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Sanitation System Solution for Kotoko Community in Suame (Kumasi), Ghana

Roland S. Kabange [a]*, Jay Graham [b], Andrews Nkansah[c]

[a]*Civil Engineering Department, Faculty of Engineering, Kumasi Polytechnic, P. O. Box 854, Kumasi, Ghana*
[b]*Global Health Program & Milken Institute of Public Health, 950 New Hamsphire Avenue, NW Suite 400, Washington, DC 20052*
[c]*Department of Energy & Environmental Engineering, University of Energy & Natural Resources, Box 214, Sunyani, Ghana*
[a]*Email: skabange@yahoo.com*
[b]*Email: jgraham@gwu.edu*
[c]*Email: ankansah@hotmail.com*

Abstract

Decades of poor sanitation coverage in developing countries suggest that conventional top-down approaches are not doing well and alternatives are needed. Few sets of comparative sanitation systems costs exist, particularly costs related to sanitation facilities sharing. With current little experience pulling a wide range of factors together for good quality sanitation planning and selection, this research explored and evaluated the interrelationship between socio-cultural, economic and technical issues in sanitation planning with sanitation facilities sharing as basis for cost comparison. A community-level framework was then developed to inform sustainable and acceptable sanitation system selection process for a low-income high-density predominantly Muslim multi-ethnic peri-urban settlement of about 2,200 inhabitants in Kumasi (Ghana). The methodology initially combined published literature and experts' views analysis to determine three preferred sanitation systems. The three preferred sanitation systems (pour-flush latrine, ventilated improved pit latrine and simplified sewerage) were costed and analysed, then cost compared on facilities sharing basis, and finally evaluated for solution. The research revealed that simplified sewerage (SS) was the likely most cost-effective sanitation solution at a sharing of seven households per flush toilet. Simple sensitivity analysis found that if energy and materials price fluctuations were likely, SS was the least sensitive – a confirmation that it was the preferred future sanitation solution under inflation.

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* Corresponding author.

"Realistic-equal-cost-point" sensitivity analysis model also confirmed SS cost-effectiveness under inflationary conditions. The change in assumptions for price sensitivity analysis did not therefore affect the overall recommendations. The research concluded that SS was the first choice sanitation solution for Ghana's densely-populated peri-urban Kotoko community at a sharing of seven households per flush toilet. The proposed framework promoted the bottom-up community-based sanitation planning philosophy and supported current thinking on the subject, with users' and experts' views well-articulated and embedded in the framework, and addressed key sustainability elements that could be incorporated into current models. The framework could thus be used by local authorities to gradually address the complexities of peri-urban sanitation challenges.

Key words: sanitation solution; cost-effective; research community; planning framework; sharing sanitation facilities.

1. Introduction

Sanitation targets inclusion in the Millennium development Goals (MDGs) is necessitated by the direct impact of sanitation improvement on improved health, living conditions, education outcomes and poverty reduction [1]. Practitioners over the decades attempted to get solutions to reduce global population proportion without access to toilets through sanitation planning frameworks (SPFs). Various planning approaches developed to further improve sanitation include Community-Led Total Sanitation (CLTS), and Household-Centred Environmental sanitation (HCES). The CLTS focused on changing attitudes and behaviours through community mobilization to stop open defecation and encourage communities to build their own toilets [2]. The HCES focused on all stakeholders' participation starting at the household level in the planning and implementation of sanitation systems [3]. Though these frameworks made a contribution, a major gap remains and doing it better would help to improve the sanitation situation.

The role of sanitation systems costs on the most appropriate and cost-effective system determination is significant and finds an acceptable balance between costs and benefits, social acceptability and environmental sustainability [4]. Financial costs are the sum of investment and recurrent costs without any adjustment to reflect economic circumstances – it thus considers future costs brought to today's values without removing the effects of inflation [5, 6]. This costing model is relevant in sanitation options selection that consumers can afford, the financial burden heavily influenced by local circumstances, level of community participation, and local materials use [5]. Economic costs are costs borne by a community (or country) as a whole, and include all resources used for the sanitation project, such as land, labour and capital [5]. Sharing sanitation facilities is therefore a key cost comparison element in this research due to its cost-effectiveness and health benefits.

It is now also well documented that non-shared sanitation facilities are virtually impossible, particularly in low-income, high-density peri-urban areas of mixed socio-cultural and religious settings with limited space for individual household sanitation facilities' construction [7]. Lower sharing of sanitation facilities is generally associated with less cost and higher health benefits. It is argued [7] that all shared facilities categorization as unimproved because they are shared is a misrepresentation of sanitation reality. There are few comparative sanitation systems costs, particularly costs related to sharing. This research therefore also explores the link between sanitation sharing and cost to determine the most cost-effective sanitation solution.

2. Research aim and objectives

A solution to unsustainable development projects lies largely in improving planning processes [8]. Success began to emerge when attention was paid to users' preferences, disaggregation of services, and the involvement of formal and informal institutions in sanitation delivery [9]. Lack of good planning frameworks that encourage a mix of community and expert engagement, cost data, and sanitation facilities sharing was therefore a gap in peri-urban sanitation delivery. Though some works on sanitation systems solutions through planning tools are available, socio-cultural and economic factors were integrated only recently. In particular, costing studies underpinned by sanitation facilities sharing cost comparison for solution are currently unavailable. An integrated approach that pulls opinions and data for good quality planning and sanitation system selection process was the focus of this research conducted in a low-income, high-density peri-urban community in Kotoko (Ghana) to inform the overall sanitation system planning framework and selection for peri-urban areas.

Effective sanitation planning successfully links community preferences and knowledge with decision-making, but this has proved challenging to develop and rarely used in practice. This research developed an approach that incorporated details of local sanitation needs, attitudes and preferences as well as technical and economic consideration into a wider framework. This research therefore proposed a conceptual framework that brought together quantitative engineering design and economic costing based on sanitation sharing scenarios with more qualitative analysis of community and experts preferences to arrive at sanitation solutions best suited to community needs. Findings of two studies on the research community's preferences and expert views were established [10] and incorporated into this research. The developed framework outlined a generalized approach to community level sanitation planning and selection with the following set objectives:

1. Determine key elements for a technical feasibility assessment and socio-cultural planning framework;
2. Design, cost and evaluate scientifically-selected sanitation systems for the research community based on socio-cultural, technical, economic and institutional considerations;
3. Evaluate the planning framework effectiveness and wider applicability; and
4. Make recommendations for community's present and future sanitation solution, and a generalized approach to sanitation planning.

3. Kumasi and research community (Kotoko)

Kumasi is Ghana's second largest city and capital of the most populous region (Ashanti). It has a population of about 1.6 million, and mainly inhabited by Christians (79%) and Muslims (16%) [11]. Kotoko is a multi-ethnic low-income high-density peri-urban predominantly Muslim community located close to Kumasi city centre (Kejetia) with 67 households and about 2,200 inhabitants. The average household size is 36 and water consumption stands at 45 litres per person per day. Characterized by inadequate infrastructure, and land tenure challenges, the community's first sanitation facilities were two unlined latrines without superstructures.

4. Planning framework and methodology

The top-down supply-driven traditional planning approaches involved well-structured written rules and procedures with limited or no community participation, and beneficiary priorities were determined by officials based on their perceptions of what users needed [12]. The emergence of strategic planning frameworks in the water and sanitation sector reflected a shift from the traditional top-down to a more participatory and consultative bottom-up demand-driven approach. The challenge of achieving the MDG targets despite this shift raises concerns over the existence of knowledge gap between developed frameworks and local stakeholder priorities [12].

4.1 Proposed planning framework

Sanitation is diverse and complex in nature, and requires cross-disciplinary work [13]. Poor planning processes are implicated in the failure of sanitation systems, and a review concluded that existing planning tools failed to encourage consideration of financial and social implications of technical options [8]. Emerging SPFs incorporate sustainability criteria that allow sanitation systems development important in peri-urban context. This assessment framework therefore proposes a blended approach that combined quantitative elements of engineering costing and design (based on sanitation facilities sharing concept) with qualitative survey-based elements on community and expert views and preferences to determine workable and affordable sanitation systems. The proposed framework (Figure 1) has users' needs, greywater use preferences, and experts' views incorporated from earlier findings in research community [10, 14]. The main steps to effective SPFs are problem identification, identification of broad options, selection process, evaluation, and implementation [12, 13]. This proposed planning framework was developed to broadly reflect these generic steps.

Step 1: Identify problems

Developing better sanitation services would usually require analysis of current problems and their causes [15]. This first step therefore made an initial community assessment to determine the sanitation system requirements from earlier studies' findings on the community's needs and preferences [10, 14]. This initial selection process employed existing literature on viable sanitation options. A long list of sanitation systems was identified based on WHO/UNICEF JMP [16] standards. Though JMP did not set standards but identified a set of technologies likely to result in effective separation of people from excreta, this criterion was used to provide a good proxy for "improved sanitation." Section 4.2 provides the selection process details.

Step 2: Identify broad options

A short-list of five sanitations systems was determined through further review of literature with city and national policy considerations on the subject. The appropriateness of the selected systems to users' and greywater use potential was given priority at this stage, and provided for by earlier research findings on research community [10, 14]. Five sanitation systems were considered a reasonable number that would enable comparison, but would not be unmanageable.

Step 3: The selection process

To find out what works in specific settings, new planning approaches need critical evaluation so progress can be made [13]. A detailed costing of the reduced short-list of appropriate solutions identified in Step 3, and analysis at various sharing levels were carried out. These technical and costs assessments were then cross-checked with community views gathered at the first two planning steps. All other factors, as evidenced by existing literature, were applied to determine the most appropriate sanitation system.

Step 5: Recommendations

The evaluation step allowed the identification and correction of mistakes or imbalances, weaknesses and strengths and the probable need for direction change to inform future recommendations.

4.2 Overall approach to methodology

The overall approach initially determined a broad list of options based on WHO/UNICEF JMP [16] definition of improved sanitation. This broad list was shortened to five through consideration for technical, global situation, government and city policy direction, as well as community views as found in Kabange and Nkansah [10]. Analysis and ranking of these five sanitation systems by experts [10] led to the selection of three sanitation systems for research area. The final sanitation system was determined through further analysis, evaluation, and the interplay of all relevant factors including costing and sizing calculations based on sanitation facilities sharing concept.

4.3 Sanitation systems selection process

It is well documented that socio-cultural aspects of a community (such as religious and cultural beliefs, needs and preferences) play important role in the proper use, operation and maintenance of sanitation facilities [17]. The community sanitation system selection process was rooted in existing literature and the community baseline research conducted earlier [10] which partly reflected community preferences and motivations, and users' sanitation needs. Failure in the past to account for users' expressed needs contributed to most failures of urban and peri-urban sanitation programmes [9]. These earlier studies [10, 14] were partly to fill this gap.

