Effects of Shallow Water Table on the Construction of Pit Latrines and Shallow Wells in the Informal Settlements of Kisumu City

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Abstract

Kisumu city, like many cities in the developing world, has increased burden of urban informal settlements where access to basic sanitation and water remain a challenge. Despite several studies focussing on sanitation and water situation within Kisumu environment, elaborate research on the influence of shallow water table on the construction of facilities and quality of structures has however not been extensively reported. In order to discuss potential implications of sanitation facility quality on public health in the informal settlements, this study characterised sanitation facilities by depth and quality of superstructure, analysed association between depth of pit latrines and types, and between depth of pit latrines and shallow wells (SWs). The study targeted five urban informal settlements in Kisumu city namely Nyalenda A, Nyalenda B, Manyatta B, Manyatta A and Obunga, and two peri-urban informal settlements of Korando and Kogony. The study involved physical ground surveys on all SWs in the study area and convenience sampling of toilet facilities within 30 m radius to the water points. Analysis was carried descriptively and with the help of GIS spatial analysis tool. A total of 100 SWs and 400 pit latrines were studied. Our findings revealed some evidence of the influence of shallow water table on the construction quality and depth of pit latrines and SWs both in the urban informal settlements and those of the peri-urban. The mean depth of pit latrines and SWs in the urban informal settlements ranged from 0.25 m–3.8 m and 0.0 m–4 m, respectively, while peri-urban areas ranged from 3.5 m–8.1 m and 7.6 m–14.4 m. The study also established that most pit latrines were raised to a mean height of 0.25 m–0.5 m above ground. Analysis of depth revealed that the depth of pit latrines and shallow wells in the urban informal settlements were overlapped while those of the peri-urban were not overlapped. Moreover, majority of pit latrines in the urban informal settlements were raised by an average 0.25 m–0.5 m above mean ground level, a strategy, identified by residents, to overcoming the double challenge of flooding and cross contamination. Overall, the study established that, where construction depth of both pit latrines and shallow wells is limited, the incentive to construct quality pit latrines or SWs lessens, the possible reason for the prevalence of low quality and less durable facilities in the urban informal settlements as opposed to peri-urban areas where deeper and improved pit latrines and wells exist. In conclusion, the high prevalence of poor-quality pit latrines and SWs in the informal settlement predisposes residents in these settlements to public hygiene challenges with potential escalation during floods. Creation of awareness on improved toilet facilities with potential of withstanding the challenges of raised water table and frequent flood risks is recommended in the short term while development of specific toilet construction guidelines concerning depth and superstructure recommended on the long term.

Keywords: pit latrine, sanitation, public health, informal settlements

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Introduction

Poor sanitation remain widespread among those living in low-income countries; according to the Joint Monitoring Program progress report of the World Health Organization (WHO) and United Nations Childrens Fund (UNICEF), about 32% of the global population lack basic sanitation, 13% used toilets or latrines where excreta were disposed in situ (WHO and UNICEF 2017: 5). In the sub Saharan Africa, 53% lack access to basic sanitation (Sengupta et al. 2018: 5–9) with a substantive number still practicing open defecation and sharing of pit latrines. This situation is more pronounced in urban informal settlements where access to basic amenities remain low (Scott et al. 2013; Kwiringira et al. 2016; Price et al. 2018). In developing countries, urban informal settlements are characterised by low economic livelihoods, factors which have contributed to low standards of hygiene and increased prevalence of poor sanitation facilities (Kimani-Murage and Ngindu 2007: 830). Finding shallow wells (SWs) and pit latrines in very close proximity is, thus, highly common in these areas (Okotto et al. 2015: 190). Factors such as unfavourable economic policies (Wasonga et al. 2014: 3) that increasingly make the provisions of water and sanitation market driven have contributed to the growing neglect of these pro-poor settlements (Simiyu et al. 2017: 1). In addition, factors of geology and soils, topography and flood-risks patterns are believed to equally influence the nature of sanitation facilities that people construct in these areas (Douglas et al. 2008: 188).

Ideally, areas with shallower water table present construction challenges and depth limitation for pit latrines (Douglas et al. 2008). In such environments, dug pits easily full-up preventing further increase in depth. Areas that encourage water retention and flooding like marshlands and riparian area and those of perched water table (Kresic 2010: 35–85) have similar effects (van Holst et al. 1982; Garg et al. 2005). Some of the options existing for such areas include raised pit latrine technology. This concept of raised pit latrines has been widely reported in flood prone environments (Nyakundi et al. 2010: 350; Sakijege et al. 2012: 1–10; Graham and Polizzotto 2013: 524; Nakagiri et al. 2015: 533). The WHO recommends toilet rising as a means of flood control (WHO 2006); a similar recommendation by United Nations Environment Program (UNEP) reported by Bertule et al. (2018) from the flood prone region of the Southeast Asia. In the same region, another study by Morshed and Sobhan (2010: 236), reported that raised pit latrines are more appropriate in flood and cyclone-prone areas, and that, such raised latrines, have wider acceptability among communities thus providing hope of increased adoption. Some other research findings like Dzwairo et al. (2006) have even reported that contamination of groundwater resources by pit latrines can be reduced using raised and lined pit latrines. This research study, therefore, aimed to characterize sanitation and water sources and present how shallow water table and flood risk conditions have influenced the quality of toilets and shallow wells in Kisumu's informal settlements and the implications of the same on public health planning.

