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Low-cost sanitation technology options for low-income high-density peri-urban communities of developing countries

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Abstract: Low-cost sanitation technology options (STOs) are the most common in developing countries' poor and densely-populated peri-urban communities. STOs literature for low-income high-density peri-urban communities are however scarce, largely scattered and sometimes unpublished. Low-cost STOs functionality, operation and maintenance (O & M) are often either not well known, understood, or lack the necessary attention. Increasing acute water scarcity triggered by population explosion globally rules out water-dependent STOs such as conventional sewerage as solution to excreta management challenges, particularly for households with either poor or no incomes. Pro-poor low-cost water-independent alternatives fit better into the norms, traditions, and socio-cultural settings of today's multi-ethnic low-income densely-populated communities. To bring clarity, improved understanding, and aggregate all feasible low-cost STOs likely to be cost-effective in low-income communities, two pairs of categorizations are offered in this review. Practical information on the design, construction, and O & M of pro-poor sanitation technologies well-suited to the socio-cultural and economic needs of peri-urban communities is offered. The paper puts up a compelling case for non-waterborne excreta management and disposal technologies, not only for the peri-urban poor largely found in developing countries, but also for the developed world. The author argues that the enormous cost of conventional sewerage (CS) and the urgent need for sanitation improvement in many poor communities suggest that simple, cheap and cost-effective STOs that use no (or minimal) water and support excreta reuse ought to be encouraged. Though ecological sanitation (ecosan) is characterized by the concept of recycling excreta, environmentally friendly with potential food and agricultural benefits, further research on ecosan implications and cost are recommended. It is further recommended that this review paper be made extensively available within Ghana and other developing countries where similar technologies are used. The review concludes that the achievements of the Sustainable Development Goals (SDGs) on sanitation coverage can only be a reality if focus and attention is given to simple but cost-effective pro-poor STOs with low (or no) water requirements.

Keywords:low-cost sanitation technology options, peri-urban communities, low-income high-density, developing countries.

1. INTRODUCTION

Excreta and wastewater management aspects of sanitation have been largely a neglected business for some time now. The most common sanitation facilities in developing countries' poor and densely-populated peri-urban communities are low-cost sanitation technologies (STOs). No significant research efforts, until the 1980s, went into finding feasible and affordable technology options to solve excreta disposal problems in the largely overcrowded poor communities of developing countries. Sanitation was a secondary problem, and so had a much lower priority compared to water supply. It is only recently knowledge, attention, and improved understanding of STOs, on- and off-site, and water-dependent (wet) and water-independent (dry) solutions inclusive, began to attract attention. Peri-urban communities' characterization is therefore relevant to make sense of the kind of sanitation solutions they require. Peri-urban communities often refer to slum dwellers living in the peripheral areas of urban settlements with unreliable aggregate data of the population [1]. Most people in peri-urban communities lack basic sanitation and planning is mostly either non-existent or challenging.

Peri-urban community sanitation provision is one of the most significant service delivery challenges linked to sustainable development and poverty reduction in low-income high-density communities of the developing world [2]. Most challenging are the characteristics that set these communities apart from urban and rural ones [3] – no or unreliable water supply, high population densities, heterogeneous communities, poor site conditions, uncertain land tenure, inferior infrastructure (if any), mostly of low income, and lack of recognition by governments. Heterogeneous populations, unclear institutional responsibilities, and inferior infrastructure, fast growing unplanned communities, and low investment levels in sanitation delivery are challenges common to peri-urban communities [4]. Most households in the peri-urban category are mostly excluded from accessing formal services [1]. There is an innovative policy shift in service delivery from the past supply-driven, and over-engineered solutions where communities' socio-cultural preferences and needs were ignored to demand-driven community-focused approaches [2].

Some STOs require water supply to successfully operate, and so the feasibility of such options depends on water supply reliability. Critical to an effective and efficient service delivery of a proposed sanitation option is an establishment of local water sufficiency. In the dry season when water is scarce in developing countries, for instance, there may not be enough water available to flush latrines, and so options such as VIP or vault (VIV) latrine may be appropriate. In Sri Lanka (The Ministry of Health) an innovative approach advocates the construction of pit latrines with a removable water-seal bowl [5]. This latrine can be used as normal during the wet season when water is in abundance, and if the latrine incorporates a ventilation pipe, the bowl can be removed during the dry season to allow it to function as a VIP latrine. Under such an arrangement, domestic water consumption is reduced to more acceptable levels, and allows an all-year-round facility use.

The STOs under review include simple ventilated improved pit (VIP) latrine, Kumasi ventilated improved pit (KVIP) latrine, urine-diverting (UD) alternating twin-vault ventilated improved pit latrine, pour-flush (PF) latrine, conventional sewerage (CS), simplified sewerage (SS), communal, and public latrines. Two sets of STOs categorizations are offered in this review – on-site and off-site sanitation technologies, and water-dependent (wet) and water-independent (dry) sanitation technologies. Whereas dry sanitation systems generally require little or no water to function, wet systems depend entirely on water. The appropriate STO selection for a community could therefore be community-specific, and partly depends on water availability and cost.

2. OFF-SITE SANITATION TECHNOLOGIES

Though off-site sanitation deals with waste transportation from one location to another for treatment and disposal or reuse [6], some on-site sanitation options (particularly in densely-populated peri-urban communities with permanent structures) can have off-site treatment components as well. On-site sanitation technologies provide services to most low- and high-cost residential areas in Kumasi [7], thereby dispensing with the need for CS. Table 1 offers a summary of on- and off-site STOs.