4.3.1 Background

Though the research community's first sanitation facilities (Section 3) were unimproved because they had no cover slabs [16], they were similar to the traditional communal latrines. The community's low income levels meant that neither households nor families could likely meet the construction cost of private sanitation facilities. Public and community latrines upon which most Ghanaians are dependent would continue to play a critical role in sanitation provision [18]. Attempts were made by UNDP/World Bank in 1985 to subsidize the installation of KVIP latrines as the most acceptable and cheapest approach to provide household sanitation, and coverage exceeded 200,000 households in 1995, which represented 38% urban sanitation coverage increment between 1985 and 1995 [18].

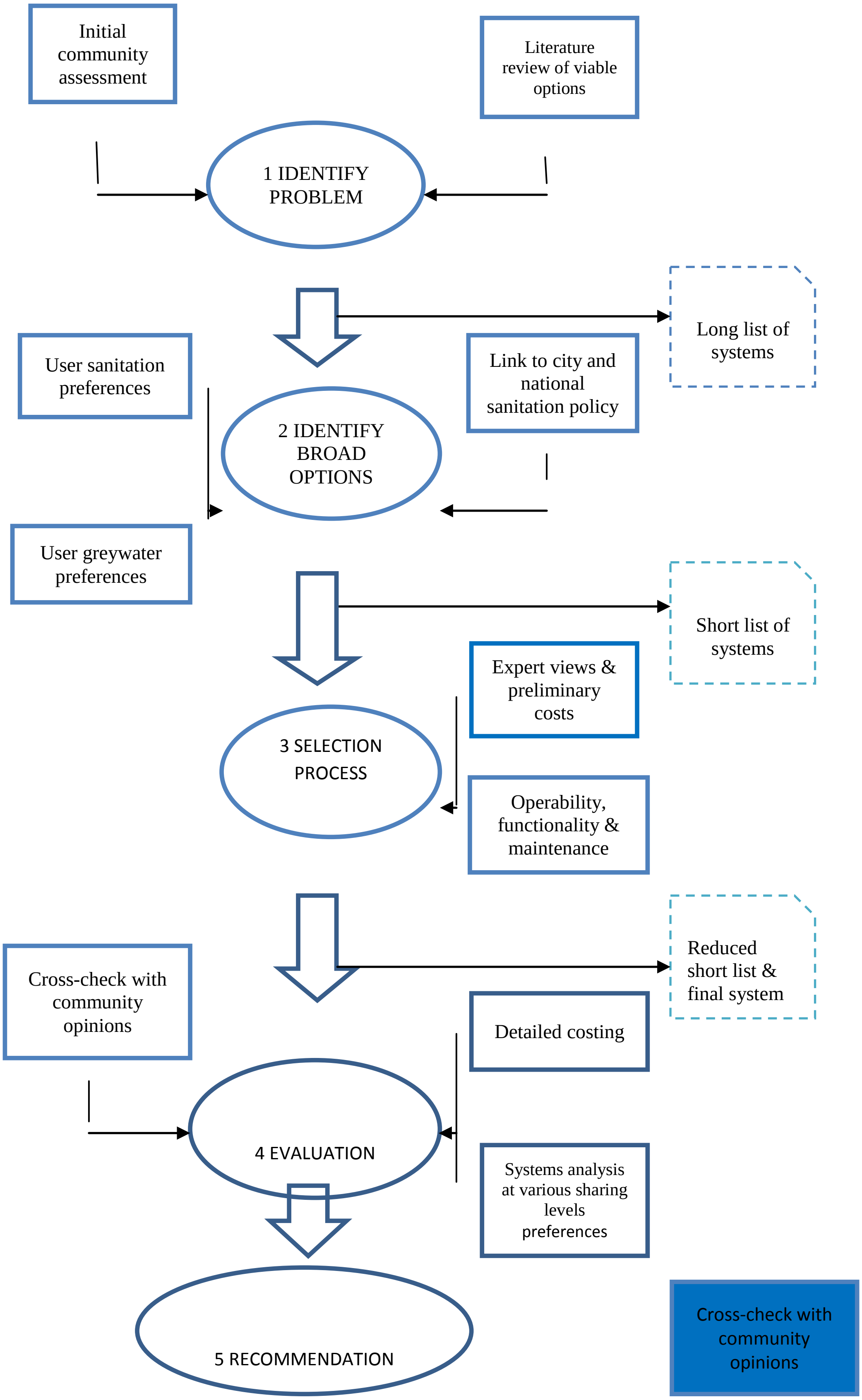

Figure 1: Schematic overview of proposed planning framework

Step 4: Evaluation

Table 1: Overview of planning methodology

Level	Selection stage	Elements
1	Long list of options	WHO/UNICEF (2014) standard definition of improved systems
2	Initial five options	2.1 Global situation: climate change, demographics, water availability, international norms 2.2 Community views: sanitation surveys, and greywater Use (from Kabange & Nkansah, 2015a) 2.3 Technical: practicability, construction, literature review 2.4 Government and city policy direction
3	Final three options	Experts' views, and community preferences (from Kabange & Nkansah, 2015b)
4	Preferred option	4.1 Detailed costing & systems analysis at various sharing scenarios 4.2 Operability: maintenance, ownership and cleaning 4.3 Finance: capital, operation, willingness to pay, community income 4.4 Cross-link with community preferences

The research community is peri-urban characterized by poorly-constructed houses, inadequate support services and poor sanitation (Section 3). Community latrines therefore were the commonest sanitation options. Adequate, well-constructed and maintained community facilities offer an opportunity for improved sanitation services in peri-urban areas, and community latrines are often considered the only technically and economically feasible options for high-density, low-income peri-urban dwellers [17]. The use of shared, community and public sanitation facilities is common in Sub-Saharan Africa (31%), and particularly in Ghana [16]. Since the research community is not water-sufficient, it might not be technically and economically sound to flush excreta using huge water volumes at the expense of drinking, cooking, washing and bathing.

4.3.2 Possible sanitation systems identification

The selection process accounted for all sanitation systems that met the WHO and UNICEF standard for improved sanitation provision: options which hygienically separate human excreta from human contact [16]. Compliance with this standard offered a broad list of options at the initial stage (Table 2). The broad list included flush or pour-flush sanitation facilities to a piped sewer system, septic tank, or pit latrine; ventilated improved pit (VIP) latrine − single and double-pit (KVIP) latrines to be emptied manually with double-pit and mechanically when single pit; simple pit latrine with slab; and composting latrine options. Flush or pour-flush options that removed excreta to places other than a piped sewer system, septic tank or pit latrine were considered unhygienic and therefore excluded in the selection process.

Table 2: Sanitation systems in compliance with WHO/UNICEF JMP improved sanitation standard

Sanitation system	Conditionality for compliance
Flush or pour-flush	To a piped sewer network, septic tank or pit latrine
Ventilated improved pit (VIP) latrine	Single or double pit
Simple pit latrine	With a slab
Composting latrine	All options

Sanitation systems feasibility was considered in the selection process based on whether they were currently used in peri-urban areas or had potential for such use. The identified sanitation options were further subjected to technical criteria in the research community to determine their appropriateness. Factors relevant included population density, costs, water and space availabilities, social acceptability, amongst others. Conventional sewerage has long been recognized by most experts as expensive, requires large water volumes for its operation, and so difficult for a city with limited resources to invest in, or operate over time [19, 20]. It is therefore unlikely that most households, particularly low-income ones could cover these costs. A research on household demand for improved sanitation services in Kumasi confirmed that conventional sewerage is not affordable to most households without massive subsidies [21].

While Mara and Broome [22] argue that simplified sewerage (SS) is often the least-cost option in high-density urban areas, both VIP and KVIP latrines are widely used in Ghana [5, 17] and so could be socially acceptable. About 44% of sanitation systems in Ghana are VIP and KVIP latrines [23], and represent nearly half of all sanitation facilities in Kumasi [24]. Options such as single-pit compost latrine may not therefore be appropriate because of the requirement to empty it immediately when full. The urine-diverting dry toilet (UDDT) was widely used in temperate African countries such as South Africa and Kenya where they are socially and culturally acceptable. Though not well known in Ghana, the UDDT is likely to perform well. The five preliminary sanitation options therefore identified as potentially feasible for the research community were as follows: pour-flush to septic tank (PST), VIP, KVIP, UDDT, and SS to septic tank. VIP latrine, SS and pour-flush latrine were the three short-listed sanitation systems based on experts' analysis of the five options [10]. These three short-listed options were then subjected to sizing, costing, sensitivity analyses, and further evaluation for community sanitation solution.

5. Three sanitation systems' sizing and costing analysis

Simplified sewerage (SS), VIP latrine and PF latrines identified in proposed planning framework (Step 3 of Figure 1), and short-listed were subjected to a number of sharing scenarios and the assumptions influencing the costs estimates were outlined. For optimum solutions, relevant community surveys' findings were combined with the technical analysis results, costs, consumer preferences and level of service. The likely impact of energy and materials prices rise on the overall cost was conducted using simple sensitivity analysis. Potential sanitation solutions under the proposed planning framework (Section 4.1) and how the different parts of the research informed the selection are presented.

5.1 Costing approach

Financial costing (the sum of the investment and recurrent costs without any adjustments to reflect economic considerations) was the design basis for this research as it was very relevant in sanitation system selection affordable to the consumer [25]. There is growing emphasis on community participation in infrastructure provision since it encouraged local materials use, skills and appropriate technology [26]. Community participation could therefore significantly reduce the financial burden on users [27]. For instance, a study in Kumasi showed that community self-help labour significantly reduced a VIP latrine system' financial cost [21]. The costs of unskilled labour for pit excavation, pipe laying were thus excluded in this investigation given the high level of community spirit amongst the community PF latrine users. The approach would lead to a sanitation system selection that users preferred, could afford and attached a sense of ownership – attributes likely to promote its operation and maintenance (O & M).

The annualized household cost (AHC) in United States dollars (USD) was used as a measure of costs for sanitation systems sharing scenarios and analyses. An exchange rate of one (1) Ghana Cedi (Gh¢1) to USD0.608 and a discount rate of 16% (0.16) were applied throughout the costs estimations. A 20-year design period (life) was considered reasonable as research conducted in Kumasi (Ghana) showed that most toilets over 20 years were in very poor conditions [21, 25]. The AHC used was the discounted costs per household divided by the design life of the project. The three sanitation systems' AHC was developed using the financial costing model with discount adjustment that gave the lifecycle discounted cost. The discounting approach where all future costs were discounted back to present values using an appropriate discount rate [28] was thus applied for costing. The effect of not including discounting would be to significantly raise the influence of operational costs on the final cost comparison. Therefore cost incurred of USDP in n years' time would have present value, $V = \frac{P}{(1+r)^n}$, where $\frac{1}{(1+r)^n}$ is the "discount factor", which was multiplied by the actual cost to give its present value.