1. Characterization of sanitation facilities and water sources

Characterization of sanitation facilities and water sources is key for efficient sanitation value chain management and public health. According to the definition provided by CSTEP (2016: 2), sanitation value chain is the collection of units and processes involved in the management of human waste, starting with the user interface and ending with the reuse of the material resources. Each aspect of the value chain has a set of different technologies and facilities (Lagardien and Muanda, 2014: 16), where, facility, refers to the infrastructure dedicated for the disposal, conveyance or treatment of waste, while, sanitation technology, refers to the specific infrastructural configurations, methods or services designed specifically to contain, transform or transport waste to another process, point of use or disposal (Tilley et al. 2014: 5). Most sanitation technologies are classified based on (a) earth/dry and water-

Table 1. Description of sanitation types and characteristics available for developing countries.

Technology	Reference	Description
Traditional pit latrine (TPL)	Graham and Polizzotto 2013	• The most common toilet system in use. A hole dug in the ground, lined or unlined, fitted with cover slab and with a superstructure of many different materials. • They are usually very smelly and fly ridden. • Can contaminate ground water if less than 30m to a well.
Ventilated Improved Pit (VIP) latrine	Morgan 2007; Tilley et al. 2014; WHO and UNICEF 2017	• Designed to control odours and flies in a pit latrine. It uses a vent pipe to draw air out of the pit. • The vent pipe also acts as a fly trap, when the superstructure is semi-dark. • It's the most promoted in low cost settlement areas, however, relatively costly to set
Sanplat latrine	Morgan 2007; Tilley et al. 2014; WHO and UNICEF 2017	• This is a concrete slab with a fitting concrete lid attached to a wire handle. This can is fitted onto a dug hole that can be used as a latrine when covered with a simple or improved superstructure. • Relatively cheaper than VIP latrines and easily adaptable to existing TPL
Pour Flush Toilets (PFT)	Morgan 2007; Tilley et al. 2014	• It's where water is used to flush or poured to drain away human waste after generation. The water may be carried in a small container like bucket as one goes to the toilet. • Waste-water could be used for flushing purposes. • The toilet could be squatting or sitting type.
Urine Diverting Dry Toilets (UDDTs)	Tilley et al. 2014	• A source-separated solution that ensures the safe capture of faecal sludge into sealed cartridges, containers, or holding tanks • It enables easy usage for residents. The structures work extremely well in slums, urban areas, and peri-urban areas with high density population.
Conventional sewerage system (CSS)	Campos et al. 2015	• Most advanced method of treating human wastes requires regular water supply, reticulation and treatment works. • It is suitable for large urban areas and estates where water supply is regular and the beneficiaries can afford to pay for its operation and maintenance
Flush/Septic Tank/ Soak-away system	Tilley et al. 2014	• This is the removal of excreta using flush from an improved toilet by the use of water or air suction. • Requires regular water supply for efficient performance • The toilet could be squatting or sitting type • The sanitation facility however has the potential of contaminating ground water where the water table is high

based types, (b) context of use i.e. shared or individual facilities, (c) types and stability of the structures for instance mobile and permanent facilities. However, despite the variety of technologies, the dug pit latrine, remains the most dominant in poor developing countries (Garn et al. 2017: 330; Orner et al. 2018: 3). Table 1 illustrates various types of sanitation technologies and facilities available for developing countries. In this research the word sanitation facility is lightly used to refer to the different types of pit latrines i.e. traditional pit latrine toilet (TPL) which describes a type without any ventilation, or the ventilated improved pit latrine (VIP)—the widely promoted among low cost settlements.

On water source types, two major categories exist, namely; improved or protected and non-protected types. An improved drinking-water source is one that by nature of its construction is protected from outside contamination i.e. faecal matter. Protected water sources are covered to prevent the entry of physical, chemical and biological contaminants into the water (WHO and UNICEF 2017). Without protection, the compounded effect of poor sanitation management negatively impacts the quality of water sources to the detriment of public health (Banks et al. 2002: 148; Cairncross et al. 2010: 195; Howard et al. 2016: 255; Horn et al. 2018: 709). In the absence of sufficient protection, water sources are potentially vulnerable to pollution arising from biological contaminats such as bacteria (Kiptum and Ndambuki 2012; Opisa et al. 2012), chemical seepage from close proximity sanitation facilities (Lapworth et al. 2017: 1094), and even from agricultural activities or run-off water carrying agrochemicals and faecal matter (Wagah et al. 2010; Abila et al. 2012; Othoo and Abrahams 2016).

Poor sanitation practices can exercabate the spread of many infectious diseases including cholera, typhoid and schistosomiasis (Abila et al. 2012: 28). An earlier WHO report indicated that about 10% of the population of developing world is severely infected with intestinal worms associated with improper excreta management (WHO 2006). One recent study by Adane et al. (2017: 13) confirmed that sharing of sanitation facilities and proximity factors were significantly associated with acute diarrhoea in Ethiopia, while, in Kenya, a recent national mid-term sanitation report acknowledged that approximately 27 million US Dollars is spent annually on sanitation related diseases (Kenya Ministry of Health 2016).

2. Methodology

2.1. Study area

The study was carried in the informal settlements of Kisumu city, the commercial capital of Kisumu County and the western Kenya region (Figure 1). The choice of Kisumu was due to the increased presence of informal settlements above national averages. The study specifically focussed in the ward of Nyalenda A, Nyalenda B, Manyatta B and Manyatta A and also Obunga slum in the southern part of the Kanyakwar ward, and the peri-urban ward of Kogony and Korando. Kisumu is situated on the shores of Lake Victoria at longitudes 34°20´E and 34°70´E, latitudes 0°20´S and 0°25´S (Simiyu et al. 2017: 3) and lies at an altitude of 1,160 m which rises to about 1,400 m, above sea level, towards the north-west of the city. The population of Kisumu is estimated to be 600,000 according to the recent Kenya populations and housing survey of 2019 (KNBS 2020). Informal settlements cover approximately 19% of the city and hosts about 60% of the city's urban population (Simiyu et al. 2017: 4). The population density in these informal settlements varies between 6,000 and 21,000 persons per km^2 (Okotto-Okotto et al. 2015: 4277). Kisumu has an annual rainfall of between 1,111 mm–1,407 mm distributed in two major rainy seasons from March to May (467 mm–477 mm) and from October to December (370 mm) and a subdued rainfall peak in August (150 mm) (Olago et al. 2007: 352; Maoulidi 2010: 15), the hot and dry seasons fall in January and February while a cold season exists in June and July. Temperature varies seasonally with a maximum annual temperature range from 25ºC to 30ºC while the mean annual temperature ranges from 18ºC to 20ºC (Maoulidi 2012: 2; Rakama et al. 2017: 44).