Table 1: On-site and off-site sanitation technology options

No.	**Sanitation Technology Option (STO)**	
	On-Site	**Off-Site**
1	Pit latrines	Communal & public latrines
2	Kumasi/Ventilated improved pit (KVIP/VIP) latrine	Conventional sewerage (CS)
3	Pour-flush (PF) toilet with septic tank	Settled sewerage
4	Urine-diverting (UD) alternating twin-vault latrine, & all ecosan options	Simplified sewerage (SS)

2.1 Conventional Sewerage (Cs)

The industrialized world's sophisticated CS option is generally unsuitable for developing countries – it is very expensive with high capital cost in both design and construction, and high operation and maintenance (O & M) cost. It is argued that the developed world has no option than to continue to use CS once adopted, and must continue to make the huge investment on it, particularly in treatment [8]. It was therefore not surprising the appropriateness of CS became questionable in the 1970s, not only in its adoption in developing countries, but also in its continued use in the advanced world. CS is inappropriate because of the colossal sums of money needed for treatment and sewer lines, the potential risk of transmitting diseases to water users downstream, leakage of raw sewage from aging sewer lines, accelerated eutrophication of lakes and estuaries, and waste of large quantities of pure drinking water to carry away small sewage [9]. Developing countries adoption of CS was therefore further questioned as it uses large quantities of expensive and scarce water. Without justification for large volumes of water use to flush small quantities of excreta, practical challenges of CS include lack of skilled manpower, blockages, and foreign currency expenditure component requirement to operate and maintain systems [8]; [10].

2.2 Settled and Simplified Sewerage

Settled sewerage or "low-cost solids-free sewerage" [11] is a system of sewers that convey only septic tank effluent [12], and so its application to areas already served by septic tanks is advisable. Simplified sewerage (SS) is however an off-site sanitation technology that removes all household wastewater from its immediate environment [13]; [14. SS – sometimes termed “low-cost solids-transporting sewerage” – is generally a cheaper and better alternative compared to other options [11]; [15]. Like CS, SS is designed to receive unsettled wastewater which is then treated before discharge or reuse. Successfully used in Bolivia, Colombia, Nicaragua, Paraguay, and Peru, SS suitability for urban and peri-urban areas is traced to cost-savings in excavation, and the flexibility in pipe-laying between housing blocks and under pavements [12]. It has the potential to provide high-quality low-cost sanitation services to low-income high-density peri-urban communities.

Originally developed in the North-Eastern Brazilian state of Rio Grande do Norte in the early 1980s [16]; [17]; [18], SS deviates from CS design principles and offers more cost-effective design approaches cheaper to low-income high-density households. As a sanitation technology stripped down to its basic hydraulics [19], SS is different from CS because it is characterized by reduced gradients, depths, and pipe diameters without compromising its original design principles [20]; [19]; [21]. SS main attraction, however, is that its capital cost is approximately half those for CS [22]. It is also cheaper than all STOs at population densities greater than 160 persons per hectare [16]; [19]; [23]. Though SS technology was developed in Brazil in 1983 and the exact breakeven density varies with location, the result was applicable to a densely-populated Kotoko community in Kumasi (Ghana) with 297 persons per hectare population density [23]; [24]. SS, however, has its challenges.

2.2.1 Simplified sewerage challenges

SS widespread use in densely-populated peri-urban and urban areas is well documented. However, its applicability in low-income high-density peri-urban communities is likely to be confronted with low connections and poor networks due to the dynamic and illegal nature of settlement, and the land tenure system. Sanitation projects that applied some elements of SS in the past reported serious challenges and sometimes complete failure. Some of the challenges include [22]: SS is not well known, and its design and construction principles are not well understood in developing countries, particularly Africa and Asia where it is most relevant; limited knowledge on how to best reduce and manage operational challenges such as blockages; and often technical failures in implementing SS, largely due to design errors, materials used and construction standards.

The use of concrete or asbestos cement pipes, for instance, has a high probability of sulphide attack on the pipe material; and attempts to adopt SS standards and practices for low-cost sewerage provision remains a challenge – a typical example is the use of interceptor tanks [22]. While interceptor tanks may minimize the quantity of silt entering sewers, which may lead to blockages, they potentially reduce the capacity of sewers to transport wastewater by reducing the peak flow from household connections. Interceptors also increase householders’ responsibilities for maintenance when it is often not clear they will be met; SS sewerage promotion has not been vigorously and effectively carried out as in the case of ecological sanitation; and limited use of SS might be due to the lack of operational costs data [22].

The author argues that if there is any justification from available evidence to review SS design rules, the consistency and simplicity of its design may not be compromised for any such reviews. In the event of unacceptable sewer blockage rise, it may be prudent to increase the minimum tractive tension design value than to import conventional out-dated sewerage rules.Suitable in medium and high-density housing developments in industrialized countries [25], SS is a technology that can ensure the achievements of the WHO/UNICEF Sustainable Development Goals (SDGs). Some studies found that SS may be more cost-effective than VIP, and pour-flush latrines [16]; [23]; [24].

2.3 Communal and Public Latrines

Communal latrines are shared sanitation facilities usually located within peri-urban communities where individual and household sanitation is either limited or unavailable. Communal latrines are used by 1% of Kumasi households in 2008, as against 6% in 2000 [26] – a significant reduction triggered by deliberate Ghana Government policy to promote improved sanitation, as shared facilities do not count towards coverage achievements. Communal latrines reduce land area required for sanitation facilities, and can be sited at most favourable geological locations; and “pay-per-use communal latrines do operate successfully in some places, though they generally require a subsidy and can present maintenance problems unless responsibilities are clearly defined” [27]. For instance, it takes only one careless person, perhaps a child avoiding the ‘frightening’ squat hole, to establish a chain of misuse for which no one is willing to take responsibility. It is recommended, as a solution to community latrine maintenance problems, that each family be given its own cubicle and its own key to the door [28]. The family is then responsible for cleaning and maintaining their part of the facility.

