Community Population Density Variation Implications on Sanitation System Cost – The Case of Kotoko Community in Suame (Kumasi), Ghana

Kabange, R. S.[1*] Graham, J.[2]
1.Civil Engineering Department, Faculty of Engineering, Kumasi Polytechnic, P. O. Box 854, Kumasi, Ghana
2.Global Health Program & Milken Institute of Public Health, 950 New Hamsphire Avenue, NW Suite 400, Washington, DC 20052

Abstract
A significant global population proportion lives in densely-populated peri-urban poor communities with inadequate sanitation facilities. When serving poor people with sanitation however, cost and affordability concerns dominate the discourse, besides space availability. There is also evidence that sanitation system cost is a function of population density. Population density strong influence on the most cost-effective sanitation system solution selection is therefore not in debate. Though sanitation systems cost literature exists, very few (if any) link these costs to the varying community population densities triggered by global population explosion, urbanization, and climate change. This research therefore looked at the effects of population density variation on sanitation system cost for a low-income high-density multi-ethnic peri-urban Kotoko community of 2,200 people in Kumasi, Ghana. The community's earlier studies identified simplified sewerage (SS) and ventilated improved pit (VIP) latrine as the most cost-effective. These solutions were then subjected to population density and cost comparison with consideration for policy, socio-cultural and affordability influences. The results revealed that SS was likely more cost-effective sanitation solution at the private level (one flush toilet per household) at an annualized household cost of USD46. Simplified sewerage became cheaper than VIP latrine at a breakeven population density higher than 160 persons per hectare – a confirmation of Sinnatamby's 1983 result for northeast Brazil. Future population rises only made SS even cheaper. Besides confirmation of SS as the better-cost option in high-density areas, this research showed that the breakeven population density at which SS was cheaper than VIP latrine varied with location. This work also confirmed the growing evidence that people were already paying more for sanitation services. The research concluded that SS was the first choice option for Ghana's densely-populated peri-urban Kotoko community at all population densities over 160 persons per hectare. To broaden the evidence base for decision-makers and allow determine whether the breakeven density for SS was unique to this community, it was recommended that more costing studies of this nature be carried out in similar communities in Kumasi. The implementation of SS in the research community on pilot basis incorporating modern greywater use approaches for added benefits was also recommended.
Keywords: annualized household cost, population density, sanitation system cost, simplified sewerage, VIP latrine

1. Introduction

Affordable sanitation provision to the majority poor in developing countries' peri-urban areas largely depends on population density (Mara, 2008). However, the health, economic, and environmental benefits of effective and efficient sanitation provision is essential (Cairn-Smith et. al., 2014). Beyond space availability, costs and affordability concerns strongly dominate the discourse when serving poor and very poor people with sanitation. Population density is therefore an important factor that affects sanitation system capital and operating costs in different locations (Dodane et. al., 2012). The World Bank Group (2015) argue that variations in sanitation systems costs are hugely influenced by housing density. Sinnatamby's (1983) population density graph, which is a function of costs (Figure 1) provides a useful approach for sanitation systems costs comparison.

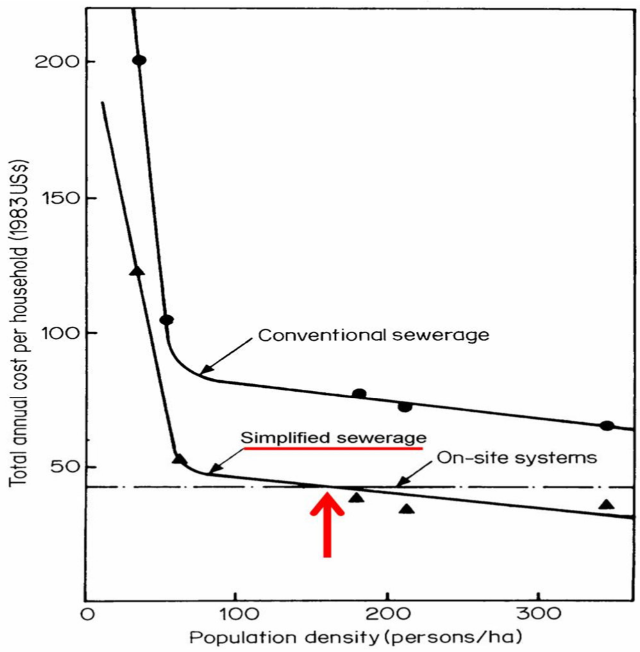

Figure 1: Population density as a function of costs for conventional sewerage, simplified sewerage, and on-site sanitation systems
Source: Sinnatamby (1983)