The city is surrounded by a mountain slope on the north, wetlands in the south and two plain belts; the Kano Plain in the south-east and Kanyakwar Plain in the north west. Phonolitic rocks describe the major part of Kisumu city while volcanic soils occupy the mountainous areas of Kisian Hills and Riat Hills towards the north west (Rakama et al. 2017: 44). The soils of the plains are prone to flooding and the water table is generally high, in fact, in the informal settlements of Nyalenda A, Nyalenda B, Manyatta B and Manyatta A, the water table can often rise to a depth of 3 m (Wright et al. 2013: 4262–4263). This phenomenon is also supported in other literature (Okotto et al. 2015: 4277–4279; Okurut et al. 2015: 88; Olago et al. 2007: 1033). The Kano plains which spans the eastern part of the city, and where the major informal settlements exist, have shallower perched water tables ranging between 0.0 m–15 m depths below ground (Khisa et al. 2013: 417–434). Water supply remains a challenge in

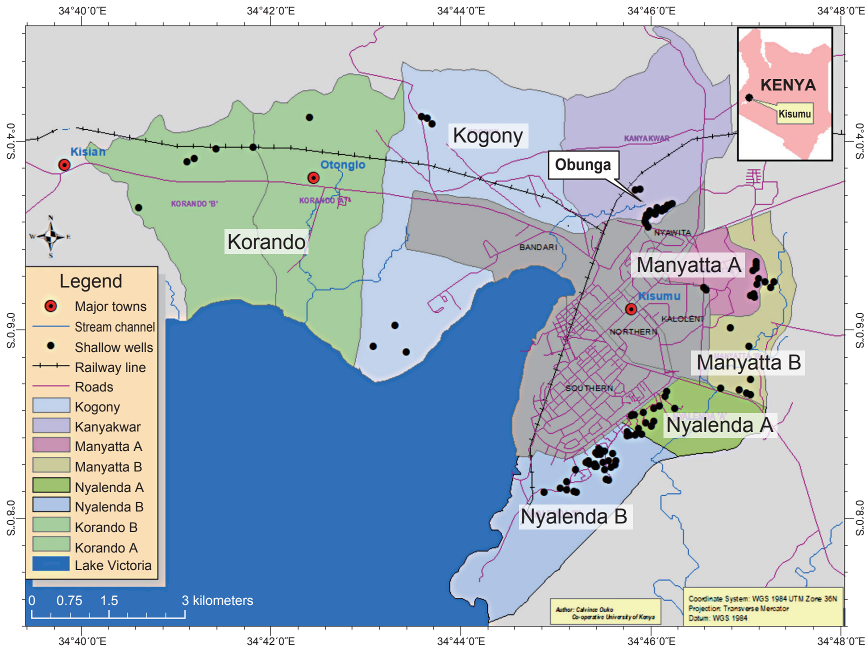

Figure 1. Map of the study area showing five urban informal settlements of Nyalenda A, Nyalenda B, Manyatta A and Manyatta B and Obunga, and the two peri-urban settlements of Kogony and Korando.

Kisumu city, especially in the informal settlements. The main water sources in Kisumu are Lake Victoria, SWs, unprotected springs and boreholes (Figure 3). During the dry season, some of the water sources run dry forcing residents to buy water at increased costs from commercial vendors.

2.2. Data collection

The study involved physical ground surveys to identify SWs in the study area and a convenience sampling of toilet facilities within 30 m radius to the SW of interest. The choice of sample design was informed by high numbers of pit latrines and SWs in the study area, and the complex informal settlement dynamics in the study area. Water sources were categorised as SWs based on the geological well classifications provided in literature (Waller 1988: 13; Hamill and Bell 2013: chp. 2; Jakeman et al. 2016). Community leaders and local government administrators assisted in identifying water sources. The study surveyed a total of 100 SWs and 400 toilets. Of the 100 SWs, 84 (84%) of the SWs and 356 (89%) of toilets were from the urban informal settlements while 16 (16%) and 44 (11%) pit latrines from peri-urban areas. GIS technique were used to delineate pit latrines within 30 m radius to the water source. Information was collected using semi-structured questionnaires while part was entered on a matrix datasheet. The depth of pit latrines was measured using a 15 m thin long wire-rod which was measured against a measuring tape. The wire-rod was inserted to the pit bottom in three multiple times and an average height (depth of pit) calculated. Additionally, sanitation facilities were assessed based on body structure, roofing material, types and the nature and height of raising above the ground. The depth of SWs was measured in the similar manner as pit latrines using 15 m thin long wire-rod.

2.3. Data analysis

Quantitative data was analysed descriptively in MS Excel and correlation analysis also undertaken to assess association between variables. The significance of the correlation coefficients (R^2) was statistical calculated based on a *p* value of 0.05 (95%) confidence interval. Spatial analysis was carried out in ArcGIS 10.6 environment. In

GIS, spatial interpolation of the SW points was applied using the Inverse Distance Weighting (IDW) interpolation method to create raster surfaces for pit latrine and SW depth in this study. Hydrology analysis was done using a 5 m resolution DEM satellite imagery to model and delineate stream pattern, order, and contours, which indicate areas of possible drainage convergence and likely stream tributaries. Besides, the stream convergence also depict possible contaminant flow directions both surface and sub-surface.