Where individual family cubicles are not feasible, each cubicle can be shared by two or three families. It is important for each family to choose those with whom to share to minimize the chances of disagreements over sharing of duties. User preference surveys are however necessary for any such sharing. For instance, it was found in Jakarta (Indonesia) that out of about one million septic tanks serving urban households and commercial establishments, most of them were fully owner-financed and unsubsidized [29]. The best decision, however, is usually to offer households or communities a choice to decide the most appropriate to their needs [6]. Another option is to provide well-paid attendants to keep the facility in good condition, and ensure that the necessary maintenance tools are provided. To ensure latrines are well operated and maintained, regular inspections are advised. Communal latrines problems include lack of privacy; difficulty in using them at night and in harsh weather conditions (especially children, the sick, and the aged), and difficulty in upgrading them to individual household latrines.

Public latrines are also shared sanitation facilities usually located in densely-populated urban areas for use by transient commuters. They are therefore common in areas where people often and consistently gather, such as markets, schools, and institutions, among others. Public latrines are the most common sanitation facilities in Ghana. The Kumasi Ventilated Improved Pit (KVIP) latrine was initially designed in Kwame Nkrumah University of Science and Technology (KNUST), Ghana, by Albert Wright as a public latrine [30], but is now popular as household sanitation. Whereas 37% of Kumasi households used public latrines in 2000, the proportion increased to 38% in 2008 [26]. Kumasi residence reliance on public latrines contributes to the spread of diseases, often due to poor O & M of the facilities [30]. User satisfaction surveys could however address these issue [27]; [30]. The common denominator is that both public and communal latrines are shared sanitation facilities. As shared sanitation facilities, Kabange and Nkansah argued in their shared sanitation review paper that restricting improved sanitation to non-shared sanitation facilities was misplaced [31].

3. On-Site Sanitation Technologies Versus Groundwater Contamination

Excreta, toilet flush water (if any) and greywater are usually disposed of into the ground within the housing area, or on the ground surface close to the community if communal facilities are provided under on-site sanitation. An environmental issue of major concern to policy formulators in on-site sanitation development is groundwater quality increasing vulnerability [32]. Whereas some sector practitioners contend that the benefits of sanitation improvement outweigh any potentially negative impact of on-site sanitation, others argue that groundwater is a scarce and valuable resource threatened by on-site sanitation. The health implications of waste discharge to groundwater however depend on how far the pathogens move vertically and horizontally from the discharge point, and for how long they can survive [33]. Groundwater pollution research found that about two metres of sandy or loamy soil placed between groundwater and pit removes virtually all bacteria, viruses and other pathogenic organisms [34].

Three important attributes of pathogens that determine their ability to contaminate a water source are [35]; [36]: pathogens do not travel farther nor faster than the water in which they are suspended; the movement of helminth (worm) eggs and protozoa is limited because their relatively large size will cause them to be retained, or efficiently removed through physical filtration process in soil. It is therefore bacterial and viral movement and survival that are of concern, and inadequately treated groundwater is a major cause of diarrhoea, cholera, typhoid, and hepatitis A outbreaks in most developing countries. Faecal pathogens in the environment, on the other hand, have a limited life span, and so die off within a few hours to several months.

Six factors account for pathogen transmission from a latrine to a nearby water source [36]: the amount of liquid in the pit, nature of the unsaturated zone, distance between pit base and water table, nature of the saturated zone (aquifer), horizontal distance between latrine and water source, and the direction and velocity of groundwater flow. Mara however contends that the possibility of groundwater contamination by viral and bacterial excreted pathogens from VIP and pit latrines should not necessarily be alarming because it is better to contaminate the groundwater than have contaminants on the ground surface [7]. He argues that it is better to have less disease due to VIP latrines availability, than no sanitation but frequent outbreak of diseases. To minimize groundwater contamination VIP latrine pits are provided with a sand filter or a sand envelope.

Preventive measures against groundwater contamination (or at least to reduce its risk) are therefore recommended as follows [7]; [36]: increase the vertical separation between pit bottom and groundwater table using shallower pits or vault latrines, as a minimum distance of two metres between pit and groundwater table will allow little microbial travel in most unconsolidated soils; increase the horizontal separation distance between latrine and water source – a horizontal distance between well and latrine of 10 m is often considered satisfactory; move water point higher than latrine; and seek specialist hydro-geological advice in the absence of the preventive measures outlined. One method for groundwater contamination prevention is to turn the latrine pit into a vault by lining it with watertight material [37]. An alternative categorization of STOs would be to classify them based on whether they use a water seal (flush/wet sanitation option) or not (dry sanitation option).

4. Dry Sanitation Technology Options

The concept of dry sanitation technology usually requires the separation of excreta into urine and faeces. Urine generally poses little threat to public health and contains most of the nutrients – nitrogen, phosphorus, and potassium. Separation of urine allows it to be used safely as a fertilizer after minimal treatment. Faeces, however, contain most of the pathogens, but can also be safely used as fertilizer after storage at ambient temperatures for two years, or composting at higher temperatures for six months [38].