5.1.1 Costing scenarios

Eleven, ten and three sharing scenarios for VIP latrine, SS and PF latrine respectively ranging from one to 42 households per facility were considered (Table 3). The effect of sharing on overall costs, and AHC was examined in each case. In compliance with users' preference to sit rather than squat [10], toilet seats were cost-estimated across the three sanitation systems instead of the less expensive squat holes. Corrugated iron sheets for superstructure roof were similarly cost-estimated instead of traditional less expensive thatched grass. The assumptions applied to the costs estimations are outlined in Section 5.1.2.

Table 3: Summary of three sanitation systems sharing scenarios

Sanitation system	No. of scenarios	No. of households/facility	Infrastructure summary
VIP	11	1,3,4,5,6,7, 8, 10,13,21,42	Pit, toilet, seats, cover slab, roof, doors, vent pipe, flyscreen
SS	10	1,3,4,5,6,7, 8,10,13,21	Septic tank, flush toilet, sewers, inspection chambers, junction boxes, doors, roof.
PF	3	13,21,42	Septic tank, toilet seats, PVC pipes, inspection chambers, junction boxes, roof, doors

5.1.2 Costs components considered

The operational costs should have included the cost of water provided for sanitation systems operation. Though water cost was an important element, all the options considered were not dependent on high water consumption, and so these costs were excluded from the comparative analysis for simplicity. The exclusion of these costs lowers the lifecycle O & M costs marginally but will have negligible impact on the relative costs of different options. Higher water supply service levels were however likely to significant impact on overall welfare, which would dwarf any marginal impact on sanitation (Hutton and Bartram, 2008). Costs estimates for materials included the cost incurred through their delivery to site (transportation costs), as construction materials costs in Ghana mostly include delivery.

The materials costs would therefore normally include the cost of hiring a transportation vehicle, the cost of fuel consumed and the labour cost needed to operate the vehicle. The O & M costs were estimated based on historical cost data collected during the research period [29]. Kabange and Nkansah [10] offered a table that gave the annual operating costs and revenue for the community which was used to make these determinations. Though interest rates, materials and labour costs might vary across regions and countries, they provided a reasonable estimate and any regional variations had little or no effect when such rates were multiplied over the whole construction period [30]. The actual costs calculations were done in excel, but a summary of items, their unit costs and information source are provided as Appendices 1, 5 and 6 for VIP latrine, SS and PF latrine respectively.

Specific cost areas included construction (materials and labour), O & M (pit emptying, cleaning and hygiene, and electric). Materials and labour costs breakdown for the VIP and PF community latrines included pit lining, superstructure wall, cover slab, superstructure roof, door (s), toilet seats and lid, ventilation pipe, fly screen. The materials costs for SS were sewer pipes, junction boxes, flush toilets and inspection chambers. The labour costs comprised of skilled and unskilled labour for construction and installation. The contributing households for the design were 42 since the remaining 25 households had their own private facilities, and average household size was 36 (Section 3). The three service levels considered in the costs analyses were private (or household), shared and community depending on the number of people sharing a facility. The private service level was limited to one household per facility, and the shared and community service levels were 2 – 12 and 13 – 42 households per facility respectively. The community PF latrine provided service only at the community level, and so three sharing scenarios 13, 21 and 42 households per pour-flush latrine were applied across the costs estimates. The three service levels (private, shared and community) were also termed low, medium and high sharing levels respectively.

It is argued [5] that communal latrine maintenance problems (such as sharing) could be solved through sharing of responsibilities. Therefore no cleaning cost was incurred because a cleaner was not required at a sharing of one household per toilet as families could generally be responsible for cleaning the facility. Each sanitation system was assumed to require waste treatment, and all three systems needed the same level of treatment since the quantity of generated waste was the same. Whereas waste treatment costs for VIP latrine was excluded, partial treatment was assumed to take place for PF community latrine and SS because waste retention in septic tanks (by their design), partially treat waste [31].

5.2 VIP latrine sizing and costs analyses

Pit latrines provide for the accumulation and decomposition of fresh excreta and infiltration of liquids into the surrounding soil [25, 31]. Eleven sharing scenarios (Table 4) were considered, and excel was used for the detailed costs estimates. The unit costs and prices summary for materials and services are shown in Appendix 1. The pit capacity, which depends on the number of users, was the basis for VIP latrine sizing and costing. For each sharing scenario, the capacity of the pit was calculated. The pit capacity, V (m^3), was calculated from [32]:

$V = 1.33 \times R \times I \times P$;   (1)   where

R was the solids accumulation rate (m^3 per person per year); I was the pit emptying intervals (years); P was the contributing population; and 1.33 was a factor that ensured a clear space above the excreta. Another design approach would be to exclude the 1.33 factor in equation (1) and add 0.5 metres free space to the calculation result [25, 33]. For Ghana, R is estimated as $0.03m^3$ per person per year [34]. As opposed to the current PF community latrine pit emptying interval of 12 times per year [10], each pit was designed to be emptied once a year. A one year emptying interval was considered appropriate because a research indicated that householders were most likely to forget to desludge pit latrines when I was greater than two [25].

Table 4: Elements of VIP latrine sharing scenarios

Scenario (no. of households per VIP)	No. of VIPs	No. of users/VIP	No. of seats/VIP	Volume (m^3)	Pit dimensions (m)
1 (1)	42	36	1	1.5	1.5m × 1m × 1m
2 (3)	14	108	2	4.3	2m ×2m × 1.1m
3 (4)	10	151	3	6.0	2m × 2m × 1.5m
4 (5)	8	189	4	7.5	2.5m × 2m × 1.5m
5 (6)	7	216	4	8.6	2.2m × 2m × 2m
6 (7)	6	252	5	10.1	2.4m × 2.1m × 2m
7 (8)	5	302	6	12.0	2.5m × 2.4m × 2m
8 (10)	4	378	8	15.1	3.5m × 2.5m × 1.7m
9 (13)	3	504	10	20.1	3.5m × 2.5m × 1.7m
10 (21)	2	756	15	30.2	3.6m × 3.5m × 2.4m
11 (42)	1	1,512	30	60.4	6.9m × 3.5m × 2.5m

The sharing scenarios were only averages and reflected the number of users per VIP. Households in reality vary in size and any sharing scenario in practice needs to consider the specific numbers. The facility's physical location could also vary under the different scenarios. The number of VIP latrines required per scenario depended on the contributing population, and determined on the evidence that for sanitation provision at the shared and communal level, 50 – 70 users per seat (or compartment) was considered acceptable [35]. A household level VIP latrine of 36 users therefore had only one seat, but shared and community ones had two or more seats depending on the number of households (or contributing population). Appendix 2 illustrates discounted lifecycle O & M cost computation (actually done in excel) for VIP latrine scenario 1 giving a discounted lifecycle O & M costs of USD 20,934. The discounted lifecycle O & M costs outcomes for the rest of the VIP latrine scenarios are reflected in Table 5.

Table 5 therefore shows the total discounted costs (capital and O & M) summary for the 11 VIP sharing scenarios with a 20-year lifecycle O & M cost implications under the discounting model already justified in Section 5.1. The AHC per toilet was USD52 and falls to USD32 when three households shared a VIP latrine. The table also shows significant AHC that was capital and discounted lifecycle O & M costs reductions of about 5 and 4 fold respectively with increasing sharing from one household to 42 households per VIP latrine. About the same margins of reductions were realized for total discounted costs and AHC. The median AHC that was capital, discounted lifecycle AHC for O & M and total AHC for VIP latrines under the 11 sharing scenarios were USD9.6, USD9.5 and USD19 respectively. There were generally noticeable costs reductions with increasing sharing.

Table 5: Summary of VIP latrine discounted costs at various sharing levels

Scenario (no. of households per VIP)	Number of users/VIP	Capital costs (USD)	AHC_ Capital (USD)	First year O & M costs (USD)	Lifecycle O & M costs (USD)	AHC_ O & M total (USD)	AHC_total (USD)
1 (1)	36	22,877	27.2	3,043.9	20,934	24.9	52
2 (3)	108	13,472	16.0	1,922.7	13,223	15.7	32
3 (4)	151	10,587	12.6	1,539.5	10,588	12.6	25
4 (5)	189	9,719	11.6	1,348.3	9,273	11.0	23
5 (6)	216	8,569	10.2	1,253.7	8,622	10.3	20
6 (7)	252	8,051	9.6	1,160.1	7,979	9.5	19
7 (8)	302	7,503	8.9	1,061.6	7,301	8.7	18
8 (10)	378	6,863	8.2	967.9	6,657	7.9	16
9 (13)	504	5,884	7.0	871.9	5,996	7.1	14
10 (21)	756	5,088	6.1	776.8	5,342	6.4	12
11 (42)	1,512	4,187	5.0	681.2	4,685	5.6	11

Figure 2 reflects a variation in capital, discounted lifecycle O & M, and total AHC under various sharing scenarios ranging from AHC of USD5 that was capital when 42 households shared a VIP, to USD52 total AHC when one household shared a VIP. The relative contribution of each cost aspect showed the total AHC that was capital, and lifecycle AHC for O & M varied within the same range of 46% – 53% regardless of sharing. The cost of VIP latrine went down substantially when more latrines were built. The total AHC per seat further went substantially down when more toilets were constructed (or higher sharing promoted). Table 5 shows that the AHC per seat to build a one-seater VIP (Scenario 1) for one household of 36 was USD52 but costed only USD11 to construct a 20-seater VIP (Scenario 11).

The AHC that was capital and lifecycle AHC for O & M were similar regardless of sharing, suggesting that the cost of building the facility and the cost of maintaining it were comparable irrespective of sharing. The total AHC of a VIP latrine was therefore approximately twice the AHC that was capital or lifetime AHC for O & M. Benefits therefore differed at each sharing level. Though the benefits were higher at lower sharing, the cost implications were significantly higher. Beyond cost-effectiveness, the practicality of digging a large pit at a high sharing level could be questionable even though latrines in East Africa were dug more than 10 m deep [36]. Based on analysis, a sharing of 10 – 21 households per VIP latrine might be considered optimum solution as it resulted in a marginal cost variation of USD4 at least sharing.