3. Results

3.1. Characteristics of sanitation facilities

The results presented in Table 2 show the number of SWs and pit latrines in the study area presented as percent of total numbers. Nyalenda B and Obunga recorded the largest number of SWs (24% and 22%) and pit latrines (24.8% and 22.5%), respectively, while the least number of SWs were recorded in Manyatta A. Pit latrines were, further, categorised as either VIPs or TPLs and presented as proportion of total number of pit latrines. It can be seen that TPLs constituted the largest share of all pit latrines in the study area. A contour map profile has been presented in Figure 2 illustrating the general topography and drainage in the area, as well as modeled stream channel networks. The stream models are predictive of flow accumulation or possible drainage corridors or directions of contaminant flow. It can, further, be seen that Nyalenda A, Nyalenda B, Manyatta B, Manyatta A and Obunga informal settlements exist within low-lying areas. Besides, these settlements exist near or within the identified stream riparian catchments. Figure 3 is presenting the spatial interpolation i.e. raster surface outlook of SWs water level depth which may be indicative of water table height. Going by the map, especially the southern part of Kanyakwar ward where Obunga is located, there were more and fuller (water-full) SWs going by the water level depth, the findings were true as well for most of Nyalenda A and Nyalenda B. The areas of Manyatta A and Manyatta B and the peri-urban areas of Korando and Kogony had deeper water levels illustrated by the changes in the increase in spectral classes from low to high. This raster map provides potential evidence to the influence that conditions of drainage and shallow water table may have on the depth and water levels on SWs in the study area.

Figures 4 and 5 show characteristics of pit latrines with regards to superstructure (body structure) materials (Figure 4), roofing materials used (Figure 5) for the two dominant latrine types i.e. VIP and TPL. VIP toilets had more concrete superstructures than TPL across all the study areas. For instance, for VIP toilets, 86% of facilities in Nyalenda B had concrete superstructure against 9% with iron sheets superstructure. In contrast, only 50% and 32% of TPLs had concrete superstructure and iron sheet rooftops in the same study site. Korando had the highest number of facilities with concrete body structure, while in Kogony, almost all VIP toilets had iron sheet roofing. Whereas most TPLs had concrete superstructure, a considerable proportion, especially urban informal settlements were, however, constructed using iron sheets; 42% of all TPLs in Nyalenda A and Obunga had iron sheet superstractures, while Nyalenda B, Manyatta B and Manyatta A had 32%, 32%, 35%, respectively. In the informal settlements, 30%–50% of the TPLs have open rooftops, while less than 5% VIPs had no roofing. The roofing pattern were of improved quality in the peri-urban areas compared to the urban informal settlements, for instance, no more than 10% of all TPLs in Korando and Kogony lacked roofing, while other roofing materials i.e tiles were also in considerable perentages (i.e., 42% in Korando).

Figure 6 shows applications of toilet raising, practiced widely, in the study area; from the findings, more VIP toilets than TPL were raised. Approximately 60%–87% of VIPs in the informal settlement area were raised against about 36%–70% of the TPLs. Nyalenda B, Manyatta B and Obunga had the highest numbers of VIPs with elevation while Nyalenda A and Manyatta B reported the largest number of TPLs with elevation. Majority of facilities in the peri-urban slums were either non-raised of slightly raised to 0.0 m–0.5 m.

Table 2. Number of shallow wells and pit latrines (VIP & TPL) expressed as percentages of total across the urban informal settlements and peri-urban informal settlements.

Study site	Shallow wells	Sanitation facilities		
	Number of SWs as percent (%) of total SWs	Total Number of pit latrines as percent (%) of total	Proportion of pit latrines that is VIP	Proportion of pit latrines that is TPL
Nyalenda A	17 (17.0%)	87 (21.8%)	23 (26.4%)	64 (73.7%)
Nyalenda B	24 (24.0%)	99 (24.8%)	42 (42.4%)	57 (57.6%)
Manyatta B	14 (14.0%)	67 (16.8%)	13 (19.4%)	54 (80.6%)
Manyatta A	7 (7.0%)	15 (3.8%)	3 (20.0%)	12 (80.0%)
Obunga	22 (22.0%)	90 (22.5%)	18 (20.0%)	72 (80.0%)
Korando	8 (8.0%)	18 (4.5%)	10 (55.6%)	8 (44.4%)
Kogony	8 (8.0%)	24 (6.0%)	14 (58.3%)	10 (41.7%)
Total	100 (100.0%)	400 (100.0%)	123 (30.7%)	277 (6.0%)

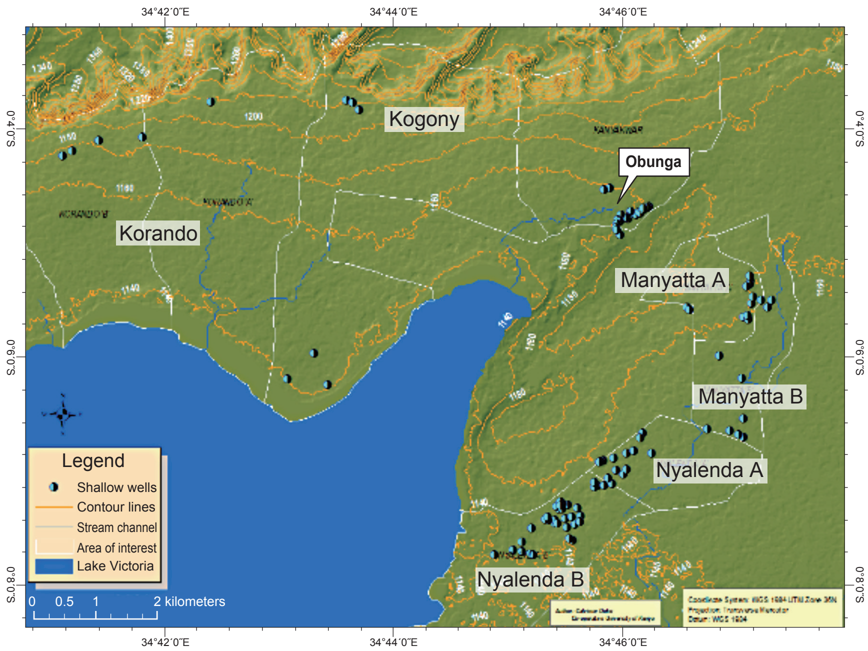

Figure 2. Contour map and spatial locations of shallow wells and pit latrines within flood risk zones.

