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Improving the method for district safe water coverage estimation in Uganda

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The clean, safe and available water is collected from protected and improved water facilities by rural communities Worldwide for their daily use. However factors such as functionality, water quality, population density, walking distances, assumptions and separations between water facilities have been identified challenges to safe water coverage estimation; leading to inaccurate Safe Water Coverage estimation. Water facilities were plotted on a map using their coordinates; walking distances of 1km radii buffered on each water facility using ArcGIS software forming rings. The rings of maximum walking distances together with water sources separation, population density were then used to derive formulae to improve Safe Water Coverage estimation. Serere District was sampled and studied to adequately assess peoples' access to safe water. This method is better than the current one because all the factors affecting safe water accessibility were considered; the results reflected water facilmities' and population distribution.

Introduction

The indicator for sector performance monitoring of Rural Water Supply is the water supply coverage; the drinking water which rural communities need should be available, clean and safe for consumption (Macdonald, *et al*, 2009; Welle, 2010; Hubbarda, *et al*, 2011; Yang, *et al*, 2013) but the problem facing our society today is the provision of adequate safe water for human survival (INSTRAW & UNICEF, 1980; MacDonald & Ó Dochartaigh, 2009; Lockwood & Smits, 2011; Oudaa, *et al*, 2014). Rural Water Supply are point improved water facilities (WFs) of different source types such as deep borehole (BH), motorized BH (MBH), rainwater harvesting tank (RWHT), yard tap (YT), public stand post (PSP), protected spring (SPW), shallow well (SW), Kiosk (K) and household connection (HC) (Victoria, *et al*, 2005; UNEP, 2002; UNICEF & WHO, 2012; Bain, *et al*, 2012; Kostyla, *et al*, 2015). Globally, Safe Water Coverage (SWC) is computed by summing the product of water systems or WFs and their respective standard number of people served; expressed as percentage to the total population (Moriarty, *et al*, 2011; Quin, 2007; Nalubega & Seidelmann, 2007). The general equation is presented as;

$$SWC(\%) = \left(\frac{\begin{array}{l} BH(s)xno.poeple + SW(s)xno.people + PSP(s)xno.people + \\ SPW(s)xno.people + MBH(s)xno.people + K(s)xno.people + \\ RWHT(s)xno.people + HC(s)xno.people + YT(s)xno.people \end{array}}{SUB-COUNTY.POPULATION} \right) x100 \quad \text{….(Equation I)}$$

The method has been used by developing Countries such as Uganda, Ghana, Tanzania, South Africa, India, Mozambigue, Malawi, Burkina Fasco, etc (Moriarty, *et al*, 2011; Jiménez & Pérez-Foguet, 2012; Gutierrez, 2005; Quin, 2007; Nalubega & Seidelmann, 2007). This method is not realistic and excludes factors that directly affect SWC estimation in the following ways:

1. The inclusion of non-functional WFs for up to five years in the SWC estimation until they are repaired or written off denies rural communities' access to safe water, they are included in the estimation. The percentage functionality statuses of WFs calculated yearly does not even have direct relationship with SWC determination method (MoWE, 2012).
2. The method do not consider water quality in the SWC determination (Sam, *et al*, 2011; Baina, *et al*, 2014). According to MoWE (2012) and WHO (2008), contaminated improved WFs are part of the total number of WFs used in the SWC estimations.
3. The method assumes a standard number of people served per technology which are fixed differently by every Developing Country (Nalubega & Seidelmann, 2007; Moriarty, *et al*, 2011). The standard numbers could be high or low depending on the level of crowding.
4. The maximum walking distances to WFs in the definition have no link to the estimation method, some people travelled long distances to access these WFs (INSTRAW & UNICEF, 1980; Gutierrez, 2005; UNEP, 2002).
5. The separations between WFs greatly affect the values of SWCs. Most WFs are concentrated in particular localities (due to settlement or high water potential) resulting into very high facility densities and therefore experiencing SWCs of over 100% (Nalubega & Seidelmann, 2007).

In this research, we improved the method for safe water coverage estimation using the additional criteria of functionality and water quality during data editing while walking distance, water source separation, and population density were used in the later stages of the formulae derivation. The specific study items were; evaluating the factors & assumptions and improving SWC estimation formular.

Methodology

The study was done in Serere District in Eastern Uganda, sampled from the 112 Districts of Uganda by random sampling. All the eight Sub-Counties of the District were involved in the study.

Data collection and presentation

Data on 800 safe WFs were collected from Serere District; 668 WFs and 757 WFs were functional and had coordinates respectively. After data editing, only 625 WFs were used in this research because they were functional and had coordinates. Another set of data collected is shown in table 1.