The Figure shows that simplified sewerage (SS) could be a low-cost option for peri-urban communities at high population densities. Though the graph is specific to northeast Brazil at the time, the broad pattern may apply elsewhere. Courtney (2011) also recently studied the same relationship for Soweto (South Africa) and found similar results as Sinnatamby (1983) except that SS was the least-cost option at a lower population density of 100 – 120 persons per hectare. With the research community's approximate population and land area of 2,200 and 7.4 hectares respectively, its population density is about 297 persons per hectare (Kabange, 2014), higher than Sinnatamby's 160 persons per hectare limit for on-site sanitation to be cheaper than SS.

Simplified sewerage (SS) is an off-site sanitation technology that removes all household wastewater from its immediate environment (Bakalian et. al., 1994; Mara et. al., 2001). Originally developed in the Northeast Brazil in the early 1980s (Sinnatamby, 1983; Mara, 2004b; Broome, 2009), SS deviates from conventional sewerage design principles and offers more cost-effective design approaches cheaper to low-income high-density households. As a system stripped down to its basic hydraulics (Manga, 2011), it is characterized by reduced gradients, depths, pipe diameters without compromising its design principles (Courtney, 2011; Manga, 2011; Foppen and Kasiime, 2012). It is found in Brazil to be cheaper than all sanitation technology options at population densities greater than 160 persons per hectare (Sinnatamby, 1983; Manga, 2011). It is however unclear whether the breakeven density of 160 persons per hectare can be applicable to the research community (Kotoko) with a high population density of 297 persons per hectare.

The ventilated improved pit (VIP) latrine was developed in rural Zimbabwe (Morgan and Mara, 1982), and receives excreta in the same way as any pit latrine: by direct deposition through a squat hole (or a pedestal seat). The urine infiltrates into the surrounding soil and the excreted solids are digested anaerobically. The VIP latrine modification is the space-minimizing alternating twin-pit VIP latrine – called Kumasi ventilated improved pit (KVIP) latrine – developed in Kumasi by Albert Wright at the Kwame Nkrumah University of Science and Technology (KNUST) in the early 1970s (Thrift, 2007). The KVIP latrine thus allows the contents of one pit to sufficiently decompose as to pose no health hazards and ready for emptying while the other is in use.

Households willingness to pay (WTP) for sanitation and water services are assessed using the "revealed preference method" and "contingent valuation method" (Evans, 1999): the former reveals what households are currently paying for the service; and the later shows what households are willing to pay using well-designed future scenarios to explain the benefits they can get. WTP is the maximum amount an individual is willing to pay for a good or service (Nyarko et. al., 2007). Affordability is however the ability of users to pay for a service or good expressed by the ratio of household expenditure to household income (Nyarko et. al., 2007). A 5% rule is usually applied to assess users affordability (Maoulidi, 2010) – a rule implemented in Ghana as a policy (Government of Ghana, 2010). Earlier studies suggest that a total of 1 – 2 % of the poorest income is available for spending on water and sanitation (Cotton & Franceys, 1991).

Merrett (2001) however rejects the view that households can afford no more than 3 – 5% of their income on sanitation services. Cotton and Franceys (1991) contend that affordability is linked to WTP and depends not only on income levels, but also on the perceived benefits to be gained from a service, the service level, and the priority given to the sanitation sector. WTP is also influenced by options availability, where alternative service sources are available either free or at a lower cost, WTP is likely to fall. Estimates on WTP confirm that people are already paying much more than the official tariff rates and will be willing to pay even more for better services (Evans, 1999). Most governments however often resist tariffs increment based on the argument that "politicians" are people "who need to be seen to be doing something for their voters" (Angel, 1981). Government policy in Ghana also stipulates that tariffs be set at levels that will not discourage the use of these services, especially where health risk can be created (Government of Ghana, 2010).