5.3 Simplified sewerage (SS)

The SS solution would transport the household waste directly for treatment through a system of pipe networks. It was assumed that the system of networks would undergo some level of annual maintenance. Topographical map of the research community and diagrammatic illustration of proposed pipe network layout are shown as Figure 3. The routes of the internal condominium sewers and the points at which they discharge to a septic tank (ST) are shown. The boundaries of natural drainage are fairly obvious due to the slightly undulating nature of the area, making it suitable for SS pipe network layout. SS could be implemented in unplanned informal communities such as Kotoko, thanks to its flexible layout. Unconnected households to the sewer network (Figure 3) are the 25 households which already had private sanitation facilities (Section 5.1.2).

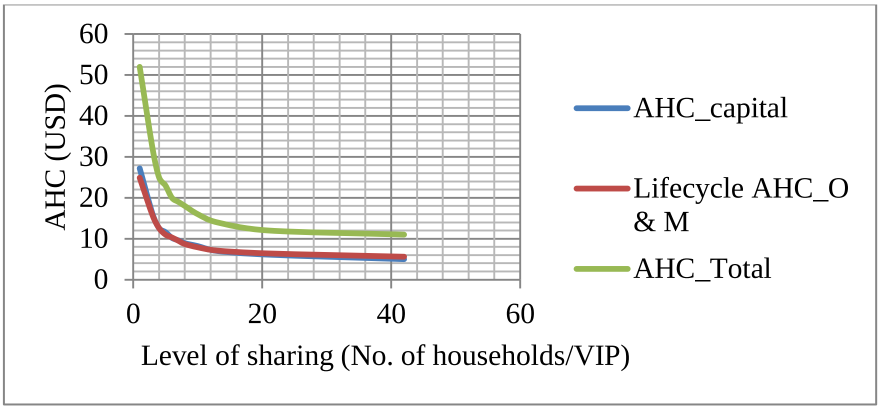

Figure 2: AHC that is capital, discounted lifecycle O & M and total AHC against VIP latrine sharing levels

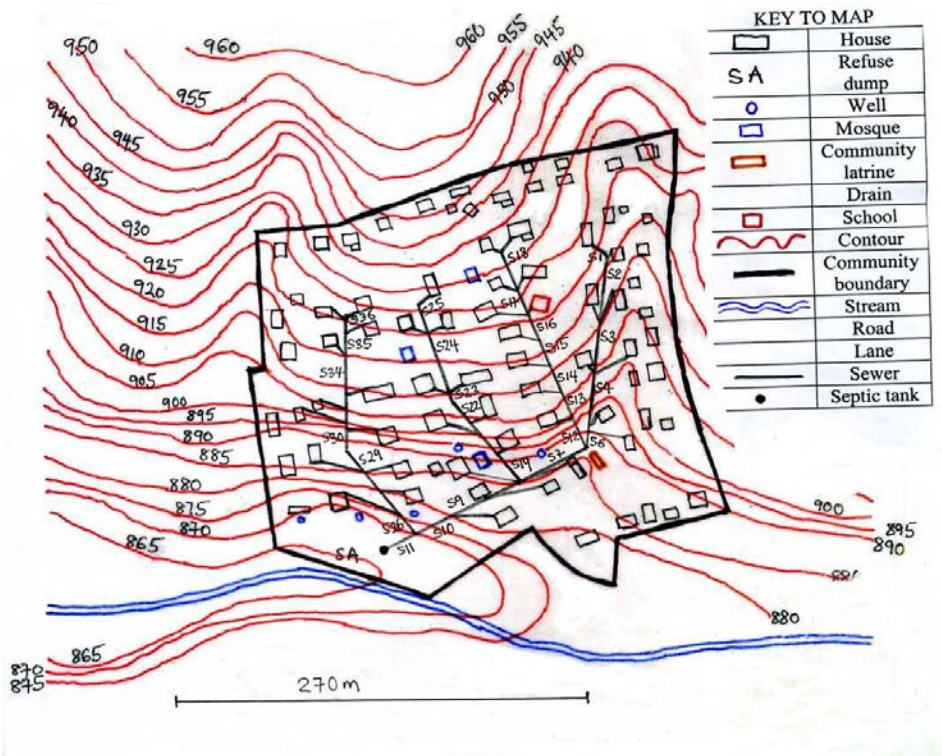

Figure 3: Topographical map of research community (Kotoko) showing proposed sewers connected to 42 households without sanitation facilities

5.3.1 Ground levels and gradients

Solids are transported further in sewers with steeper gradients than ones with less steep gradients [37]. Striking a balance between sewer gradient and excavation depth was thus critical for cost-effectiveness in pipe network laying. The research community topographical suitability for SS pipe network laying was determined. Its suitability meant that pipes could be laid at negative gradients without the requirement for excessive excavations. Ground levels and gradients along the main, secondary and tertiary sewers are shown in Appendices 3 and 4. The numbers in these tables are determined by physically measuring the individual sewer lengths, their upstream and downstream levels on the topographical map (Figure 3) drawn to scale [30, 38]. As illustrated in Appendices 3 and 4, negative average gradients were recorded across all primary, secondary and tertiary sewers, which indicated favourable excavation works [30].

5.3.2 The maximum number of households served

Experimental results on sewer blockage prevention show that solids are transported further in smaller diameter pipes than larger ones [37]. The minimum allowable sewer diameter was therefore used for design in this research, as wastewater flows better in small sewers. The study community had an average household size (P) of 36 and water consumption (W) of 45 $litres\ per\ person\ per\ day$ (Section 3), and a return factor of 0.85 (assuming a self-cleansing velocity of 0.5 m/s achieved at a daily peak flow equal to 1.8 times the average daily flow). Then, the peak flow from each household, q_n (litres/s) was given by $1.8 \times 10^{-5}PW$, which gave 0.03 $litres/s$ < 1.5 $litres/s$. From the design chart for simplified sewers based on Manning's equation [25], for d/D = 0.6, q/Q = 0.6718; and for d/D = 0.8, q/Q = 0.9773. Therefore, increased water consumption by designing the sewers to flow with d/D of 0.6 was 45 (0.9773/0.6718) which gave 66 $litres/day$. From the hydraulic elements of a circular section table [25] and solving for d/D = 0.6, we have k_a = 0.4920 and k_r = 0.2776 when τ = 1 Pa and q in litres/second.

Thus, $q = 9.8 \times 10^{-5} \times D^{13/6}$ ………………………………………………… (2)

Peak flow per household was 0.03 litres/s, which meant q = 0.02916N.…… (3)

Equating (2) and (3) gave $N = 3.361 \times 10^{-3} D^{13/6}$ ……………………………. (4)

For D = 100 mm in equation (4), N = 72. Therefore for the designed values, a 100-mm diameter sewer could serve up to 72 households each of average size 36 in research community. The detailed costs estimates at various sharing were done on excel. The unit costs and prices of materials and services and the detailed costs estimates for SS with septic tank are presented as Appendix 5.

5.3.3 Septic tank volume and dimensions

Septic tanks are usually constructed using concrete blocks or bricks, rectangular in nature and made watertight using cement mortar as interior lining to retain household wastewater for a period of 1 – 3 days [25, 31]. To minimize suspended solids content of the tank effluent, a two-compartment tank system was designed so that any solids re-suspended from the sludge layer in the first compartment due to peak flows entering it were able to settle again in the second compartment [25]. The anaerobic baffled reactor (ABR) which was a septic tank with baffles can accommodate up to 50 households [39]. The ABR was thus a decentralized treatment location for sewerage to be installed due to the number of people connected. It would also reduce odour and waterborne diseases because of wastewater transfer, organic compounds in wastewater, and its effluent could be reused [39]. The baffled septic tank was therefore the option for this research design.

(i) Septic tank volume

The most important consideration in septic tank is the correct volume determination [40]. Septic tank volume has four zones, namely the scum storage, sedimentation, sludge digestion, and digested sludge storage zones. The septic tank volume was therefore the sum of these four volumes.

Scum storage

As scum accumulates at about 40% of the rate of accumulation of sludge, the tank volume for scum storage, V_{sc} (m^3) = $0.4V_{sl}$, where V_{sl} is the volume of sludge [25].

Sedimentation

Time required for sedimentation of settleable solids, t_h (days) = 1.5 – 0.3log (Pq); where t_h is the minimum mean hydraulic retention time for sedimentation (days), P is the contributing population, and q is the wastewater flow per person, (litres/day). As q = return factor × water consumption = 80% × 45 litres/day = 36 litres per person per day, and P = average household size × number of households = 1,512, t_h = 1.5 – 0.3 × log (1,512 × 36) = 0.1 day. Since t_h = 0.1 day < 0.2 day, the design value for t_h = 0.2 day. Therefore, the tank volume for sedimentation, V_h (m^3) = $10^{-3}\,Pqt_h$ = **10.89 m^3**.

Sludge digestion

Time required for settled solids to be digested anaerobically, t_d (days) varies with temperature, T (º C) and was given by the equation: $t_d = 1853T^{-1.25}$. With temperatures ranging from 21º C and 32 º C in tropical Ghana [17, 24], an average temperature of 26.5 º C (T) was used for the septic tank design. Therefore, t_d = 1853 × 0.016632 = 30.82 days. Thus, the volume of the sludge digestion zone, V_d (m^3) = = $0.5 \times 10^{-3}\,Pt_d = 0.5 \times 10^{-3} \times 1{,}512 \times 30.82 = 23.30\ m^3$.

Digested sludge storage

Sludge storage zone volume, V_{sl} (m^3) depends on the rate of digested sludge accumulation, r (m^3 per person per year) and the interval between successive desludging operations, n (years). Since n = 1 < 5 for this design, r = 0.06 m^3 per person per year [25]. Therefore, sludge storage volume, V_{sl} = rPn = 0.06 × 1,512 × 1 = 90.72 m^3. Overall septic tank volume, V (m) = $V_h + V_d + 1.4V_{sl}$, where $1.4V_{sl} = V_{sl} + 0.4V_{sl}$

$= 10.89 + 23.30 + 1.4 \times 90.72 = 161.20\text{m}^3$.

(ii) Septic tank dimensions

To reduce short-circuiting of the raw wastewater across the tank for improved suspended solids removal, a rectangular-shaped septic tank with a length-to-breadth ratio of 2 – 3 in 1 is recommended [25]. A shallow tank of depth between 0.9 m and 2.0 m was designed for two reasons: excavation depth is reduced and lessens problems associated with groundwater infiltration; and improves solids retention through a greater reduction in outflow velocity and the provision of more hydraulic surge storage capacity [25].