4.1 The Simple Pit Latrine

The simple pit latrine (Figure 1) has a pit for excreta accumulation and decomposition from which liquids infiltrate into the surrounding soil [34]. Still one of the most common sanitation options in low-income peri-urban communities, it needs no water to operate and can accept bulky anal-cleansing materials. The simple pit latrine, in its basic form, has three components – an excavated pit, a covering platform, and a superstructure. It however produces offensive odours in its basic form, and promotes fly and mosquito breeding. The platform can also lead to hookworm transmission if inadequately cleaned. Despite the unsatisfactory nature of simple pit latrine, care and attention to it is critical as it reflects users' socio-cultural preferences and willingness to invest. Simple pit latrine opponents often contend that it is unsuitable for small plots in urban areas. Regulations in Jamaica, for instance, prohibit its construction in communities with population densities higher than 23 households per hectare [34]. Though still popular in Ghana, the revised environmental sanitation policy of Ghana outlawed pit latrines [39]. Objections to the use and acceptance of pit latrines have largely been overcome with the development of VIP latrines.

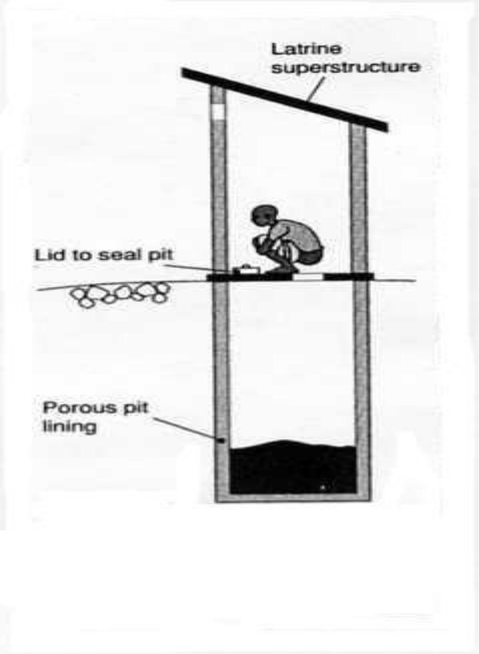

Figure 1: Simple improved pit latrine (section view)
Source: [43]

4.2 Ventilated Improved Pit (VIP) Latrine

The VIP latrine design technology is sufficiently simple and in tune with customs and traditions of many developing countries, and so allows wide community acceptance. First developed in rural Zimbabwe [40], it receives excreta in the same manner as any pit latrine does – 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. A VIP latrine (Figure 2) consists of the pit, a cover slab (usually made of reinforced concrete) which covers the pit, and two holes (squat and ventilation pipe holes), superstructure, roof (for privacy and protection from sun and rain), the ventilation pipe, and fly screen.

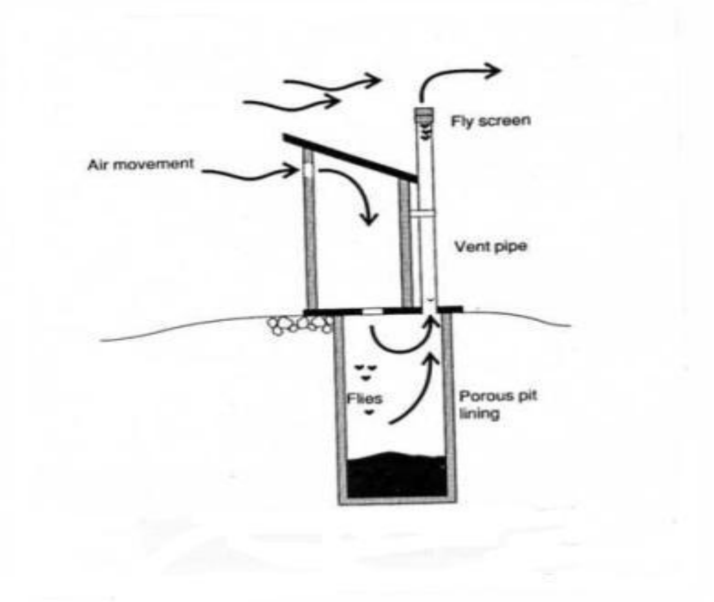

Figure 2: Ventilated improved pit (VIP) latrine (cross sectional view)
Source: [43]

VIP latrines are provided with a masonry collar lining around the pit's upper part to prevent collapse due to structural instability at the construction, use, and emptying stages. Pit lining is particularly useful in loose soils or where the pit is full of water. Lining however has the disadvantages of increased construction cost, and construction difficulties in high groundwater areas. A variety of materials including open-jointed brickwork, masonry, and rot-resistant timber could be used for lining. To minimize problems in rocky or high groundwater table areas, pits may be partially raised above ground level. Pits are provided with a concrete squatting slab (or seat) to prevent floor soiling, allow easy cleaning, and offer comfort to users during defecation. Categorized into dry and wet (or flush) STOs is Table 2.