2. Aim and objectives

Population density, a characteristic often used to define cities, has strong influence on the most appropriate sanitation system selection (Cairns-Smith et. al., 2014). It is also well-documented that population density is one of the most important drivers of per capita capital cost for sanitation systems (Cairns-Smith, et. al., 2014). A significant global population proportion lives in densely-populated poor peri-urban communities without improved (or adequate) sanitation provision. Besides space availability, cost and affordability issues are paramount when serving the poor with sanitation. While there is a relationship between population density and sanitation system cost, population density effect on cost-effective sanitation system solution is not debatable. Very little work (if any) has so far been conducted that linked sanitation system cost to population density changes in communities. The aim of this research is therefore to examine population density variation implications on sanitation system costs for a low-income high-density multi-ethnic and growing peri-urban Kotoko community in Kuamsi, Ghana. Based on this aim the under-listed objectives were set to:

(a) Determine the fixed costs for SS and VIP latrine system;
(b) Determine the household annualized cost with variable population density based on objective (a);
(c) Determine the community's cost-effective sanitation system option under variable population density;
(d) Ascertain the community's breakeven population density; and
(e) Make recommendations on the community's sanitation system solution implementation strategy and for future works.

3. Methodology

An earlier study on the research community's socio-cultural preferences and experts' views on sanitation system solution identified SS and VIP latrine as the most cost-effective options for the research community (Kabange and Nkansah, 2015b). With an increase in the community's population of 10% over a five-year period (Kabange, 2014), future population increments were likely. The effect of population density variation on cost was investigated since any identified sanitation system was to serve the community for about 20 years. Population variation effect on sanitation system cost was important for both sanitation system sustainability and cost-effectiveness. The two sanitation systems were therefore subjected to population density and cost comparative analysis with consideration for policy, socio-cultural and affordability influences.

The VIP latrine was defined by a unit fixed cost where each household installation represented the same cost. SS however had a fixed cost and cost of additional households connected. The fixed cost for both sanitation systems, the total additional costs of installation required for SS individual household connections, and the additional cost per household were initially determined for the research community population density of 297 persons per hectare (Table 2). For varying population densities, these costs were then calculated and presented as Table 2. The graph of annualized cost per household against population density for both systems without sharing was determined and constituted basis for comparative analysis. The comparative cost analysis of population density variation with cost for solution looked at SS and VIP latrine at the private (or single household) level.

4. The research community: Kotoko

Kotoko is a multi-ethnic low-income high-density peri-urban community in which the investigations were undertaken. It is located very close to the Kumasi city centre (Kejetia) in the Suame district of the Ashanti Region. The community consists of 67 households built mainly from mud and bamboo, and roofed using old rusted and often leaking corrugated iron sheets. The community is a heterogeneous one and composed of descendants of immigrants from northern Ghana. It has a rough population of 2,200, and the main religion is Islam. It is a slum community characterized by inadequate infrastructure, land tenure challenges, and a mix of high and low income areas.

5. Results and discussions

The research community's population density variation effects on the two sanitation systems costs, the breakeven population density boundary at which one sanitation system is cheaper than the other, policy and socio-cultural and affordability implications are all discussed under this section.

5.1 Population density influence on SS and VIP latrine costs

The research community's population rose by roughly 10% within a five-year period (Kabange, 2014), and so future population variations were therefore likely. Since any identified and recommended sanitation solution has to serve the community for a 20-year period (Kabange et. al., 2015), the effect of population density variations on cost was investigated. Analysis of population density changes looked at private or single-household SS and VIP latrine. The VIP latrine was defined by a unit cost (USD52) where each household installation represented the same cost (Courtney, 2011). SS however had a fixed cost on installation, normally consisted of the primary and secondary pipeline costs serving the community. The cost of any additional households connected added to this fixed cost – resulting in a reducing average cost with increasing population density. The reducing cost of SS was therefore identified and compared graphically with the VIP latrine cost. It is this fixed cost for SS (summarized in Table 1) that enabled the installation of the SS network for the 297 persons per hectare population density of Kotoko's 7.4 hectare area.