For a depth of two metres and width $\varkappa$, the length of the tank is $3\varkappa$. Therefore volume of septic tank, V = $161.20 = 3\varkappa \times \varkappa \times 2 = 6\varkappa^2$, which gave the width of the tank as 5.18 m; length as 15.54 m and depth as 2m. For a septic tank of volume 161.20 m^3, the thickness of walls was 200-mm while the top and bottom slabs each of thickness 150 mm (Water for the World, 2011). The tank's outside dimensions were as follows: outside length is (15.54 + 0.2 + 0.2) m = 15.94 m; outside width is (5.18 + 0.2 + 0.2) m = 5.58 m; and the outside depth is (2 + 0.15 + 0.15) m = 2.30 m.

5.3.4 Simplified sewerage costs analyses

The discounted lifecycle O & M costs for each SS scenario were computed in excel and summarized in Table 6 with SS costs estimates summary with septic tank at various sharing. The table confirms that sharing under a sewer network might have limited impact on costs, as the discounted lifecycle AHC for O & M were the same regardless of sharing, except the "every-household-has-their-own" scenario. The AHC that was capital had not experienced huge costs disparities with sharing. The unit cost of materials and services, and the detailed costs estimates for SS with septic tank for 10 sharing scenarios were estimated using excel. The unit costs and prices for materials services and data sources are however in Appendix 5. AHC for capital and discounted lifecycle AHC for O & M reductions were significantly less pronounced with increasing sharing as compared to the VIP latrine scenarios. Whereas AHC that was capital reduced by about 18% and total AHC reduced by 20% from a sharing of one household per VIP to 42 households per VIP latrine (Section 6.3), there were reductions of 27% on AHC that was capital and 43% on total AHC for SS.

The VIP latrine AHC was USD52 under one household per toilet facility arrangement, USD6 higher than for SS (USD46) at the same sharing level. The median AHC that was capital, discounted lifecycle AHC for O & M and total AHC of SS with septic tank under 10 sharing scenarios were about USD15, USD9.6 and USD25 respectively. Figure 4 shows SS AHC that was capital, discounted lifecycle AHC for O & M and total AHC under various sharing scenarios – ranging from USD7.5 discounted lifetime AHC for O & M to USD46 total AHC when every household had a flush toilet. The relative contribution of each cost aspect showed the total AHC that was capital and discounted lifecycle AHC for O & M varies from 51% – 83% and 17% – 49% respectively regardless of sharing. There was a sharp lifecycle O & M cost rise from a sharing of one household per flush toilet to three households per flush toilet – shown by the dent on discounted lifecycle O & M cost curve (Figure 4). This cost rise might be mainly attributable to the requirement for sewer networks to connect individual households. Analysis showed that a sharing of 7 – 21 households per flush toilet results in a marginal AHC variation of USD4. If sharing had to be an option, it might be cost-effective to consider it at the 7 households per flush toilet level.

Table 6: Summary of SS and septic tank discounted costs at various sharing

Scenario (no. of households/ FT)	Number of users/FT	Capital costs (USD)	AHC_capital (USD)	First year O & M costs (USD)	Lifecycle O & M (USD)	AHC_O & M total (USD)	AHC_total (USD)
1 (1)	36	32,009	38.1	919.9	6,326.52	7.5	46
2 (3)	108	17,198	20.5	1,173.8	8,072.69	9.6	30
3 (4)	151	14,730	17.5	1,173.8	8,072.69	9.6	27
4 (5)	189	13,747	16.4	1,173.8	8,072.69	9.6	26
5 (6)	216	12,718	15.1	1,173.8	8,072.69	9.6	25
6 (7)	252	12,363	14.7	1,173.8	8,072.69	9.6	24
7 (8)	302	11,480	13.7	1,173.8	8,072.69	9.6	23
8 (10)	378	10,603	12.6	1,173.8	8,072.69	9.6	22
9 (13)	504	9,443	11.2	1,171.9	8,059.63	9.6	21
10(21)	756	8,540	10.2	1,171.9	8,059.63	9.6	20

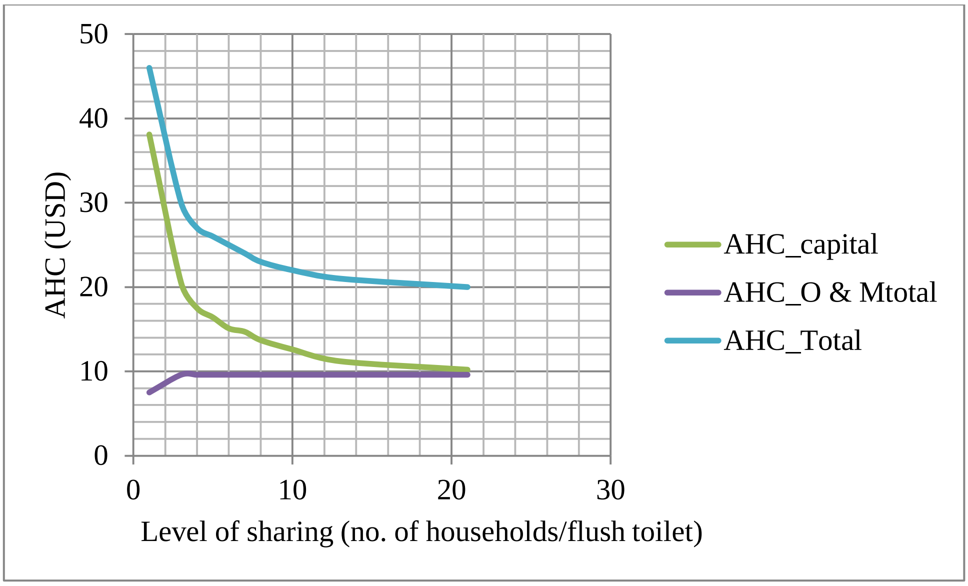

Figure 4: Simplified sewerage AHC that is capital, discounted lifecycle O & M and total AHC against sharing levels

5.4 Pour-flush (PF) community latrine costs analyses

PF community latrines sharing was restricted to 13, 21 and 42 households per pour-flush community latrine, as it was not feasible to build pour-flush communal latrine for small sharing. The unit price of materials and services, and detailed cost estimates for the three scenarios were computed in excel and summary presented in Table 7. The unit costs and prices of materials and services are however summarized in Appendix 6.

Table 7: Summary of community pour-flush and septic tank discounted costs at various sharing levels

Scenario (no. of households/ PFT)	Number of users/PFT	Capital costs (USD)	AHC_capital	First year O & M costs (USD)	Lifecycle O & M costs (USD)	AHC_O & Mtotal (USD)	AHC_total (USD)
1 (13)	504	8,180	9.7	1,182.0	8,129	9.7	19
2 (21)	756	7,169	8.5	1,177.7	8,079	9.6	18
3 (42)	1,512	6,331	7.5	1,173.4	8,070	9.6	17

The total AHC that was capital and O & M stood at about 50% each. The relative contribution of each cost component showed the total AHC that was capital and lifecycle AHC for O & M varied from 44% – 50% and 46% – 53% respectively regardless of sharing. This variation was relatively lower in terms of capital cost and the same for O & M cost of SS system. There was thus a significant capital and total costs variation with sharing. The discounted lifecycle O & M cost however remained unchanged regardless of sharing. A sharing of between 13 – 42 households per PF toilet resulted in a marginal USD2 cost variation in annualized household cost. The median AHC that was capital, discounted lifecycle AHC for O & M and total AHC under the three sharing scenarios were USD8.5, USD9.6 and USD18 respectively.

Figure 5 shows discounted AHC that was capital, lifecycle O & M, total AHC and sharing levels. Whereas PF latrine total AHC was about twice its AHC that was capital regardless of sharing, the discounted lifecycle AHC for O & M remained nearly the same irrespective of sharing. Tables 6 and 7 show AHC that was capital for SS and PF latrine were about the same and relatively higher than that for VIP latrine (Table 5) at the same sharing levels of 13 and 21 households per toilet. Lifetime running costs for SS and PF latrine were also about the same but comparatively higher at lower sharing of 1 – 6 households per toilet. The results therefore suggested VIP latrine system might be less expensive to build and run compared to SS and PF latrine.

6. Three sanitation systems comparison for solution

Figure 6 offers comparison of the three sanitation systems already analysed individually to determine the most cost-effective sanitation system solution for the research community. Costing-based comparison, practicalities, issues with sharing and the relationship between an ideal technical solution and what the community would want were considered.

6.1 Comparison of costs

The results indicated that the least-cost solution depended on sharing level. When there was no sharing SS was the least cost option. SS was also cheaper than VIP latrine when up to three households shared a toilet. VIP latrine became cheaper than SS when four or more households shared a facility. Sharing in this research involved huge numbers and this was accounted for in analysis for solution. For example, six households represent 6 × 36 or 216 people, as average household size is 36 (Section 3). VIP latrine cost was however high at low sharing, and impractical to construct at high sharing due to large pit size. VIP latrine might therefore be cost-effective at medium sharing. Though a PF community latrine was used by the community, the calculations indicated that construction of a new PF facility would cost about USD6 more per household per year than VIP latrine at a high sharing level (20 – 42 households per toilet). It was however not possible to say if this was true of the current facility as its AHC that was capital was unknown and limited data on recurrent costs existed.

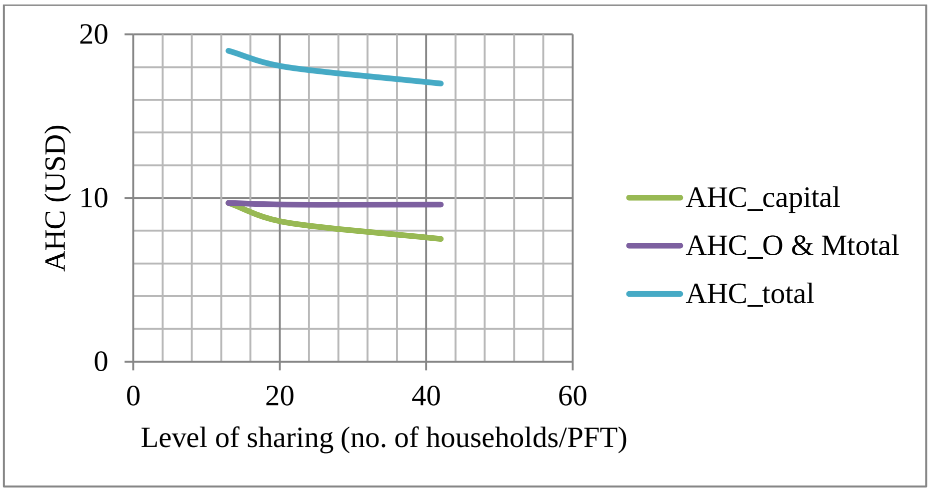

Figure 5: Pour-flush community latrine AHC that is capital, discounted lifecycle O & M and total AHC against sharing levels