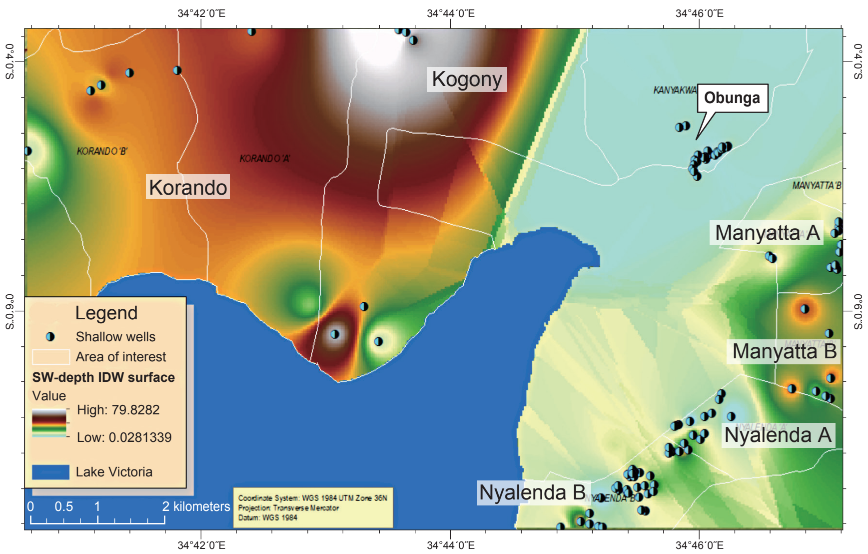

Figure 3. Depth interpolation raster map developed in an ArcGIS 10.6 environment. The spectral variation denote variations in water table characteristics.

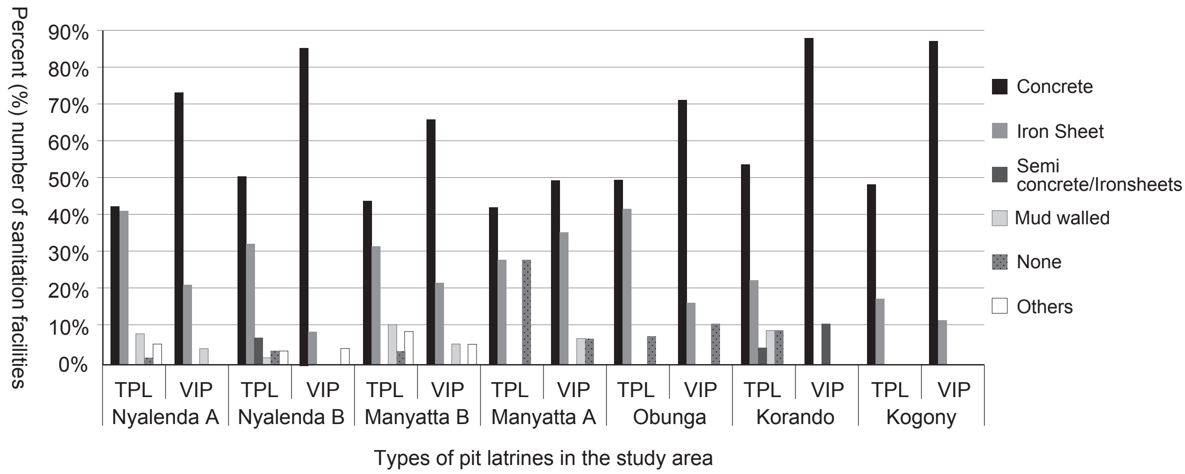

Figure 4. Characteristics of pit latrines by types and nature of superstructure material.

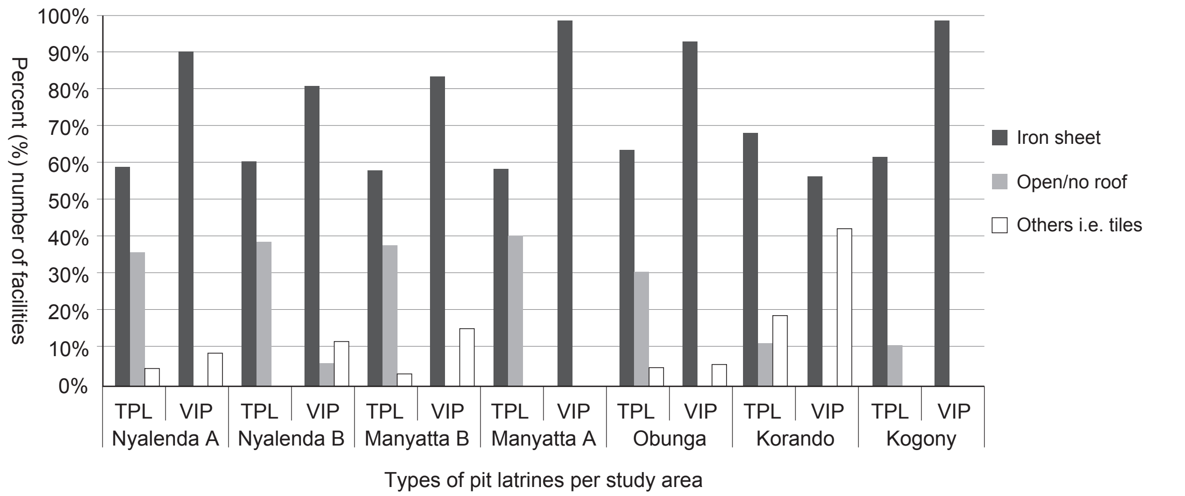

Figure 5. Characteristics of pit latrines by roofing material.