Table 1: Fixed cost for simplified sewerage

Fixed cost item	**Cost (USD)**
Main sewers	957.53
Secondary sewers	4,612.63
Labour for sewers installation	1,205.31
Total Fixed Cost	6,775.47
Total System Cost	38,336.00
Total additional Cost	31,560.53
Additional Cost/household	751.44

The total additional costs of installation required for individual household connections was calculated from the fixed cost identified in Table 1 by subtracting it (fixed cost of USD6,775.47) from the total system cost of USD38,336.00. By dividing this total additional cost by the total number of households (42) connected by SS, the additional cost per household was determined as USD751.44. The fixed cost, total additional cost, and additional cost per household were then used with other data to develop Table 2 that illustrated the variation of the research community's population density with annualized household cost. The row with 42 households in the table represented the present costs (USD45.64) of SS in Kotoko at its current population density of 297 persons per hectare, and the determination of the key components of Table 2 explained.

The additional cost per household multiplied by the extra number of household connections required as the community's population density varied gave a cost (which could be an addition or subtraction) relative to the total additional cost. This cost was then added to, or subtracted from, the total additional cost depending on whether there was an increase or decrease in the number of households relative to the current 42 households highlighted in bold to obtain a new total system cost under a different population density. While the cost per household was determined by dividing the total system cost by the number of households, this cost per household was then divided by the 20-year operational period to give the annualized cost per household. The resulting Table 2 identified the reducing annualized cost per household from USD105.32 when the population density was 35 persons per hectare to USD39.83 with a population density of 1,060 persons per hectare.

Table 2: Simplified sewerage per household annualized cost variation with population density

Population density (persons/ha)	Number of people	Number of households	Fixed cost (USD)	Total cost (USD)	Cost/household (USD)	Annualized cost/household (USD)
35	180	5	6,775.47	10,532.72	2,106.54	105.32
71	360	10	6,775.47	14,289.92	1,429.00	71.45
141	720	20	6,775.47	21,804.32	1090.22	54.51
212	1,080	30	6,775.47	29,318.72	977.29	48.86
297	**1,512**	**42**	**6,775.47**	**38,336.00**	**912.76**	**45.64**
353	1,800	50	6,775.47	44,347.52	886.95	44.35
424	2,160	60	6,775.47	51,861.92	864.36	43.22
495	2,520	70	6,775.47	59,376.32	848.23	42.41
565	2,880	80	6,775.47	66,890.72	836.13	41.80
636	3,240	90	6,775.47	74,405.12	826.72	41.33
707	3,600	100	6,775.47	81,919.52	819.20	40.96
1,060	5,400	150	6,775.47	119,491.52	796.61	39.83
Total additional cost (USD)	31,560.53		Additional cost/household (USD)	751.44		

5.2 Research community breakeven population density

Figure 2 on AHC and population density for Kotoko community confirmed earlier findings that SS was the least-cost option in high-density communities (Sinnatamby, 1983; Mara, 2008; Courtney, 2011; Manga, 2011). The figure also demonstrated that AHC decreased with increasing population density for SS in the research community (Kotoko) – a result confirmed by Courtney (2011), whereas VIP latrine AHC remained costant. SS became the cheaper-cost option at a population density greater than about 160 persons per hectare, and VIP latrine was cheaper than SS at population densities below this margin. The lower cost option changed from a system of VIP latrines to SS network at a population density of between 160 – 170 persons per hectare, when the AHC was a little below USD52. Though SS was confirmed as the cheaper option in high-density areas, it also suggested that the breakeven population density at which SS was cheaper than on-site varied with location. The breakeven population density was 160 persons per hectare for Brazil in 1983, it was 100 – 120 persons per hectare for South Africa (Soweto) in 2011 and 160 persons per hectare for research community, Kotoko, in Kumasi (Ghana) in 2011 (Figure 2).