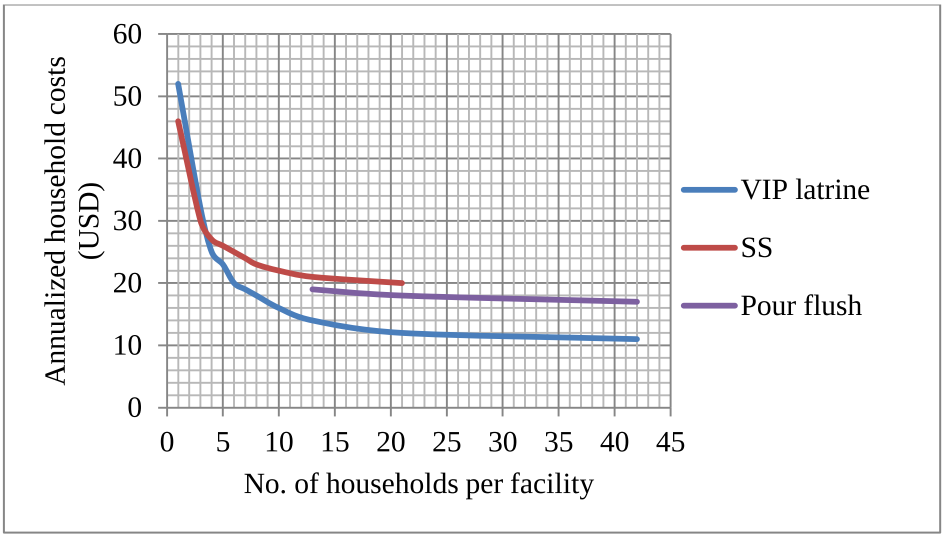

Figure 6: Three sanitation systems' AHC against sharing levels

Based on cost and technical factors alone, VIP latrine might be the research community's appropriate sanitation solution at medium sharing (between 15 and 20 households), because of its relatively low AHC variation, minimal variation in household numbers, and the fact that it could provide the same service level (community or shared) as PF latrine. The provision of VIP latrines at high sharing was not a feasible option as large pit dimensions were impracticable. There were also challenges at lower sharing levels as it would result in numerous pit latrines that needed regular emptying, a real challenge in its own right. PF community latrine was relatively expensive at all sharing levels (13 – 42 households per latrine) compared with VIP latrine. It was excluded as a feasible solution at low sharing as numerous small septic tanks were not feasible, but retained as an option at high sharing.

At higher levels of sharing, however, VIP latrine's AHC is comparatively lower than SS. For instance, while USD12 was the annualized household cost for VIP latrine for 21 households per facility (Table 5), the cost rose to USD20 in the case of SS at the same sharing level (Table 6). Therefore, VIP latrines were more expensive than SS at lower sharing whereas SS was more expensive at higher sharing levels. A balance was thus useful in arriving at a cost-effective solution. A sharing of 7 – 21 households per flush toilet facility results in a marginal AHC variation of USD8. If sharing would be an option, it might therefore be cost-effective to consider it at seven households per flush toilet facility.

6.2 Sensitivity analysis

An important element in sensitivity analysis studies is uncertainty in data and difficulty in model validation [41]. Fluctuating prices of materials and services (such as cement and energy) in Ghana meant that their exact prices at any time were uncertain, and phenomenal price swings of products occurred in Ghana nearly on weekly basis. These price fluctuations often impact on cement-related products (e.g., a bag of cement, concrete block and reinforced concrete slab) and energy-related services (such as pit emptying, electricity and cleaner's pay). An understanding of how price variations impact on the total project cost was therefore important, and required analysis. A strong result from earlier analysis (Figure 6) that related the AHC of the three sanitation systems to the sharing levels was used as basis for the sensitivity analysis. By increasing the price of cement and energy and their related products by 20%, the AHC were determined at the various sharing levels for all the three sanitation systems from the costs estimates provided in excel, and the effects discussed.

A 20% price rise in cement and its related products was a capital expenditure increase. The O & M cost therefore remained unchanged but capital cost rose. The total AHC thus increased. Figure 7 shows the influence on AHC with sharing when cement and cement-related products' prices rose by 20%. The AHC increment for VIP, SS and PF latrines across all sharing scenarios ranged from 0% – 10%, 4.8% – 9.1% and 5.6% – 10.5% respectively under a 20% cement and related products rise – PF latrine realized the highest increase when 13 households shared a facility. The average rise in AHC were 6.3% for VIP latrine, 6.2% for SS and 7.3% for PF latrines – PF latrine recorded the highest and SS the least average increments. The graph indicates that sharing from four households and less, a 20% price increase in cement and its related products had little or no effect on AHC across all three the sanitation systems.

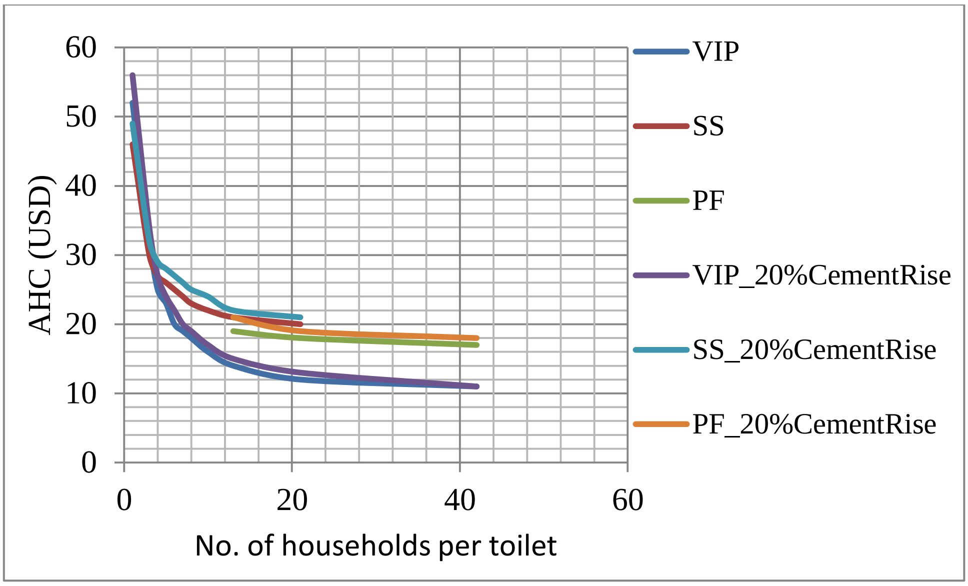

Figure 7: Effect of 20% price rise in cement and its related products on AHC of three systems

A 20% price rise in energy and its related services, on the other hand, represented an increase in O & M expenditure. The capital cost therefore remained unchanged while the O & M cost increased. The total AHC for each sanitation system thus increased. Figure 8 shows the effect of the influence on AHC with sharing when energy and energy-related services prices rose by 20%. The AHC increment for VIP, SS and PF latrines across all sharing scenarios ranged from 5.6% – 15%, 2.2% – 10% and 10.5% – 11.8% respectively under a 20% energy and related services rise. VIP latrine had the highest increment when six households shared a facility. The average rise in AHC were 11.2% for VIP latrine, 7.8% for SS and 11.1% for PF latrines with VIP latrine recording the highest and SS the least average increments. The graph indicated that sharing of four households and lower, a 20% price increase in energy and its related services had little or no effect on AHC across all three sanitation systems.

The percentage increase in AHC when more than four households shared a toilet under 20% price rises was higher for energy than for cement. The sensitivity analysis therefore showed that on average SS had the least increment in AHC under price rises in cement and its related products, as well as energy and its related services. Of the three sanitation systems, SS is therefore least sensitive to both cement and energy prices rise – suggesting that the change in the assumptions for price sensitivity analysis did not influence the overall recommendations.

Another useful sensitivity analysis model was to get a feel of how all the parameters influenced the results and offered an indication of the most important in design. A sharing scenario for each system around a "realistic-equal-cost-point" was considered and the prices of both cement and energy were increased by 20% to find the new total AHC for the scenario. The relative AHC increase was then determined by dividing the new total AHC by the initial total AHC. The parameter with the highest number was the most influential. Tables 5, 6 and 7 give 'realistic-equal-cost-points' for VIP, SS and PF latrines at sharing scenarios of 7 households per VIP (USD19 total AHC), 21 households per SS (USD20 total AHC) and 13 households per PFT (USD19 total AHC). Table 8 was developed by increasing the cost of all three scenarios parameters by 20% using appendices

8, 9 and 10. It shows that VIP latrine was more influenced by 20% cement and energy rise than SS and PF latrine, which suggested that SS and PF latrine might be feasible solutions under inflationary conditions.

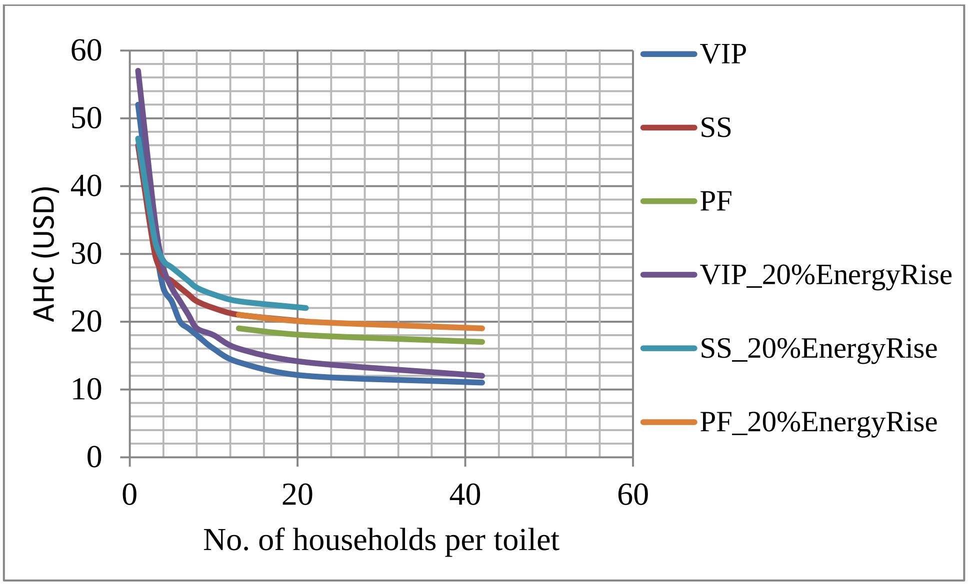

Figure 8: Effect of 20% price rise in energy and its related services on AHC of three systems

Table 8: Relative increase in total AHC across equal-cost points of three sanitation systems at 20% price rise

System	Equal-cost-point	Initial total AHC (USD)	New total AHC at 20% rise (USD)	Relative increase
VIP	7 household/VIP	16,030	18,668	18,668/16,030 = 1.16
SS	21 household/FT	16,600	19,102	19,102/16,600 = 1.15
PF	13 household/PFT	16,309	18,734	18,734/16,309 = 1.15

7. Evaluations

For purposes of clarity, evaluation of this study is categorized into Planning Framework, and Socio-economic and Technical evaluations.