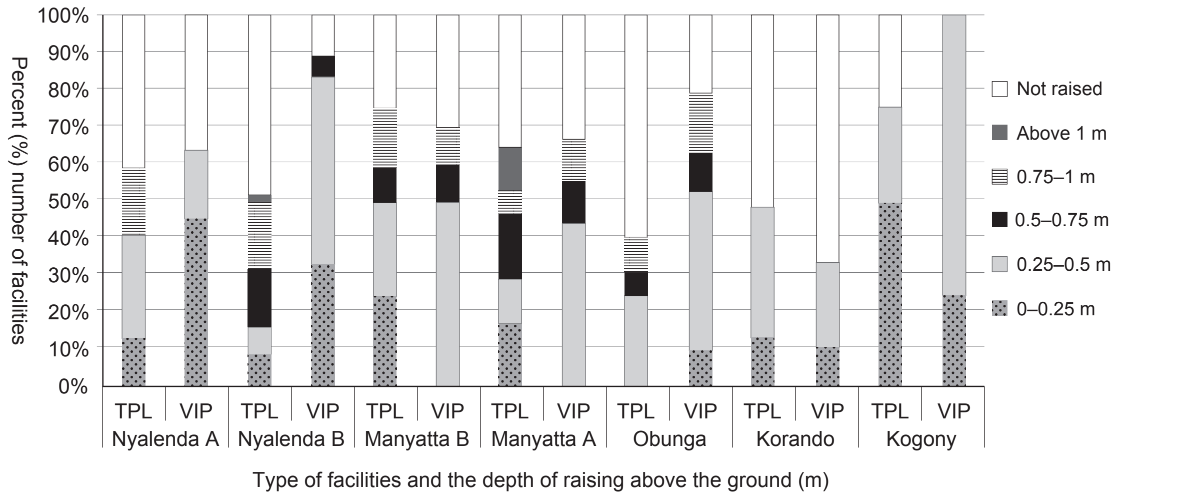

Figure 6. Characteristics of pit latrines by raising-height above the mean ground level.

3.2. Relationship between depth and quality of structures

Figure 7 illustrates the variation of pit latrines depth and SWs depth across the urban and peri-urban informal settlements. Majority of pit latrines (90%–95%) have depths between 0.25 m–4 m except in Korando and Kogony where they are relatively deeper (between 4 m–10 m depth). The mean depths were recorded as follows; Nyalenda A = 2.3 m; Nyalenda B = 2.2 m, Manyatta B = 2.5 m, Manyatta A = 3.5 m, Obunga = 2.5 m, Korando = 3.5 m and Kogony = 8.1 m. On the other hand, the shallow wells depth ranged from a mean of 2 m in Obunga to 14.4 m in Kogony. Nyalenda A, Nyalenda B, Manyatta B, Manyatta A and Korando had mean SW depth of 2.6 m, 2.8 m, 2.7 m, 2.2 m and 7.1 m, respectively. The results showed most shallower pit latrines were from Nyalenda A and Manyatta B while shallower wells from Obunga.

Figures 8 show correlation analysis results between pit latrines and SW depth; first, for urban informal settlements (Figure 8(a)) and, secondly, peri-urban areas (Figure 8(b)). The results showed a weak association ($R^2 = 0.1128$) between pit latrine depths and shallow well depth across all urban informal settlements. However, a positive association (Figure 8(b)) was observed across all the peri-urban areas ($R^2 = 0.8975$; $p < 0.05$) between pit latrine depth and shallow wells, an indication that homesteads with deeper shallow wells have also deeper pit latrines.

Figure 9, on the one hand, presents results from verbal communication with the well owners after asking the reasons behind the choices of sanitation facilities in the area, and, the reasons for the predominance of TPLs in their settlements. The results show that poverty/inability to afford the cost of constructing quality facilities (22%), high water table and unstable soils (both at 16%) were identified as reasons for the high prevalence of TPLs. High water table (29%) and high cost of construction (22%) were cited as the reasons for the existence of shallow depth facilities.