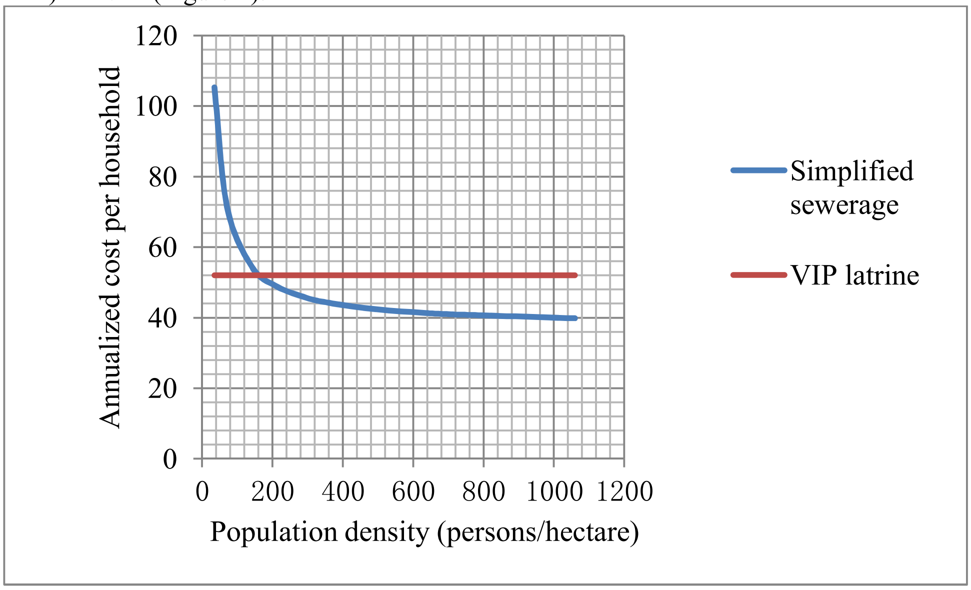

Figure 2: Annualized cost per household against population density for VIP latrine and SS with no sharing

At Kotoko's population density of 297 persons per hectare (Section 1), SS was the lower cost option – about USD6 per household per year cheaper than VIP latrine. Future population increases would only make SS in research community even cheaper, confirming similar work done in Soweto (South Africa) by Courtney (2011). SS was likely to be a more cost-effective sanitation solution for the low-income high-density Kotoko community – its provision feasible at the household level for an annualized household cost of USD46. The evidence confirmed SS as a cheaper option in high-density areas with a breakeven density of 160 people per hectare, the same to that of Brazil in 1983 and similar to that for South Africa (Section 1). The evidence also confirmed that people were already paying more for sanitation (Evans, 1999). However it was important to note that each of these studies used a different approach to build up AHC so these comparisons might not be quite as clear-cut as they seem.

5.3 Policy and socio-cultural influence on solution

If SS was cheaper than VIP latrine, why was it not implemented in the research community at the expense of other alternatives? SS promotion had not been vigorously and effectively carried out, yet it had to be known much more widely if the poor had to receive improved sanitation (Mara, 2006). Policy reforms in Ghana generally favoured sanitation improvement by encouraging individual household sanitation facilities installation, and community participation. Technology choice, especially in developing countries, was mostly based on the country's sanitation and environmental policy of what should be implemented where (Schouten and Mathenge, 2010). Though Paterson et. al. (2006) argued in their pro-poor sanitation technologies review that SS was the only technically feasible and economically appropriate solution for low-income high-density urban areas, water requirement might be an obstacle to its implementation in research community. However, with an internationally recognized minimum water consumption of 20 – 25 litres per capita per day (UNDP, 2008) and a flush toilet using typically 10 – 20 litres of water per flush (Cotton and Franceys, 1991), the about 45 litres per capita per day community water consumption (Kabange & Nkansah, 2015a) and greywater use potential to flush toilets suggested that water availability for flushing might not be an issue. What remained unresolved and a real concern was funding.