Table 2: Dry and wet (flush) sanitation technologies

Sanitation technology option		
	Wet (flush) sanitation option	
Dry sanitation option	**Water seal device**	**Effluent disposal**
Pit, public, community latrines	Pour-flush (PF) latrines	Leach pits
Ventilated improved pit (VIP/KVIP) latrines		Septic tanks
Urine-diverting (UD) alternating twin-vault VIV latrines, & all ecosan options	Cistern-flush latrines	Conventional sewerage
		Settled sewerage
		Simplified sewerage

4.2.1 Wind role in VIP latrine odour control

Wind plays a significant role in odour prevention and control, and the ventilation pipe (VP) concept in odour control is well demonstrated in VIP latrine design. Wind blowing over the VP top creates a strong circulation of air through the superstructure, and this air moves down the squat hole into the pit, across the pit, and up and out of the VP. Such air circulation allows any excreta odour inside the pit to be sucked up and exhausted out of the VP, leaving the superstructure odour-free. Ventilation rate is however governed by wind speed and direction. An effective way to demonstrate strong air circulation in a VIP latrine is to hold a lighted newspaper near the squat hole [41] – the smoke is sucked down the squat hole and exits via the VP. It is recommended that VP be extended a minimum of 500 mm above the superstructure's highest point, a 100-mm minimum diameter polyvinyl chloride (PVC) pipe be used for VP, and ventilation openings be provided in the superstructure [41].

4.2.2 Heat role in VIP latrine odour control

The VIP latrine also ventilates on hot still days in the absence of wind. The sun heats the wall of the VP, which in turn heats up the air inside the pipe. Since warm air is lighter than cooler air, it rises and passes up the VP and cooler air is drawn in from the pit. This mechanism works particularly well in thin-walled pipes which heat up quickly, but less effective in thin-walled brick pipes [28]. Thin-walled pipes made of asbestos, steel, and polyvinyl chloride (PVC) are usually coloured black or grey to assist the effect. Fieldworks in Botswana and Zimbabwe however showed that the blowing of wind across the VP top was more effective than painting the pipe black, as heated pipe causes the air to rise and allows odour to escape [34].

4.2.3 Fly control in VIP latrines

The instinctive fly behaviour helps fly control in VIP latrines [42] – whereas flies move in the direction of odour on their way into a latrine, they move towards light on their way out. Flies are therefore frequently attracted to latrines due to the odour emanating from them [28]; [43]. The odour normally comes from the VP top for VIP latrines, and so the flies are attracted there. They cannot however enter since the VP top is covered with a fly screen, which serves as a barrier. A few flies may however sometimes enter the pit through the squat hole via the superstructure and lay their eggs. These eggs develop into adult flies and move in the direction of strongest light (phototaxis). Provided the superstructure is reasonably well shaded, the strongest light visible to flies is the light coming down the VP, but they cannot leave because of the fly screen. Unable to find food, they finally fall into the pit and die.

4.2.4 Superstructure and fly screen roles in VIP latrines

A good superstructure design is one important feature of VIP latrine. The superstructure provides privacy and shelter, and reflects community socio-cultural needs, and so its acceptance by users is critical. Ventilation openings with doors in the superstructure produces an internal conducive environment which necessitates a drop-hole cover. A good superstructure design also finds relevance in fly control. The most important component of the superstructure is however its entrance. The door could be self-closing by connecting it to an internal counterweight. If the door is left open when the latrine is not in use, newly emergent adult flies are presented with an alternative source of bright light (other than the VP light), and so fly control becomes ineffective. A spiral-structured rural VIP latrine design keeps the interior sufficiently shaded to maximize fly control without the need for a door [40]. The VIP latrine superstructure must be fitted with a roof to allow the VP to effectively act as a fly trap rather than the hole. Some cheap permanent roofing material include ferro-cement made with sand and cement reinforced with chicken wire; tin and asbestos roofs are also used but more expensive. Though in rural Ghanaian communities thatched grass roofs are used as roofing material, they allow in light when they deteriorate. They are however preferred largely because they are very cheap and create a cool environment inside the latrine.

A suitable fly screen on top of the VP is very necessary for both fly and mosquito control. The fly screen usually has a 1mm mesh, preferably of stainless steel or glass fibre to resist corrosive gases effect emerging from the pit [28]. A bucket of water may be poured down the pipe annually to clear cobwebs, and the fly screen checked and replaced if necessary [28]. In controlled experiments in Zimbabwe, for instance, 13,953 flies were caught during a 78-day period from an unventilated pit latrine, while only 146 were caught from a ventilated (but otherwise identical) one over the same period [28]. These experiments demonstrate the significant role ventilation mechanisms incorporation plays in pit latrines to control flies and mosquitoes. It is argued that little consideration was given to the urban context of latrines at the time where wind and sunshine fail to reach the VP because of high-rise buildings [34]. They maintained that "the effectiveness of VPs which do not protrude well above roof level in densely-populated areas where local wind speed and direction is governed by the height and location of neighbouring buildings is unclear".

These measures are however not sufficient against the C*ulexpipiens* mosquito which breeds in flooded pit latrines, since they are less attracted to light because they appear at dusk and find alternative escape routes through the squat hole or any small opening [44]. Other suggested devices effective against fly and mosquito control are: fly trap placed over the drop hole instead of a cover; addition of a cupful of kerosene to the pit each week – the kerosene floats above the pit water and suffocates the mosquito larvae, achievable by lowering the surface tension so mosquitoes cannot cling to the surface underside and breath through it [28]. An alternative to kerosene is expanded polystyrene beads – a 2-cm thick layer of 2 mm beads is required to stop mosquito breeding in pits because of their extremely high buoyancy which ensures that they always return to the surface [28].

4.3 Kumasi Ventilated Improved Pit (KVIP) Latrine

Space-minimizing alternating twin-pit VIP latrine (Figure 3) is a modification of the VIP latrine. First developed in Kumasi (Ghana) by Albert Wright at KNUST in the early 1970s, the model is called Kumasi Ventilated Improved Pit (KVIP) latrine [30]. The KVIP latrine is a twin-pit VIP latrine that allows the contents of one pit to sufficiently decompose and pose no health threats to users, while the second is in use. Though initially developed as a technology for public latrines in Ghana, it is currently a preferred option for household sanitation [30]. Various improvements have however been made to the KVIP latrine since its development and include fans installation and additional VPs to increase ventilation. Challenges however remain [30] – its misuse creates inconvenience and unsanitary latrine conditions to users, and excessive water use prevents adequate decomposition.