Table 1. Serere District data: population, PD and area (MoWE, 2012)

S/N	SUB-COUNTY	POPULATION	POPULATION DENSITY
1	BUGONDO	33800	142.720
2	KADUNGULU	25700	160.638
3	LABORI	7400	27.368
4	PINGIRE	48700	231.081
5	KATETA	52400	297.65
6	ATIIRA	20400	174.3
7	KYERE	46700	205.01
8	OLIO	37200	218.6

Plotting water points and PDs on a map

The coordinates of the WFs were plotted on a map using ArcGIS to find their locations (Quin, 2007; Welle, 2010; Boyina, *et al*, 2015); walking distances of 1km radii were buffered on each WF forming rings as shown in figure 1& 2, Population Densities (PDs) of each Sub-County were also inserted in the map. This is done by loading shape file for Uganda into ArcMap window from a drive where data for Uganda is stored. The District name were added from the title bar by selecting attributes containing District names, all other levelings were done and presented in figure 1.

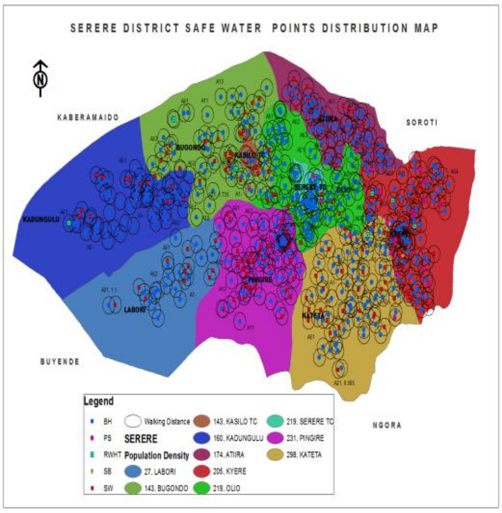

Figure 1. Serere district water points and PD distribution map

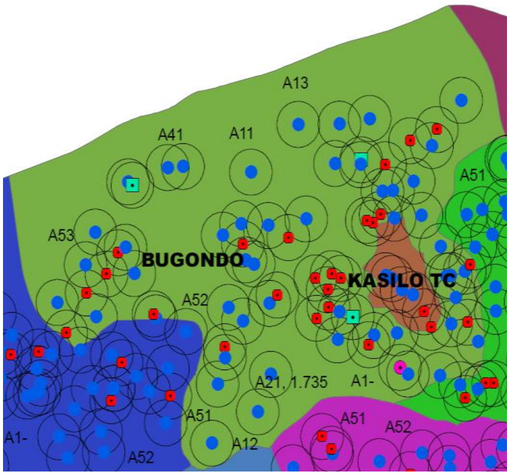

Figure 2. Location and WFs' access in Bugondo Sub-county

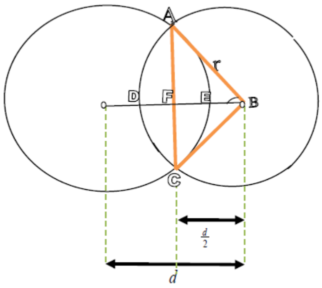

Figure 3. Double served area by 2WFs

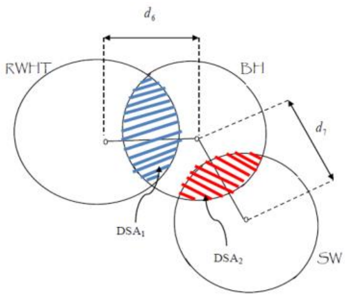

Figure 4. Two double served areas by 3WFs

Estimation procedure

There are seven stages in the estimation process and in stages 1-6, one formular was derived per stage for the calculatin of Populations Served ($PS_{1\text{-}6}$). In the last stage, Populations Served per stage were aggregated to come up with the overall PS. This formula was applied on the assumptions that population is evenly distributed, there is constant water supply by the WFs, there is/are overlap of areas served, WFs produces >0.5m^3 per hour and only people within the walking distances accesses the WFs.

Stage 1: Estimation of population served (PS_1) when $d \geq 2km$.

WFs marked A11, A12 and A13 in figure 2 which are atleast 2km from each other donot cause overlapping and are used in this stage for formula derivation to compute PS_1 for the sub-county. Each WF having a ring of maximum walking distant was considered as a circle, the area of each circle is taken as the area served by the WF. PS_1 (Equation II) was derived from first principle and presented as;

$$\Leftrightarrow PS_1 = n\pi r^2 \times PD \quad \text{(Equation II)}$$

Stage 2: Estimation of population served (PS_2) when $d \angle 2km$.

In figure 2, two WFs marked A21 has separation d (1.735m). It's shown in figure 3 for PS_2 derivation where d is separation of the two WFs and r its radius. The actual area served is the sum of the two individual areas of the 2WFs minus the Double Served Area (AECD). The formula was derived from first principle and presented as Equation III.

$$PS_2 = \left[2\pi r^2 \left(1 - \frac{1}{180^0} \cos^{-1}\left(d/_{2r} \right) \right) + d\sqrt{\left(r^2 - d^2/_4 \right)} \right] \times PD$$ ……….……(Equation III)

Stage 3: Estimation of population served (PS_3) when (d_6 & d_7 $\angle 2km$).