7.1 Planning framework evaluation

The usefulness of the developed framework with particular focus on its wider applicability was reviewed. It also examined the weaknesses and strengths of the framework, and proposed refinements to improve the approach in future. The evaluation thus allowed for the identification and correction of mistakes, imbalances and revision of the overall framework. The framework was intended to assist a wide range of stakeholders from users, planners, service providers, and city officials, political and financial authorities. The proposed framework promotes the bottom-up sanitation planning and delivery philosophy and supports current thinking on the subject. The introduction of users' and experts' views at the planning stages was useful and expected to encourage community participation, promote a sense of ownership, and the eventual use and O & M of sanitation facilities. The approach adopted therefore represents a significant step in the effective assessment of sanitation systems, as it identifies and addresses key sustainability criteria and provides for locally relevant criteria formulation that could be incorporated into current models. The planning framework proposed in this research had four broad characteristics:

(a) Accessing community knowledge through engagement and participation;
(b) An attempt to link local solutions to city systems;
(c) The need to take into account the technical and financial viability of the system; and
(d) Comparative sanitation systems costs, particularly related to sanitation facilities sharing.

7.2 Socio-economic and technical evaluations

7.2.1 Accessing community knowledge through engagement and participation

Whereas some planning framework evaluations recognize the importance of allowing consumer preferences and demands to influence outcomes, there is inclusive evidence that higher levels of participation, for example, are always the best [8]. Poorly-designed participatory interventions could give rise to unrealistic expectations or unsustainable solutions. Community participation makes services and providers more responsive and accountable to beneficiaries, enables the incorporation of users' needs and preferences into community planning frameworks resulting in communities' sense of ownership, proper use, and management of facilities. It is however important to get the balance right by identifying only those elements of consumer preferences that would contribute to sustainability.

Earlier development of indicative costs of the five preliminarily selected sanitation systems with a clear presentational approach to discuss with the community before the detailed costing undertaken in Step 4 of the planning process would have therefore further improved community participation and engagement. This would have provided an earlier indication of cost implications to community members engaged in the process. Future applications would therefore benefit from its inclusion, as it sought to deepen user experiences and understanding of the costs of options available to them.

7.2.2 Local solutions linkage to city systems

The challenges associated with community engagement were exacerbated by lack of clear information at the early stages on the overall Kumasi sanitation system as a whole. During the first two community-level interventions [10, 14], discussions with the community did not take into account the limitations and potential of services and facilities outside the community. The lack of contextual information on potential wastewater treatment options both within and outside the community further limited the value of initial community assessment around appropriate sanitation options. Only once detailed costing of options was included would the implications of such decisions be more clearly understood.

7.2.3 Technical and financial viability

(i) Technical viability

Once the technical options were identified by the experts, the short-list of appropriate sanitation systems was assessed for their viability. This entailed carrying preliminary designs to examine the practical aspects of implementation as well as to form the basis for costing. This part of the research was critical to establish which options could be built and operated given the physical constraints of the site, as well as their overall costs. A key challenge was gathering sufficient topographical information to carry out the preliminary designs. This was achieved using a combination of remote sensing data from Google Maps and site inspections. Once reliable topographical information was assembled on a site map, preliminary design of options was relatively quick and simple.

(ii) Costing

Unavailability of accurate and timely data on sanitation is a challenge [42]. Reliable data on costs of operating sanitation systems in Kumasi were difficult to get. This was largely due to lack of government engagement in the process. Either the information was unavailable or stakeholders were unwilling to give them. To make better decisions in this research, cost data were therefore triangulated from household surveys, projects and institutional documents, and local market surveys. These challenges militate against efforts towards effective sanitation planning that encourages a mix of critical elements necessary for sustainability.

Financial constraints at the community level and shortage of municipal funds to cover operating costs of sanitation systems mean that systems must have the lowest possible capital and operating costs [5]. Often this represents a challenge since the low operating costs may often be associated with higher infrastructure capital costs. Overall the operating costs of sanitation far outweigh its capital costs, and difficult to calculate with confidence given uncertainties over future costs of critical inputs such as fuel and labour. Latrine management costs are also generally acknowledged as extremely high. The costing analysis in Section 5 showed that a major latrine cost was pit emptying (~ 40% of total annual expenditure), compared with literature which stood at about 68%. Another challenge in discussing costs of solutions was that the overall cost was a function of two variables – the choice of sanitation option and the level of sharing of any identified solution. The inclusion of multiple dimensions of choice was challenging – individuals, groups and experts engaged in the consultation often focused on either sanitation option choice or level of sharing, but both were rarely considered together. One of the strengths of the approach used in the analysis was however to take all options identified by the community and experts and evaluate their financial performance under a range of sharing scenarios.

7.2.4 Cost comparison based on sanitation systems sharing

Though shared sanitation facilities are inevitable in low-income high-density peri-urban communities of developing countries, their cost-effectiveness under various sharing scenarios are rarely considered. The cost comparison of sanitation systems based on sanitation facilities sharing is therefore important but long neglected component in determining sanitation systems solutions. Its application thus represented one of the strengths of this research.

8. Conclusions and recommendations

A gap in urban sanitation delivery was the lack of good planning framework that encouraged community and expert engagement, cost data input (particularly based on sharing scenarios), among other variables. This research therefore sought to design an innovative planning framework to address the strengths and weaknesses of urban sanitation planning through the framework application to a particular community. The research outlined a generalized approach to community level sanitation planning framework development aimed at unplanned or semi-planned peri-urban communities; proposed a planning framework that brought together quantitative assessment of engineering design and economic costing with qualitative community survey and experts' views necessary for effective sanitation planning and system selection. The framework was tested and refined in Kotoko in Kumasi (Ghana), a low-income high-density peri-urban community.

8.1 Conclusions

The following conclusions were thus drawn from the study:

- The generalized sanitation planning framework was developed using a wide range of factors represented a good and significant starting point for interventions of this type. This led to the identification of socially acceptable and cost-effective solutions for the particular community. The framework could thus be used by local authorities to gradually address the complexities of urban sanitation challenges, as it encouraged the development of plans enshrined in the local context, captured sanitation systems compatible with the local environment and with due consideration for the socio-cultural and institutional factors.
- Though the planning framework was a good starting point, some improvements were needed to further strengthen it: local government technicians and officials engagement in the process (Step 3 of proposed framework – Section 4.1) was critical to strengthen the link between community knowledge and city institutional constraints; early introduction of cost (Step 3) and institutional elements relating to technical options in the process (Step 2 of framework). Thus, a more robust iterative process in the planning framework that would provide adequate engagement with government officials was recommended to ensure the institutional and technical viability of the solution by initially influencing decision-making through community, city and expert-level information and knowledge.
- The proposed planning framework promoted the bottom-up sanitation planning philosophy and supports current thinking on the subject. The users' and experts' views under the planning arrangement were well articulated and embedded in the framework as critical elements to sustainable sanitation planning and selection. They encouraged community participation, promoted ownership and the eventual use, and O & M.
- There was generally a noticeable costs reduction with increasing sharing across the three sanitation systems under analysis. Benefits differed at each sharing level, but better at lower sharing. Costs comparison analyses showed that SS was less expensive at lower sharing compared to VIP latrine. PF latrine was however relatively expensive at all sharing, and so was excluded as a feasible solution even at lower

sharing. Therefore if sharing would be an option, it might be cost-effective solution to consider SS at seven households per flush toilet.

- Sensitivity analysis of the three sanitation systems under comparison showed that on average SS had the least increment in AHC under price rises in both cement and its related products, as well as energy and its related services. SS was therefore least sensitive to both cement and energy prices, suggesting that the change in assumptions for price sensitivity analysis did not influence the overall recommendation made in conclusion 4. The "realistic-equal-cost-point" sensitivity analysis model also confirmed SS as a feasible future sanitation solution for the research community under inflationary conditions

8.2 Recommendations

The authors' recommendation to authorities of Kumasi Metropolitan Assembly would be to consider SS at a sharing of seven households per flush toilet as the present and future most likely cost-effective sanitation solution for the research community. A pilot scheme could be developed in the research area, and the nearest houses to the current PF community facility could be connected to the existing septic tank. The scheme could then be gradually scaled out as experiences were gained and lessons learnt. Prior to implementation, sanitation stakeholders such as Government of Ghana and Donor Partners could be contacted to address the financing aspect. Cost comparison studies underpinned by sanitation facilities sharing are currently unavailable. It is therefore recommended that more costing studies of this type be carried out to widen the evidence base for decision makers on the most cost-effective sanitation solutions and infrastructure options.

9. Study limitations and further work

Cost data was limited and reliable data on operating costs of existing sanitation facilities were difficult to get largely due to lack of government engagement in the process. Either information was unavailable or stakeholders were unwilling to give them. The lack of adequate government engagement meant some of the solutions might not be institutionally viable even if technically attractive. The financial model could be strengthened through the use of more detailed field-based cost data for materials and labour supplemented by more in-depth analysis of price and discounting sensitivity, and inclusion of more accurate estimation of costs for wastewater treatment options. The effective implementation and application of the proposed planning framework might present a challenge in communities with long history of top-down decision-making approach, as it would often be difficult for stakeholders to express their opinions or offer constructive solutions if they were not used to being consulted.