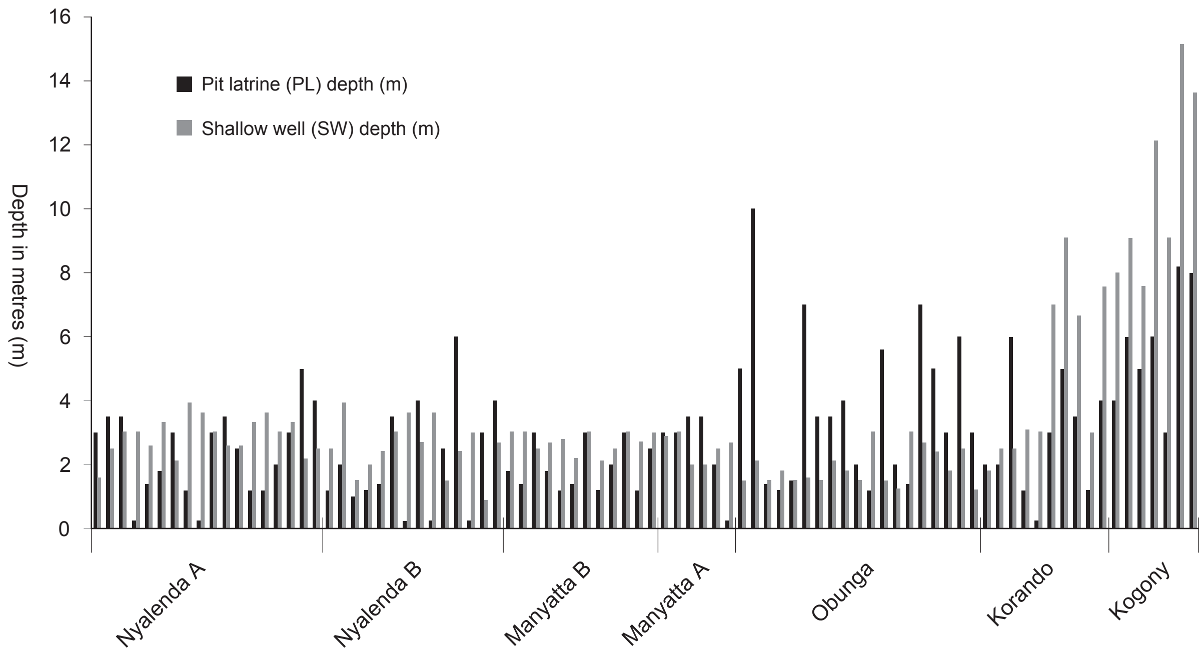

Figure 7. Trends and patterns of pit latrine depth and shallow well depth.

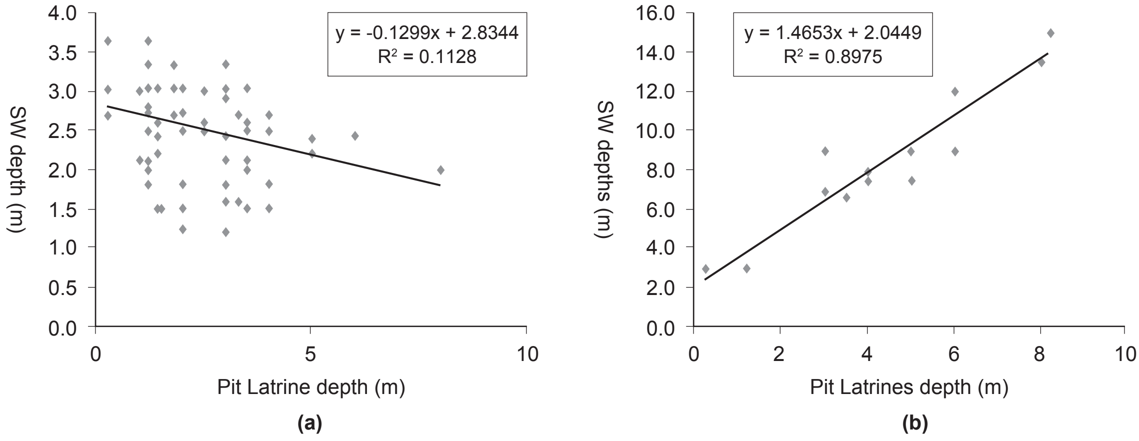

Figure 8. (a) Assessment of correlation and associations in urban informal settlements. (b) Peri-urban informal settlement.

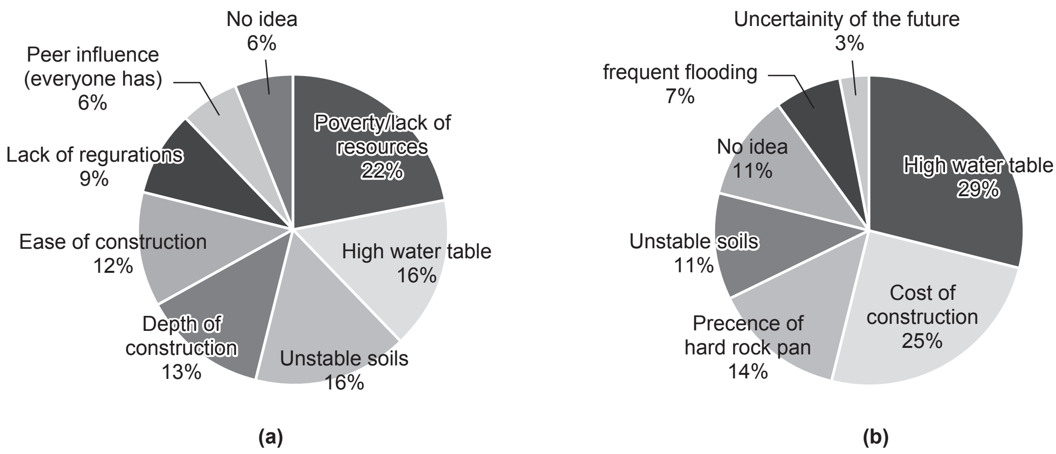

Figure 9. (a) Reasons for the prevalence of traditional pit latrines. (b) Shallow depth facilities.

4. Discussion: Sanitation characteristics and link to drainage conditions and public health

There is evidence from this study to suggest that water table and drainage charactersitics have majorly influenced the types, quality, and depth of construction of sanitation facilities in the study area. The distribution pattern of VIPs and TPLs between urban and peri-urban reveal differences in superstructure quality, roofing materials and depth of construction with TPLs dominating the urban informal settlements. High water table was cited as the main reason behind shallow depth of SWs and pit latrines, while the combined effects of high water table and unstable soils was identified as leading reasons for the prevalence of TPLs. Ideally, in environments of high water table, the construction of pit latrines and SWs become limited. Pit latrines full-up with water when still under construction thus preventing further digging, consequently, most facilities done, have less durability and longevity. This is why areas of Nyalenda A, Nyalenda B, Manyatta B, Manyatta A and Obunga, areas of known flood risk, have higher records of TPLs as opposed to VIPs, relative to peri-urban areas. Interestingly, areas where pit latrine depth is limited, the incentive to invest heavily in quality, also, lessens. By nature of their design, VIP toilets are more improved compared to TPLs, and it takes more resources and time to construct a VIP toilet than TPL—a probably reason why VIP toilets dominate peri-urban settlements while TPLs, in the urban pro-poor areas.

