Supplementary Information

Dataset A: Data sources

Table A1: Overview of different data sources used and their purposes

Data Sources	Purpose
Primary	
Author observations during household questionnaires	• Verification of population distribution • Verification of possible locations of TSs, Community Treatment Facility and SDSs
Google Earth Imagery	• Verification of road/pathway networks • Construction of extra pathways and linking roads between community and centralised network • Verification of population distribution • Verification of possible locations of TSs, Community Treatment Facility and SDSs
Manually constructed ESRI ArcGIS-compatible maps	Network constructed consisted of: • Internal community pathways road • Collection points • Connecting pathways/roads (between primary and secondary) • Fixed infrastructure locations (TSs, SDSs)
Secondary	
ESRI ArcGIS-compatible maps 1. Water distribution network in informal settlements 2. Centralised road network 3. Centralised sewerage network	• Pipeline networks used as indicator of primary road and pathways network • Water kiosk and individual tap location used as indicator of distribution of population • Centralised networks used as secondary road network
Sanitation Master Plan	Identification of technically feasible locations for SDSs

Dataset B: Input parameters

Conversion rate of 5335 ZMK to US $ 1 used throughout.[1] 'Author directly' means the input parameters used are from the analysis conducted or selected based on primary observations made by Author from the field.

Network data	Symbol	Unit	Kanyama Value	Chazanga Value	References
Number of collection points	N_c	-	65	42	Author directly
Number of TS (single)	T_s		1	1	Author directly
Number of TS (multiple)	T_m		5	4	Author directly
Collection points to end point Scenario 1A	d_{ce}	km	333.68	88.67	Author directly
Collection points to end point Scenario 1B		km	192.89	79.23	Author directly
Collection points to end point Scenario 3		km	116.74	116.30	Author directly
Collection points to transfer station Scenario 2	d_{ct}	km (single TS)	111.15	70.77	Author directly
		km (multi TS)	77.34	60.90	Author directly
Collection points to transfer station Scenario 3		km (single TS)	111.15	70.77	Author directly
		km (multi TS)	77.29	60.90	Author directly
Transfer station to end point Scenario 2	d_{te}	km (single TS)	8.01	9.57	Author directly
		km (multi TS)	24.64	25.67	Author directly
Transfer station to end point Scenario 3		km (single TS)	4.02	10.79	Author directly
		km (multi TS)	14.52	28.21	Author directly
Socioeconomic data	**Symbol**	**Unit**	**Kanyama Value**	**Chazanga Value**	**References**
Baseline population	N_p	cap	137,000	86,000	Author directly
Number of people per household	$N_{p,h}$	cap	6	6	2
Annual population rate	r_g	%/ year	4.2		2
Average number of households per facility	$N_{h,f}$	-	3	2	Author directly
Minimum Wage	C_w	US$/ day	0.68		3
Working Hours	W_h	hours/ day	8		Author directly
Working Days	W_d	days/ week	5.5		Author directly
Working Weeks	W_w	weeks/ year	45		4
Fuel price (petrol)	C_f	US$/ litre	1.48		5
Discount Rate	r_d	%/year	12		6
Inflation Rate	r_i	%/year	9.5 (average of historic inflation rate)		7
Filling rate parameters	**Symbol**	**Unit**	**Kanyama Value**	**Chazanga Value**	**References**
Sludge generation rate	r_s	m^3/cap/year	0.06		8
Current pit size	V_p	m^3	2.6		9
Transportation equipment data	**Symbol**	**Unit**	**Vacutug (U_v)**	**Vacuum Tanker (U_{vt})**	**Manual Cart (U_{mc})**
Cost per unit of equipment	C_{tr}	US $/ unit	15,000 [4,10,11]	50,000 [12]	800[13]
Shipping costs	C_{str}	US $/ unit	8,000 [4]	-	-
Maintenance	C_{mtr}	%/ year	10 (Author directly)	10 (Author directly)	10 (Author directly)
Wear and Tear	C_{wttr}	%/ year	7 (Author directly)	7 (Author directly)	20 (Author directly)