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APPENDICES

Appendix 1: Ventilated improved pit (VIP) latrine unit costs and prices

No.	Item	Unit cost/price (Gh¢)	Information source (2011 data)
	Materials		
1	Toilet seats (c/unit)	50.00	Market data
2	Cover slab (c/m^2)	40.00	Market data
3	Inspection chamber (c/unit)	58.20	Market data
4	Junction box (c/unit)	42.33	Market data
5	Cement (c/bag)	13.50	Market data
6	Sand (c/m^3)	80.00	Market data
7	Blocks (c/block)	2.00	Market data
8	Roofing sheets (c/sheet)	1.75	Market data
9	Door (c/door)	25.00	Market data
10	Ventilation pipe (c/3 meters)	32	Market data
11	Flyscreen (c/screen)	7	Market data
	Operation and maintenance		
12	Septic tank desludging (c/m^3)	8.00	Community data
13	Electric (c/year)	100.00	Community data
14	Cleaner's yearly pay	480.00	Community data
15	Hygiene (c of soap/year)	7.20	Community data
	Labour		
16	Skilled (c/day)	25.00	Market data
17	Lining (m^2/day)	4.00	Market data
18	Build wall (m^2/day)	4.00	Market data
19	Slab installation (no./day)	6.00	Market data
20	Toilet seat installation (no./day)	6.00	Market data
21	Roofing (m^2/day)	6.00	Market data
22	Engineer/Manager (c/day)	50.00	Market data
23	Wall plastering (m^2/day)	10.00	Market data

Key: "c/unit" means "cost per unit"

Appendix 2: VIP latrine scenario 1 lifecycle O & M discounted cost

Year (r)	$(1+r)^n$	Discount factor	Discounted lifecycle O & M cost (USD)
0	1	1	3043.90
1	1.16	0.8621	2624.05
2	1.3456	0.7432	2262.11
3	1.5609	0.6407	1950.10
4	1.8106	0.5523	1681.12
5	2.1003	0.4761	1449.24
6	2.4364	0.4104	1249.35
7	2.8262	0.3538	1077.02
8	3.2784	0.3050	928.47
9	3.8030	0.2630	800.40
10	4.4114	0.2267	690.00
11	5.1173	0.1954	594.83
12	5.9360	0.1685	512.78
13	6.8858	0.1452	442.06
14	7.9875	0.1252	381.08
15	9.2655	0.1079	328.52
16	10.7480	0.0930	283.21
17	12.4677	0.0802	244.14
18	14.4625	0.0691	210.47
19	16.7765	0.0596	181.44
Discounted lifecycle O & M cost for scenario 1			**20934.29**
Discount factor			$1/(1+r)^n$
Discount rate, r			0.16 (16%)
First year O & M cost (USD)			3043.90

Appendix 3: Ground levels and gradients along primary and secondary sewers for SS

Sewer name	Sewer length (m)	Upstream level (m)	Downstream level (m)	Change in length (m)	Level change/metre	Average gradient (%)
S1	10.0	917.5	915.0	-2.5	-0.250	-0.3
S2	37.0	915.0	910.0	-5.0	-0.135	-0.6
S3	34.0	910.0	905.0	-5.0	-0.147	-0.6
S4	37.0	905.0	892.0	-13.0	-0.351	-1.4
S5	3.4	892.0	890.0	-2.0	-0.588	-0.2
S6	10.0	890.0	887.0	-3.0	-0.300	-0.3
S7	50.0	887.0	885.0	-2.0	-0.040	-0.2
S8	23.6	885.0	883.0	-2.0	-0.084	-0.2
S9	27.0	883.0	880.0	-3.0	-0.111	-0.3
S10	27.0	880.0	870.0	-10.0	-0.370	-1.1
S11	20.0	870.0	867.0	-3.0	-0.150	-0.4
S12	20.0	899.0	887.0	-12.0	-0.600	-1.3
S13	20.0	907.0	899.0	-8.0	-0.400	-0.9
S14	20.0	912.0	907.0	-5.0	-0.250	-0.6
S15	17.0	917.0	912.0	-5.0	-0.294	-0.6
S16	20.0	922.0	917.0	-5.0	-0.250	-0.5
S17	17.0	927.0	922.0	-5.0	-0.294	-0.5
S18	27.0	932.0	927.0	-5.0	-0.185	-0.5
S19	23.6	893.0	885.0	-8.0	-0.338	-0.9
S20	17.0	900.0	893.0	-7.0	-0.411	-0.8
S21	10.0	903.0	900.0	-3.0	-0.300	-0.3
S22	17.0	908.0	903.0	-5.0	-0.294	-0.6
S23	6.8	910.0	908.0	-2.0	-0.294	-0.2
S24	44.0	920.0	910.0	-10.0	-0.227	-1.1
S25	20.0	925.0	920.0	-5.0	-0.250	-0.5
S26	17.0	875.0	870.0	-5.0	-0.294	-0.6
S27	20.0	880.0	875.0	-5.0	-0.250	-0.6
S28	13.0	885.0	880.0	-5.0	-0.384	-0.6
S29	17.0	888.0	885.0	-3.0	-0.176	-0.3
S30	17.0	895.0	888.0	-7.0	-0.411	-0.8
S31	3.4	900.0	895.0	-5.0	-0.470	-0.6
S32	10.0	905.0	900.0	-5.0	-0.500	-0.6
S33	10.0	908.5	905.0	-3.5	-0.350	-0.4
S34	27.0	915.0	908.5	-6.5	-0.240	-0.7
S35	13.0	918.0	915.0	-3.0	-0.230	-0.3

S36	10.0	920.0	918.0	-2.0	-0.200	-0.2

Appendix 4: Ground levels and gradients along the tertiary sewers

Sewer name	Sewer length (m)	Upstream level (m)	Downstream level (m)	Change in length (m)	Level change/metre	Average gradient (%)
S37	10.1	923.0	920.0	-3.0	-0.297	-0.3
S38	10.1	922.0	920.0	-2.0	-0.198	-0.2
S39	13.5	920.0	918.0	-2.0	-0.148	-0.2
S40	10.1	916.0	915.0	-1.0	-0.099	-0.1
S41	10.1	910.0	908.5	-1.5	-0.149	-0.2
S42	16.9	906.0	905.0	-1.0	-0.059	-0.1
S43	30.4	902.0	900.0	-2.0	-0.066	-0.2
S44	20.3	900.0	895.0	-5.0	-0.246	-0.6
S45	16.9	887.0	885.0	-2.0	-0.118	-0.2
S46	27.0	886.0	885.0	-1.0	-0.037	-0.1
S47	15.2	881.0	880.0	-1.0	-0.066	-0.1
S48	40.6	878.0	875.0	-3.0	-0.074	-0.3
S49	27.0	881.5	880.0	-1.5	-0.056	-0.2
S50	37.1	884.0	883.0	-1.0	-0.027	-0.1
S51	1.7	883.5	883.0	-0.5	-0.294	-0.1
S52	33.8	885.5	885.0	-0.5	-0.015	-0.1
S53	33.8	886.0	885.0	-1.0	-0.030	-0.1
S54	6.8	895.0	893.0	-2.0	-0.294	-0.2
S55	20.3	902.0	900.0	-2.0	-0.098	-0.2
S56	10.1	905.0	903.0	-2.0	-0.198	-0.2
S57	10.1	912.0	910.0	-2.0	-0.198	-0.2
S58	10.1	911.0	910.0	-1.0	-0.099	-0.1
S59	10.1	921.0	920.0	-1.0	-0.099	-0.1
S60	6.8	921.0	920.0	-1.0	-0.147	-0.1
S61	10.1	928.0	925.0	-3.0	-0.297	-0.3
S62	11.8	933.0	932.0	-1.0	-0.085	-0.1
S63	5.1	932.5	932.0	-0.5	-0.098	-0.1
S64	10.1	927.5	927.0	-0.5	-0.050	-0.1
S65	8.4	928.0	927.0	-1.0	-0.119	-0.1
S66	5.1	922.5	922.0	-0.5	-0.098	-0.1
S67	20.3	923.0	922.0	-1.0	-0.049	-0.1
S68	13.5	918.0	917.0	-1.0	-0.074	-0.1
S69	13.5	914.0	912.0	-2.0	-0.148	-0.2

S70	11.8	908.0	907.0	-1.0	-0.085	-0.1
S71	10.1	901.0	899.0	-2.0	-0.198	-0.2
S72	27.0	893.0	890.0	-3.0	-0.111	-0.3
S73	10.1	894.0	892.0	-2.0	-0.198	-0.2
S74	27.0	905.5	905.0	-0.5	-0.019	-0.1
S75	6.8	907.0	905.0	-2.0	-0.294	-0.2
S76	27.0	911.0	910.0	-1.0	-0.037	-0.1
S77	13.5	913.5	910.0	-3.5	-0.259	-0.3
S78	13.5	916.0	915.0	-1.0	-0.074	-0.1
S79	10.1	921.0	917.5	-4.0	-0.396	-0.4

Appendix 5: Simplified sewerage and septic tank unit costs and prices

No.	Item	Unit cost/price (Gh¢)	Information source (2011 data)
	Materials		
1	Primary, secondary & tertiary sewers (c/metre)	10.67	Market data
2	Flush toilet (c/unit)	106.61	Market data
3	Inspection chamber (c/unit)	58.20	Market data
4	Junction box (c/unit)	42.33	Market data
5	Cement (c/bag)	13.50	Market data
6	Sand (c/m^3)	80.00	Market data
7	Blocks (c/block)	2.00	Market data
8	Roofing sheets (c/sheet)	1.75	Market data
9	Door (c/door)	25.00	Market data
	Operation and maintenance		
10	Septic tank desludging (c/m^3)	8.00	Community data
11	Check inspection box (no./day)	16.00	Community data
12	Cleaner's yearly pay	480.00	Community data
	Labour		
13	Skilled (c/day)	25.00	Market data
14	Lining (m^2/day)	4.00	Market data
15	Build wall (m^2/day)	4.00	Market data
16	Slab installation (no./day)	6.00	Market data
17	Flush toilet installation (no./day)	6.00	Market data
18	Roofing (m^2/day)	6.00	Market data
19	Engineer/Manager (c/day)	50.00	Market data

20	Primary, secondary and tertiary sewer installation (m/day)	50.00	Market data
23	Wall plastering (m^2/day)	10.00	Market data

Appendix 6: Pour-flush community latrine unit costs and prices

No.	Item	Unit cost/price (Gh¢)	Information source (2011 data)
	Materials		
1	Toilet seats (c/unit)	50.00	Market data
2	Cover slab (c/m^2)	40.00	Market data
3	Inspection chamber (c/unit)	58.20	Market data
4	Junction box (c/unit)	42.33	Market data
5	Cement (c/bag)	13.50	Market data
6	Sand (c/m^3)	80.00	Market data
7	Blocks (c/block)	2.00	Market data
8	Roofing sheets (c/sheet)	1.75	Market data
9	Door (c/door)	25.00	Market data
10	110 mm PVC interconnecting pipe (c/meter)	10.67	Market data
	Operation and maintenance		
11	Septic tank desludging (c/m^3)	8.00	Community data
12	Check inspection box (no./day)	16.00	Community data
13	Cleaner's yearly pay	480.00	Community data
14	Hygiene (c of soap/year)	7.20	Community data
	Labour		
13	Skilled (c/day)	25.00	Market data
14	Lining (m^2/day)	4.00	Market data
15	Build wall (m^2/day)	4.00	Market data
16	Slab installation (no./day)	6.00	Market data
17	Toilet seat installation (no./day)	6.00	Market data
18	Roofing (m^2/day)	6.00	Market data
19	Engineer/Manager (c/day)	50.00	Market data
20	Pipe installation (m/day)	50.00	Market data
23	Wall plastering (m^2/day)	10.00	Market data