Figure 4 shows 3WFs with separations d_6 & d_7 ($d_6 \neq d_7$) and two Double Served Areas (DSA_2). The formula for PS_3 was derived from first principle and presented as;

$$PS_3 = \left[3\pi r^2 - \frac{1}{90^0} x \pi r^2 \left(\cos^{-1}\left(d_6/_{2r} \right) + \cos^{-1}\left(d_7/_{2r} \right) \right) + d_6\sqrt{\left(r^2 - d_6^2/_4 \right)} + d_7\sqrt{\left(r^2 - d_7^2/_4 \right)} \right] \times PD$$ ……….. (Equation IV)

Stage 4: Estimation of population served (PS_4) when (d_{10}, d_{11}, …., dn $\angle 2km$).

Consider four or more WFs marked A41in figure 2, the circular ring of each WF overlap each other several times. It was noted that some areas were served by several WFs, making it complex to come up with a single formula for area estimation. Area served (AS_4) was then directly measured using ArcGIS software, multiplying it by Population Density gives PS_4.

$\Leftrightarrow PS_4 = AS_4 \times PD$ ……………………….…………………..…. (Equation V)

Stage 5: Estimating population served (PS_5) at the boundary

WFs marked A51 is located less than 1km (<1km) from the sub-county boarder and serves both sub-counties because the Area served overlaps to another Sub-County. Area served in each Sub-County were measured using ArcGIS software, multiplied by population density of that Sub-County gives PS_5 of the Sub-County as presented in(Equation VI).

$\Leftrightarrow PS_5 = AS_5 \times PD$ ………………..………….……………..… (Equation VI)

Stage 6: Estimation of Population Un-served (PUS)

The area un-served (AUS) marked A1- in figure 2 is within served area A52 measured in stage 5. This area was first measured together with the served area A52 and will be deducted later in the next stage. A1- was separately measured using ArcGIS software, multiplied by population density to get PUS.

$\Leftrightarrow PUS = AUS \times PD$ ……………………………….……….… (Equation VII)

Stage 7: Aggregation of Population Served (PS)

In this stage, PS_1 to PS_5 of stages 1-5 was added up and PUS subtracted from it to arrive at PS, the expression of PS is presented as;

$\Leftrightarrow PS = PS_1 + PS_2 + PS_3 + PS_4 + PS_5 - AUS$ ……..… (Equation VIII)

SWC is then calculated from the fraction PS/ TP, expressed in percentage.

$\Leftrightarrow SWC = PS/_{TP} \times 100$ ……………………………….….… (Equation IX)

Results

The formulae of stages 1-6 were used to calculate PS1 to PUS of every Sub-county. The aggregated PS is presented in table 2.

Discussion of results

The factors affecting SWC estimation in developing Countries were identified such as assumption of people served per WF, walking distances, non-funtionality, contamination, separation, and Population Density which are not always incorperated in the SWC estimation. This research identified these factors, evaluated and included them in the method for SWC inorder to improve its estimation. Serere District SWC has reduced from 78% to 67% using this proposed method . The fall in the District SWC is attributed to the reasons such as:132 non-functional WFs and 43 WFs without coordinates which were excluded from estimation, Serere sub-counties have lower population densities which resulted in lower population served and lastly the District has experienced very high facilities' densities in previous Internally Displaced Peoples' (IDP) camps, growing towns and places of high goundwater potential which are actually used by fewer people than assumed.

Table 2. Serere District estimated SWC									
SUB-COUNTY	**PS1**	**PS2**	**PS3**	**PS4**	**PS5**	**PUS**	**PS=** $\sum_{PS1}^{PS5} PS - PUS$	**TP**	**SWC (%) =** $\frac{PS}{TP} X100$
BUGONDO	1345.27	871.57	0	1152.06	18041.37	110.18	21300.116	33800	63.018
KADUNGULU	0	0	0	5977.98	11542.48	68.11	17452.355	25700	67.908
LABORI	0	143.00	0	0	1662.414	1.368	1804.054	7400	24.379
=PINGIRE	1452.11	0	0	0	29049.42	350.55	30150.987	48700	61.912
KATETA	0	0	0	0	16598.98	70.07	16528.915	20400	81.024
ATIIRA	0	1278.7	0	0	54195.20	3434.82	52039.084	52400	99.311
KYERE	644.16	0	0	0	28010.92	227.15	28427.928	46700	60.874
OLIO	0	1132.65	0	0	28516.23	781.44	28867.445	37200	77.601
DISTRICT SWC = AVERAGE SUB-COUNTY SWCs									**67.003**

Conclusion

Generally,various factors that affect SWC estimation in developing Countries were identified; these factors were considered to be affecting safe water access but were not incorperated in the SWC estimations.. Non-functionality, safety and WFs without coordinates were screened and excluded from estiomation meanwhile population densities, walking distances and separations were incorperated into the formulae for SWC estimation.. According to the findings of this research, the definition of SWC is modified to be the percentage ratio of the product of areas served by safe functional WF(s) within walking distances of 1.0km and its population density to the total population of that place.

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Note:

i) no. people in equation I differs per WF and per country, ii) scenario of stage 3 is redundant in Serere and Mbarara Districts where we did sampled but common in Lamwo and Nakaseke Districts.

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