A study conducted showed that the direction one sits to defecate and posture during defecation matters. While preference to sit rather squat might be expected, users preference to sit in a particular direction – the North-South direction was unexpected (Kabange and Nkansah, 2015b). Evidence however supported this preferred position during defecation in Muslim communities as they were religiously required not to face Mecca or give their back to it (Kabange & Nkansah, 2015b). These results emphasised the critical role of socio-cultural preferences in sanitation selection and improvement, especially in multi-cultural settings, as providing what users needed would promote latrine use, and operation and maintenance.

With the community currently using a pour-flush facility, it might be seen as a step backwards for them to make a shift to VIP latrine unless this gave them more convenience and benefits through less sharing. It was thus likely that the community's growing youth population who were expected to demand for improved sanitation options might resist attempts to introduce VIP latrines. Research indicated that VIPs/KVIPs were not properly used in Ghana and their image was gradually being tarnished, though they are currently the preferred technology (Thrift, 2007). This development was likely to trigger a preference switch to other sanitation options. Government of Ghana sanitation policy shift towards more improved sanitation options (Government of Ghana, 2010) also meant that VIP latrines might not be the right policy choice. Ghana's population preference for sewered sanitation (Kabange & Nkansah, 2015a) could mean that future sanitation solutions might be limited to flush or "flush-and-forget" systems.

5.4 Payment for sanitation services and affordability

The average annual household income in Ghana was Gh¢1,217 (USD740) – Ghana Statistical Service (2008). Ghana Statistical Service survey (GLSS5) definition of a household (Kabange & Nkansah, 2015b) represented a family in this research, and this was factored into the analysis. For each household per toilet facility, SS annualized household cost was USD46. The research community average expenditure per person per month on sanitation under the revealed preference method was about USD3.01 (Kabange, 2014). With an average of 4 persons per household (actually a family size in this study), the average annual household expenditure on sanitation was USD144.48 – constituting 19.5% of their annual income. Assuming the whole cost fell on households, each household would need to contribute about 31.8% (under half) of what they were currently paying for sanitation, or 6.2% of their annual income under the SS program. This might be unaffordable as expenditure in the range of 3% – 5% of annual household income on sanitation was generally accepted as affordable (Maoulidi, 2010). This result further confirmed the growing evidence that people were already paying more for sanitation services (Evans, 1999).

6. Conclusions and recommendations

Population density is an important factor that can affect sanitation system capital and operating costs in different locations. The effect of population density variation on sanitation system cost for low-income high-density peri-urban community in Suame (Kumasi), Ghana, was therefore studied. The more cost-effective and acceptable sanitation solution for the high-density peri-urban community was likely to be SS, and the breakeven population at which SS was cheaper than VIP latrine varied with location. Future population rises would only make SS in the research community even cheaper. The results indicated that it might be feasible to provide this at the private level (one household per flush toilet) for an annualized household cost of USD46. It also concurred with previous studies that indicated that SS was the least-cost option in many high-density areas, and the breakeven densities were about the same: 160 people per hectare for Kotoko (Ghana) in 2011 compared to 100 – 120 people per hectare in 2011 for Soweto in South Africa, and 160 people per hectare for Brazil in 1983. SS with individual household connections was recommended as the more likely cost-effective future sanitation solution for the research community. At this level of provision, each household would have to contribute about 32% of what they were currently paying for sanitation or 6.2% of their annual household income if the whole capital and operation cost fell on them. This research therefore confirmed the growing evidence that people were already paying more for sanitation services. The research concluded that SS was the first choice option for Ghana's densely-populated peri-urban Kotoko community at all population densities.

Carrying out the same costing studies in other similar communities in Kumasi would allow determine whether the breakeven density for SS was unique to this community. It was therefore recommended that more costing studies of this type be carried out to widen the evidence base for decision makers on cost-effective sanitation solutions and infrastructure options. It was further recommended that SS be implemented on a pilot basis in a community such as Kotoko incorporating modern approaches to greywater reuse, thereby providing additional benefits in terms of reduced water use and household additional income.

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