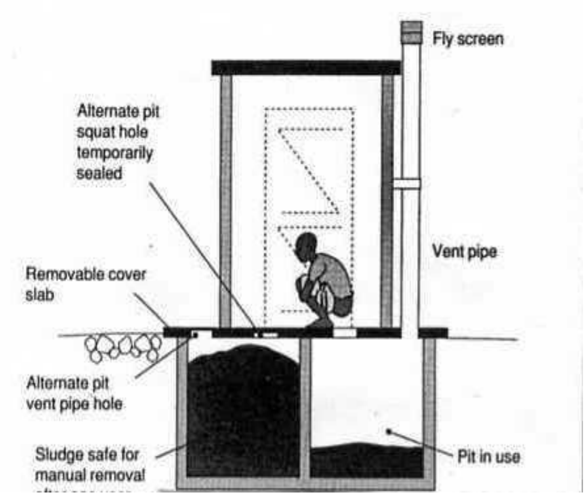

Figure 3: Kumasi ventilated improved pit (KVIP) latrine ((section view)
Source: [43]

4.3.1 Alternative sanitation technology option to KVIP latrine

An alternative to KVIP latrine is the technology option that uses two separate single pits alternatively subject to space availability. One pit is constructed initially and used for 3 – 5 years depending on its effective volume and local solids accumulation rate. When it is full, the cover slab and superstructure are dismantled and re-erected over a second newly dug pit, which is used for the next 3 – 5 years. The first pit is then sealed with soil, emptied and put back into service after the second pit is full. This arrangement, besides giving the latrine an unlimited lifespan, ensures its pathogen-free content, and allows it to be emptied mechanically. Cover slab and superstructure dismantling can be kept to minimum with a good superstructure design, and eliminated if the superstructure is lightweight (<150kg) to allow its complete movement. The merits of deeply dug pits include the possibility of a long-life span (many years of usage before filling up); fewer problems with flies and odour; and the further down the excreta, the lower the risk of disease. Many latrine pits in East Africa are more than 10 m deep, and pits 15 m to 20 m deep are dug in firm soil [45]. Though single large pits could be used when possible to minimize maintenance in terms of emptying frequency, digging a deep pit could prove expensive under rocky ground and high groundwater table.

4.3.2 "Out-house" and "in-house" latrines

VIP latrines are generally considered external sanitation facilities ("out-houses"), but not necessarily the case today since developments in Kumasi (Ghana) and Olinda (Brazil) show that latrine superstructure can be an integral part of a house [46]. To provide access for emptying, the excreta fall into an offset pit partially under the house, but the majority outside of it. In-house bucket latrines in Ghana were upgraded to in-house twin-pit VIP latrines [47] – the pit's external parts were first excavated and lined with open-jointed brickwork, the pits were then extended 45 – 60 cm inside the house, passing below the foundation wall, while timber was used to support the foundation during the excavation. The pit lining was then completed, the reinforced cover slab placed in position, and the old bucket latrine access doors bricked up.

In-house latrines are generally more convenient and encourage usage. They slightly decrease capital costs, especially when a suitable closet already exists as part of a house; they are permanent and emptiable facilities that may be either single-pit units with mechanical emptying, or alternating twin-pit ones with manual or mechanical emptying; and they may be the only feasible VIP design option in high density areas due to lack of space for external units [46]. In-house VIP latrines were installed in a peri-urban slum community Olinda (Brazil) with 500 people per hectare density [46]. Community self-help labour greatly reduces latrines' costs, and a research in Kumasi (Ghana) indicates that a VIP latrine can significantly reduce the costs of sanitation as compared to conventional sewerage [48].

4.4 Ecological Sanitation (Ecosan) Technologies

Ecological sanitation (ecosan) is based on the concept of recycling human excreta – a system where excreta are not disposed of but retained and turned into an economically useful fertilizer [49]. Ecosan technologies include Arborloo, sometimes called "tree-latrine," urine-diversion latrines of all types, Blair VIP latrine, among others. Ecosan is based entirely on natural processes where excreta and soil combine to produce a "new soil" more fertile than the original because of extra nutrients gained, particularly phosphorus and potassium [42]. Ecosan is based on three main principles [50] – it offers a safe sanitation solution that prevents disease and promotes health by hygienically removing pathogen-rich excreta from the immediate environment; it does not pollute groundwater or use the already scarce water resources; and it creates a valuable resource from what is usually regarded as a waste product by converting excreta into fertilizer.

An ecosan latrine that offers real relief to rural poor with widespread food insecurity and poor health conditions is the Arborloo[51]; [52]. Designed by Peter Morgan and implemented by the Ethiopian Government, it cost a household about USD5 and takes about 12 hours to build [52]. The Arborloo is a simple single pit compost toilet of depth 1 – 1.5 metres and consists of a ring beam, slab, and a structure which moves from one site to another at intervals of 6–12 months. Ash, leaves and soil are added to the excreta in the pit during use, and the structure is moved to another location when full after the first is covered with soil to decompose. A tree is normally planted on the old location by family members during rains. The Arborloo is known to work best in rural and peri-urban areas with available space for planting trees [51].