Economic life	L_{tr}	years	4 [14]	10 (Author directly)	3 (Author directly)
Fuel usage	F_1	litres/ km	0.2[15]	0.5 [15]	-
Vacuum Pump Fuel Usage	F_2	litres/hr	6 [16]	10 [17]	-
Oil usage	F_3	US$/ year	-	-	-
Volume	V_{tr}	m^3	2[10]	10[12]	0.33[13]
Speed	S	km/ hour	2.5 [18]	35[19]	2.5[18]
Number of operators	N_{otr}	-	3[10]	3[12]	4[13]
Time to fill tank	T_f	minutes	10 [20]	15 (Author directly)	40 (Author directly)
Preparation and setting up	T_p	minutes	30 [20]	15 (Author directly)	30 (Author directly)
Transfer station (I_{ts}) parameters	**Symbol**	**Unit**	**Kanyama Value**	**Chazanga Value**	**References**
Cost per unit	C_{ts}	US $/ unit	100,000		[21]
Operation and Maintenance	C_{omts}	%/ year	10		Author directly
Economic life	L_{ts}	years	25		Author directly
Volume	V_{ts}	m^3	135		Author directly
Number of operators	N_{ots}	-	2		Author directly
Sewer discharge station (I_{sds}) parameters	**Symbol**	**Unit**	**Kanyama Value**	**Chazanga Value**	**References**
Cost per unit	C_{sds}	US $/ unit	40, 000		[21]
Operation and Maintenance	C_{omsds}	%/year	10		Author directly
Economic life	L_{sds}	years	25		Author directly
Volume	V_{sds}	m^3	50		Author directly
Number of operators	N_{osds}	-	2		Author directly
Sewer discharge station pump (U_p) parameters	**Symbol**	**Unit**	**Kanyama Value**	**Chazanga Value**	**References**
Cost per unit (pump)	C_{sdsp}	US $/ unit	40, 000		[21]
Operation and Maintenance	C_{omsdsp}	%/year	10		Author directly
Economic life	L_{sdsp}	years	5		Author directly
Community level treatment facility (I_{clt}) parameters		**Unit**	**Kanyama Value**	**Chazanga Value**	**References**
Cost per unit	C_{tf}	US $/ unit	600,000	400,000	[21, 22]
Operation and Maintenance	C_{omtf}	%/year	10		Author directly
Economic life	L_{tf}	years	25		Author directly
Volume	V_{tf}	m^3	100	60	Author directly
Number of operators	N_{otf}	-	2	2	Author directly
Disposal costs		**Unit**	**Value**		**References**
Charge	C_d	per m^3 dumped	5.6		[12]

Dataset C: Financial calculations

Equation 1: Net Present Value

$$NPV\ (\$)\ (r_d, n) = \sum_{t=0}^{n} \frac{C_t}{(1 + r_d)^t}$$

where, n = design life, t = year, C_t = net cash flow per year (total yearly expenditure minus total yearly income) and r_d= discount rate[23]

Equation 2: Present Value

$$PV\ (\$) = \frac{X_t}{(1 + r_d)^t}$$

where X_t = projected future cost in year t and r_d= discount rate [24]

Equation 3: Average Incremental Cost

$$AIC = \frac{\sum PV(costs)}{\sum PV(benefits)}$$

where PV (costs) = the total present value cost for project in each year and PV (benefits) is the total volume of FS emptied per year. [24]

Dataset D: Equations used in costing methodology

Table D1: Calculations to determine baseline cost per unit of transportation equipment

Calculation	Unit	Equation
Total capital cost, C_{CAPtr}	**US \$/unit**	$\mathbf{C_{CAP} = C_{tr} + C_{str}}$
Maintenance cost, C_{maintr}	**US \$/year.unit**	$C_{main} = \frac{C_{mtr}}{100} \times C_{tr}$
Wear and tear cost, C_{weartr}	**US \$/year.unit**	$C_{wear} = \frac{C_{wttr}}{100} \times C_{tr}$
Labour cost, $C_{labourtr}$	**US \$/year.unit**	$C_{labour} = C_w \times N_{otr} \times W_h \times W_d \times W_w$
Fuel and oil cost, C_{fueltr}	**US \$/year.unit**	$C_{fuel} = (C_f \times F_1 \times (d_{ce}/d_{ct}/d_{te}) + (F_2 \times T_f \times N_{trips} \times W_d \times$
Total O&M cost, C_{OMtr}	**US \$/year.unit**	$\mathbf{C_{OM} = C_{main} + C_{wear} + C_{labour} + C_{fuel}}$

Table D2: Calculations to determine operational capacity per unit of transportation equipment

Calculation	Unit	Equation
Total time per trip, T_{trip}*	hours	$T_{trip} = \frac{(d_{ce}/d_{ct}/d_{te})}{N_c \times S} + \frac{T_f + T_p}{60}$
Number of trips per day, N_{trips}	-	$N_{trips} = \frac{W_h}{T_{trip}}$
Operational capacity, V_{year}	**m^3/year.unit**	$\mathbf{V_{year} = N_{trips} \times W_d \times W_w \times}$

Table D3: Calculations to determine population growth and equipment quantities required per settlement

Calculation	Unit	Equation
Population in year t, $N_{p,t}$		$N_{p,t} = N_p \text{ x } (1+(r_g/100))^t$
Total FS generated, V_{FS}	m^3	$\mathbf{V_{FS} = N_{p,t} \text{ x } r_s}$
Total number of transportation equipment units required per year, U_{tr} (U_V, U_{vt},, U_{mc})		$\mathbf{U_{tr} = V_{FS} / V_{year}}$
Total number of transfer stations required per year, U_{ts}		$\mathbf{U_{ts} = T_{s \text{ or }} T_m}$
New equipment units to be purchased taking into consideration population growth and economic life, U_{new}		$\mathbf{U_{new} = (U_{tr/} U_{ts}/U_p) +}$ **OFFSET** $\mathbf{(L_{tr}/L_{ts}/L_p)}$

