalboka and Nungu. With the exception of the CHPS facility sited at Nungu, all the other CHPS facilities would serve at least two communities.

Table 6: Optimal locations of CHPS facilities within 6 km service distance

Best sites (P=5)	**Communities served**	**Population covered**
Tongo Baare	Gambibigo, Tongo Baare, Yamnega Yamsoko, Gbeogo, Nungu	133148 (99.2%)
Shiega Winduri	Pwalugu, Balungu, Shiega Winduri, Santienga	
Gorogu	Tenzugu, Tongo, Dusi Gaare, Pusu-Namogo , Gorogu, Winkogo	
Dushe	Yazore, Gbega , Dusi Yale, Dushe, Pelungo	
Kalboka	Shega, Datuku, Datoko Zanwure, Kalboka, Biungu, Kupielga	
Best sites (P=6)	**Communities served**	**Population covered**
Tongo Baare	Shega, Tongo Baare, Yamnega Yamsoko, Yazore, Gbeogo	134157 **(**100%**)**
Shiega Winduri	Pwalugu, Balungu, Shiega Winduri, Santienga	
Gorogu	Tenzugu, Tongo, Dusi Gaare, Pusu-Namogo , Gorogu, Winkogo	
Pelungo	Gbega, Dusi Yale, Dushe, Pelungo	
Kalboka	Shega, Datuku, Datoko Zanwure, Kalboka, Biungu, Kupielga	
Nungu	Nungu	

Further sensitivity analysis was conducted by increasing the service distance to 7 km and number of CHPS facilities varied from 4 to 5. The results are displays in Table 7.
The best communities are Balungu, Gbega, Gorogu and Datuku. CHPS facilities sited in these four communities could cover 99.2% of the population. A 100% coverage of the population is achieved by increasing the number of CHPS facilities to five. The best communities are Balungu, Gbega, Gorogu, Datuku and Nungu. Each CHPS facility would serve at least two communities, except, the one at Nungu.

Table 7: Optimal locations of CHPS facilities within 7 km service distance

Best sites (P=4)	**Communities served**	**Population covered**
Balungu	Pwalugu, Balungu, Nungu	133148 (99.2%)
Gbega	Yamnega Yamsoko, Yazore, Gbega, Dushe, Pelungo	
Gorogu	Gambibigo, Tongo Baare, Shiega Winduri, Tenzugu, Tongo, Santienga, Dusi Gaare, Pusu-Namogo, Gorogu, Winkogo	
Datuku	Gbeogo, Shega, Dusi Yale, Datuku, Datoko Zanwure, Kalboka, Biungu, Kupielga	
Best sites (P=5)	**Communities served**	**Population covered**

Balungu	Pwalugu ,Balungu	34147 (100%)
Gbega	Yamnega Yamsoko, Yazore, Gbega, Dushe, Pelungo	
Gorogu	Gambibigo, Tongo Baare, Shiega Winduri, Tenzugu, Tongo, Santienga, Dusi Gaare, Pusu-Namogo, Gorogu, Winkogo	
Datuku	Gbeogo, Shega, Dusi Yale, Datuku, Datoko Zanwure, Kalboka, Biungu, Kupielga	
Nungu	Nungu	

Further increasing the service distance to 8 km and varying the number of CHPS facilities from 4 to 5 produces the results in Table 8. The best communities to site three CHPS facilities are Shiega Winduri, Yazore and Shega. The CHPS facilities sited would cover 99.2% of the population. Increasing the number of CHPS facilities to four results in 100% coverage of the population. These CHPS facilities are sited in Pwalugu, Gorogu, Dushe and Biungu communities. Each CHPS facilities would serve at least two communities.

In summary, with a service distance of 6 km, the model sites five and six CHPS facilities to cover 99.2% and 100% of the population respectively (see Table 6). When the service distance was set to 7 km, the model sites four and five CHPS facilities to cover 99.2% and 100% of the population respectively (see Table 7) and finally, when the service distance became 8 km, three and four CHPS facilities were sited to respectively cover 99.2 and 100% of the population (see Table 8).

Table 8: Optimal locations of CHPS facilities within 8 km service distance

Best sites (P=3)	**Communities served**	**Population covered**
Shiega Winduri	Pwalugu, ,Balungu, Shiega Winduri, Tenzugu, Tongo, Santienga, Pusu-Namogo, Gorogu, Winkogo, Nungu	134148(99.2%)
Yazore	Gambibigo, Tongo Baare, Yazore, Gbega, Dusi Gaare, Gbeogo, Dusi Yale, Dushe, Pelungo.	
Shega	Yamnega Yamsoko, Shega, Datuku, Datoka Zanwure Kalboka , Biungu, Kupielga	
Best sites (P=4)	**Communities served**	**Population covered**
Pwalugu	Pwalugu, Shiega Winduri	134157 (100%)
Gorogu	Gambibigo, Tongo Baare, Balungu, Tenzugu, Tongo, Santienga, Dusi Gaare, Pusu-Namogo, Gorogu, Winkogo	
Dushe	Yamnega Yamsoko, Yazore , Gbega, Gbeogo, Dusi Yale, Dushe, Pelungo , Kupielga	
Biungu	Shega, Datuku, Datoka Zanwure, Kalboka, Biungu, Nungu	

Conclusion

Access to health facilities is a major challenge particularly in deprived communities. This study provides alternative siting plans for CHPS facilities taken to consideration resource constraints of the districts. The findings of the study provide flexibility for duty bears to choose CHPS facilities siting plans that suit their resources. However, some compromises may be required in terms of number of facilities to be sited against service distances.

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