Another ecosan low-cost technology is the urine-diverting (UD) alternating twin-vault ventilated improved vault (VIV) latrine developed by eThekwini Water in KwaZulu-Natal province of South Africa [53];[54]. Designed to separate excreta into urine and faeces, the latrine ensures excreta are handled in an economically and environmentally friendly and sustainable manner. It is a dry system that requires no water for its operation, and works based on the double vault principle. The design adopted by eThekwini is such that urine is diverted to a soak away or collector container to keep the vault content from becoming too wet [54]. This allows faeces alone to accumulate in one of the sealed vaults below the latrine. The faeces become innocuous (pathogen-free) over time, and so safe to handle at no cost. The first vault is sealed when full, and the pedestal is moved to the second vault. During the second vault design life, the faeces in the first can dry for at least six months before they are removed for either disposal or agricultural use.

The Blair VIP latrine is an ecosan technology developed in Zimbabwe, and usually has a doorless spiral-shaped superstructure to provide structural stability (or strength) and a dark interior – factors critical for effective fly control [42]. The pit's spiral shape does not only provide stability, but also reduces latrine slab cost – an important consideration in latrine adoption by low-income communities. Under the Blair VIP concept, pits are usually made wider, but shallower to increase the distance between groundwater table and excreta for groundwater contamination prevention and to increase the surface area for biological degradation of excreta.

Despite ecosan environmental friendliness, potential agricultural and food security benefits, its opponents argue that individual ecosan users at the household level are yet to be convinced that its advantages sufficiently outweigh any potential disadvantages or added costs [55]. Mara argues that ecosan may be good for the environment but may not be feasible if it is too costly, particularly one stands to be convinced that it is low-cost and appropriate in any part of the world [56]. Another criticism of ecosan is the absence of cost documentation on ecosan projects, though it is ambitiously implemented in many parts of the world (including China, Sweden, South Africa, Ethiopia, and Sri Lanka). It is therefore important that ecosan performance is evaluated to allow its cost comparison with other similar STOs. There is also little research on ecosan health implications in urban and peri-urban settlements [57]. Further research in this grey area is therefore required, particularly when ecosan practices and designs that work are context-specific and may not necessarily be replicable elsewhere.

5 Wet Sanitation Technology Options

The wet (or flush) STOs are characterized by the concept of the water seal, achievable by a vertical drop pipe penetrating a water surface. The PF latrine (Figure 4) consists of a superstructure, a squat pan for excreta deposition with its integral water seal connected by a small diameter pipe-work to a single or alternating twin leach pit. The latrine pan and water seal can be a squat pan or pedestal unit depending on whether users are squatters or sitters. The pan is connected to one of two sealed leach pits and flushed manually with a small quantity of water (usually 2-3 litres) after use. The excreta are flushed through the pan and trap along the pipe-work into the leach pit. Insect and odour control is achieved by some of the clean water remaining in the trap to maintain the water seal. The PF latrine may be located in-house, dispensing with the need for a separate superstructure but requires water supply at a higher level of 3 – 6 litres/person/day. The water seal depth in the trap unit is very significant – if the water seal depth is too great, the flush water volume required is too high; and if it is too small, water seal formation may not be possible.

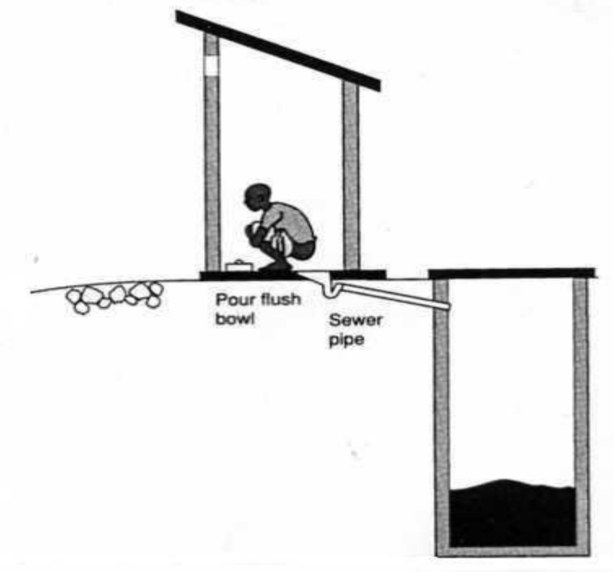

Figure 4: Pour-flush latrine (section view)
Source: [43]

Though PF latrines are well-tried and in widespread use in most developing countries, they are widely used in Asia where anal cleansing with water is traditional. For instance, the Kotoko community in Suame (Kumasi) uses a 24-seater PF latrine to septic tank [23]. The PF latrine major advantages are: odour and insect control is perfect with minimum household care and maintenance; low capital costs – for example, capital costs in India ranged between USD120 and USD150 in 1983, which could further be reduced by self-labour[7]; the possibility of locating latrine in-house and multi-storey buildings; low water requirement; and no (or minimal) sanitation agencies involvement needed for proper O & M of the system. Other advantages of PF latrines include high social acceptability in many developing countries, especially where water is used for anal cleansing; the potential to be upgraded, normally dictated by increasing population densities or higher water use; easy and safe for use by both children and adults; and O & M is very simple, as daily maintenance consists of washing the latrine floor and cleaning the squat pan. PF latrines are inappropriate where bulky anal cleansing materials are used, a minimum of 2 – 3 litres of water for flushing cannot be guaranteed, and incomes are extremely low [28]; [58]. However, additional water is required in cultural settings where anal cleansing is by water. The total water usage is therefore determined for each project as it could be culture-specific.