The poor state of sanitation facilities, emphasised by the high precence of TPLs, support the earlier record by Reed (1994: 6) who expressed that pit latrines occur only under two circumstances: poor design, construction, operation or maintenance or poor environmental conditions, which conditions, generally agree to those in the informal settlements under study. This also, perhaps, serves to explan the reasons why urban informal settlements, where livelihood indicators are lower, recorded more TPLs than the peri-urban areas. It is, further, important to note that, poorly constructed sanitation facilities directly influence the state of community hygiene and health (Dodos et al. 2017); for instance TPLs are prone to smell, frequent overflows and emptying needs, thus, potentially, becoming key sources of contamination to adjuscent water sources. Areas with shallow water table may experience surface overflows, and in the precence of pit latrines with overflow problems, contaminat mixing with such waters may present public health on users of such water sources in the poor urban informal settlements.

The study, moreover, established that majority of pit latrines—more VIPs than TPLs comparatively—were raised above the ground (mean height = 0.25 m–0.5 m). This practice was more pronounced in the urban informal settlements than peri-urban. To many residents, the practice of raising toilets were flood control measures and a means of overcoming limitations in depth of construction. Understandably, residents in the urban informal informal settlements may not afford deeper latrines due to the effects of the high water table prevalent in the settlements, thus, the only option left is to have raised toilets. As previously outlined, raised pit latrines have been widely recommended for flood prone environments (WHO 2006; Morshed and Sobhan 2010: 237; Mamani et al. 2014: 31; Bertule et al. 2018: 24). Several studies have recommended the use of raised facilities in developing countries (Dzwairo et al. 2006: 780; Nyakundi et al. 2010: 347; Sakijege et al. 2012: 2; Graham and Polizzotto 2013: 522; Nakagiri et al. 2015: 530). Sanitation studies in the informal settlements of Kenya (Kimani-Murage and Ngindu 2007: 830; Bard and Lennmalm 2015: 25; Okurut et al 2015: 92) reported existence of raised pit latrines in different urban and rural areas. Furthermore, raising pit latrines may also directly contribute to stability and quality of pit latrines in the area, most raised pit latrines were observed to be VIP toilets with concrete walls.

Besides the limitations on construction depth of pit latrines, shallow water table may also present increased exposure to groundwater contamination in the urban areas, the vertical distance to the water table is critical in defining the degree of contaminant degradation as they transmit through the soil column sink (Abila et al. 2012; Bhallamudi et al. 2019). This is the reason safety-distance guidelines by WHO (WHO 2015) specify, not only, horizontal distance between pit latrines and SWs, but also vertical distances of separation between pit latrines and water table, which should be atleast 2 m (Ahaneku and Adeoye, 2014; Islam et al. 2016: 26; UNEP-DHI Partnership et al. 2018).

In addition to characterization of facilities, correlation analysis were also undertaken by the study. The analysis, however, observed no clear association between pit latrine depth and SW (Figure 8(a)) in the urban informal settlements, this was probably because SWs and pit latrines in urban informal settlements were ranged only in shallow depth. Nevertheless, the analysis observed a positive association in depth of SWs and pit latrines (Figure 8(b)) in the peri-urban areas ($p < 0.05$), the findings may probably demonstrate the fact that these area have less proximity distance/facility-density challenges or depth limitation as opposed to urban informal settlements, thus the construction of deeper facilities was more probable. The positive association provides a likelihood that areas with deeper wells also reported deeper pit latrines respectively.

In conclusion, the study observes that areas with high water table and flood-risks presented challenges to the construction of quality pit latrines and limited the depth of construction, and, to a grater degree, these factors have pushed residents into compromised sanitation practices characterised by widespread use of TPLs in the urban slums. This study observes, however, that despite their relative cost implications, raised VIP toilets may provide sustainable solution to the present challenges in the urban informal settlements not only for Kisumu but across many urban slums across the developing world existing within similar environmental conditions like Kisumu. In the end however, targeted interventions may include expanding sewerage networks into the informal settlements and increasing household water connections as envisioned in Kenya's environmental sanitation and hygiene policy (Kenya Ministry of Health 2016). There is also an opportunity in promoting deeper wells as they could be less susceptible to contamination than shallower wells; solutes transport is faster and more likely in the near sub-surface than in the deeper horizons (Jakeman et al. 2016).

Conclusions and recommendations

The study characterised sanitation facilities and analysed relationship between pit latrine and shallow well depth in the informal settlements of Kisumu city, our findings observed that shallow water table and flooding conditions have influenced the types of pit latrines and shallow wells in the area. The limitation in depth affected the construction quality of the facilities and this is manifested in the standards of materials used for roofing, body stracture as well as in the depth of construction and durability of the pit latrines. The shallower the water table, the higher the probability of poor state of sanitation, which also raises health risk concerns as most of these poorly constructed facilities are prone to frequent filling and overflows. Additionally, the study observed no clear association between depth of pit latrine and SWs in the urban informal settlements, while at the same time establishing a positive association in the peri-urban areas. The study recommends sensitization on the benefits of raised improved pit latrines which in consequence will result into more quality durable facilities in the urban informal settlements, while in the long term recommending development of sustainable toilet construction guidelines for specific environmental challenges and expansion of sewerage and water connection networks into the informal settlements as a way of transforming the urban informal settlements.

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