Table D4: Calculations to determine baseline cost per unit of infrastructure

Calculation	Unit	Equation
Total capital cost, C_{CAPi}	**US \$/unit**	$\mathbf{C_{CAPi} = C_{ts} / C_{sds} + C_{sdsp}/C_{tf}}$
Maintenance cost, C_{maini}	**US \$/year.unit**	$C_{maini} = \frac{C_{omts}/C_{omsds} + C_{omsdsp}/ C_{omtf}}{100} \times C_{tr}$
Labour cost, $C_{labouri}$	**US \$/year.unit**	$C_{labouri} = C_w \times (N_{ots}/N_{osds}/N_{otf}) \times W_h \times W_d \times$
Total O&M cost, C_{OMi}	**US \$/year.unit**	$\mathbf{C_{OMi} = C_{maini} + C_{labouri}}$

Table D5: Calculations for projected costs for transportation

Year, t	Total number of units required, U_{tr}	Number of new units, U_{new}	Factor for inflation, I	Total CAPEX (US $) for U_V, $U_{vt,}$, U_{mc}	Maintenance cost, M (US $) for U_V, $U_{vt,}$, U_{mc}	Wear and tear cost, W (US $) for U_V, $U_{vt,}$, U_{mc}	Labour cost, Lab (US $) for U_V, $U_{vt,}$, U_{mc}	Fuel and oil cost, FO (US $) for U_V, $U_{vt,}$, U_{mc}	Total OPEX (US $) for U_V, $U_{vt,}$, U_{mc}	Total Expenditure (US $) for U_V, $U_{vt,}$, U_{mc}
(0-24)	U_V, $U_{vt,}$, U_{mc}	U_{tr}	$I = 1+(r_i/100))^t$	$CAPEX_{tr} = C_{CAPtr} \times U_{new\ tr} \times I$	$M_{tr} = C_{maintr} \times U \times I$	$W_{tr} = C_{weartr} \times U \times I$	$Lab_{tr} = C_{labourtr} \times U \times I$	$FO_{tr} = C_{fueltr} \times U \times I$	$OPEX_{tr} = C_{OMtr} \times U \times I$	$= CAPEX_{tr} + OPEX_{tr}$

Table D6: Calculations for projected costs for fixed infrastructure

Year, t	Total number of units required, U_i	Number of new units, U_{new}	Factor for inflation, I	Total CAPEX (US $) for I_{ts}, $I_{sds,}$, I_{clt}	Maintenance cost, M (US $) I_{ts}, $I_{sds,}$, I_{clt}	Labour cost, Lab (US $) for I_{ts}, $I_{sds,}$, I_{clt}	Total OPEX (US $) for I_{ts}, $I_{sds,}$, I_{clt}	Total Expenditure (US $) for U_V, I_{ts}, $I_{sds,}$, I_{clt}
(0-24)	I_{ts}, $I_{sds,}$, I_{clt}	U_{ts}/U_p	$I = +(r_i/100))^t$	$CAPEX_i = C_{CAPi} \times U_{new} \times I$	$M_i = C_{maini} \times U \times I$	$Lab_i = C_{labouri} \times U \times I$	$OPEX_i = C_{OMi} \times U \times I$	$= CAPEX_i + OPEX_i$

Table D7: Calculations for Net Present Value

Year, t	Total number of units required, U_{tr}	Volume of FS emptied (m^3)	Factor for PV, PVF	PV CAPEX (US $)	PV Maintenance costs (US $)	PV Wear and tear cost (US $)	PV Labour cost (US $)	PV Fuel and oil cost (US $)	PV Total Expenditure (US $)
(0-24)	$\mathbf{U_{tr}}$	= U x V_{year}	PVF = $1/(1+(r_d/100))^t$	= CAPEX(tr+i) x PVF	= M(tr+i) x PVF	= W(tr+i) x PVF	= Lab(tr+i) x PVF	= FO(tr+i) x PVF	= (CAPEX(tr+i) + OPEX(tr+i)) x PVF

Table D8: Calculations for Average Incremental Costs

Year, t	Number of people per latrine*, $N_{p,l}$	FS generated per latrine, $V_{FS,l}$ (m^3)	Time between emptying events, T_e (years)	Emptying Frequency (events per year)
(0-24)	$N_{p,l} = N_{p,h}$ x $N_{h,l}$ x $(1+(r_g/100))^t$	$V_{FS,l} = N_{p,l}$ x r_s	$T_e = V_p / V_{FS,l}$	= $1/ T_e$

Table D9: Calculations for pit latrine emptying frequency

Year, t	Total Expenditure (US $)	Factor for inflation, I	Total User Charge (US $)	Net Cash Flow, C_t (US $)	Present Value (US $)[1]
(0-24)	= CAPEX(tr+i) + OPEX(tr+i)	I = $(1+(r_i/100))^t$	= variable charge x $(N_p/N_{p,h})$ x I	C_t = Total Expenditure - Total user charge	= $C_t/(1 + r_d)^t$

[1] Net Present Value equation shown by Equation 7-2

Supplementary Information References

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