The squat pan and pedestal units in PF latrines can be easily upgraded, if users so desire, to operate as low-volume cistern-flush latrines. The cistern-flush latrine has a flush volume of about 3 – 20 litres depending on the age and design of the latrine [58]. It has two interconnected parts – when the latrine is flushed, the outlet from the lower part discharges 1.5 litres flush water, but the outlet from the upper to the lower part is closed; after the flush handle release, the lower outlet closes and the upper opens, so refilling the lower compartment in readiness for the next flush. The cistern-flush latrine is especially suitable for use in urban areas with regular water supply.

5.1 Flush Water Disposal Technologies

The flush sanitation option design, apart from excreta storage, disposes generated flush water from the water seal operation. Flush water disposal may be achieved by the following technologies: septic tank, leach pit, or vault, and a brief description of each is offered.

5.1.1 Septic tank

A septic tank (section view shown as Figure 5)is a watertight chamber that retains, partially treats and discharges wastewater for further treatment [34]. Designed to separate excreta and flush water by sedimentation, the excreta are stored in the septic tank and digested anaerobically but periodically removed for off-site treatment and /or disposal. The flush water passes from the septic tank and usually disposed of by soil absorption using drainfields or soakaways – open-jointed brickwork pits, like leach pits but without excreta storage[34]. Septic tanks with soakaways are very common in low-density, middle- and high-income areas of developing countries not served with sewers.

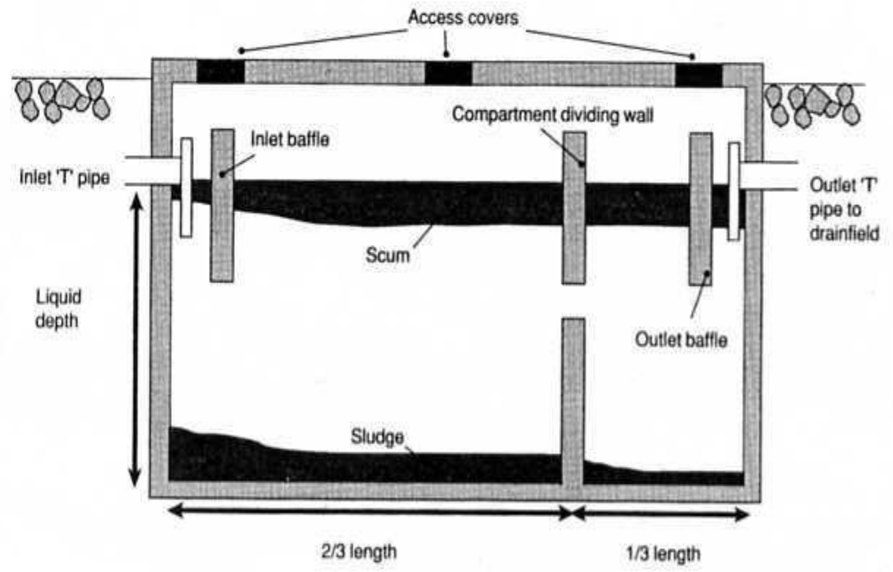

Figure 5: A typical septic tank arrangement (section view)
Source: [43]

5.1.2 Leach pits

Leach pits can be either single or alternating twin-pits usually lined with open-jointed brickwork and receive both excreta and flush water. While the flush water is absorbed into the soil, the excreta are accumulated in the pit and periodically removed for off-site treatment and/or disposal. Leach pits have two functions: storage and digestion of excreted solids, and infiltration of the wastewater liquids. Both leach pits and septic tanks are classified as soil absorption systems, and are designed on the following external parameters: solid accumulation rate (expressed in litres per capita per annum); the minimum period (years) required for effective pathogen destruction; the long-term infiltration rate of the liquid fraction across the pit-soil interface (expressed in litres per square metre of infiltration surface area per day); the hydraulic loading on the pit (expressed in litres per day); and the emptying frequency (per year).

5.1.3 Vaults

Vaults are sealed tanks used to store both excreta and flush water. The vault content must be regularly (every 2 – 5 weeks) removed for treatment and/or disposal. In contrast to septic tanks and leach pits, vault design is dependent only upon the volume of wastewater generated. However, the technology choice imperatively depends on several factors such as cost, acceptability to users, physical environment, among others.

6 Conclusions and Recommendations

The most common sanitation facilities available to densely-populated low-income peri-urban communities in developing countries are the low-cost STOs. The scattered and largely unpublished literature of low-cost STOs, coupled with insufficient knowledge, understanding, and lack of attention to the technical operation, maintenance, and functionality of STOs prompted this review. The author argues strongly for non-water based sanitation technologies for low-income high-density peri-urban communities of developing countries, and emphasis the inappropriateness of conventional sewerage for even the developed countries. A compelling case is therefore made against water-based STOs not only for the high-density peri-urban poor communities in developing countries, but also question their applicability in the developed world. Huge conventional sewerage (CS) cost (of both O & M) and the urgent need for sanitation improvement in many low-income communities of developing countries favours cheap, simple, but cost-effective STOs that use little or no water and encourage excreta reuse. Ecological sanitation (ecosan) is one sanitation option that is underpinned by the concept of recycling excreta, environmentally friendly with potential agricultural and food security benefits, but further research on ecosan health implications and costs is required. This paper, it is recommended, and deservedly so, to be made extensively available within Ghana and developing countries where the technologies are used. The review concludes that sanitation coverage under the Sustainable Development Goals (SDGs) can only be achieved if focus and attention is paid to these simple and cost-effective pro-poor STOs with minimal (or no) water requirement.

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