

Development of cost functions for water supply and sanitation technologies: case study of Bahir Dar and Arba Minch, Ethiopia

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ABSTRACT

Sustainable and improved water supply and sanitation service provision for communities who are lacking it is the forefront issue of the Millennium Development Goals (MDGs). To assist the achievement of the MDGs, it is essential to overcome the traditional approach to planning water supply and sanitation (WS&S) systems. This study developed user and/or service provider cost functions for available WS&S technologies in the vicinity of Bahir Dar and Arba Minch townships. The cost functions help to estimate the life cycle cost of WS&S systems. Eight water supply and eleven sanitation technologies' design documents and cost data were collected and analysed. Results revealed that the *maximum daily water demand* and *person equivalent* were the responsive variables for the initial investment and/or recurrent costs of almost all WS&S technologies, respectively. In addition, disinfectant types, pump head, pipe length and diameter, tower height, well depth, conveyance distance and composting volume were identified as important parameters for the corresponding WS&S technologies. However, the cost of *shallow well equipped with hand pump* was influenced merely by the well depth. The obtained cost functions contribute to overcoming the common practice of WS&S systems comparison in the study area, which largely focus on their initial investment costs.

Key words | daily water demand, initial investment cost, person equivalent, recurrent cost, water supply and sanitation

INTRODUCTION

Access to safe and adequate amounts of drinking water and improved sanitation service is one of the basic demands for community health and well-being. Sustainable and improved water supply and sanitation (WS&S) service provision for communities who are lacking it is the forefront issue of the Millennium Development Goals (MDGs). The Government of Ethiopia has been attempting to improve the national WS&S coverage in an equitable and sustainable manner by harmonizing the contribution of all actors involved in the sector (OWNP 2013). Clearly, sustainability of WS&S projects is directly associated with the social merit and economic feasibility of the systems. In most

developing countries, economic feasibility of WS&S systems has often focussed on initial investment cost (IIC) despite the considerable influence of recurrent costs on the system's sustainability and on the total life cycle cost (LCC) (Brikké & Bredero 2003).

The LCC of WS&S systems comprises user and/or service provider costs and environmental/social costs. Service provision costs encompass IIC, operation and maintenance (O&M) cost and rehabilitation cost. The IIC includes the cost of design and construction of the WS&S system in general and technologies in particular (Plappally & Lienhard 2013). The O&M costs are the expenses needed to sustain

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the serviceability of the system within acceptable performance levels, which includes all preservation works, pre-scheduled and damage-based maintenance, and energy, chemical and labour costs. The rehabilitation cost relates to restoration and reconstruction of the entire system or part of the system. All costs caused by construction, O&M and rehabilitation of the WS&S systems on the surrounding environment or society are considered as environmental/social costs, which are not included in this study. The LCC refers to the sum of initial investment and recurrent costs over the whole life span of the system by considering the time value of money (Amini *et al.* 2011). All the recurrent costs need to be normalized or discounted into present values before summing them with IIC (Bull 2003; Dhillon 2011).

The authors' review found very little published literature which documents the applicability of LCC as part of the decision support tool for WS&S systems for developing countries like Ethiopia. Even the available cost-based WS&S decision support tools contain either outdated cost data or country/site-specific data (Palaniappan *et al.* 2008). The WASHCOST tool was developed to estimate LCC of water, sanitation and hygiene services specifically for Burkina Faso, Ghana, Mozambique and India (Burr & Foneseca 2011; Moriarty *et al.* 2011). Because of the gap related to a LCC-based planning approach, system users are not well-informed of the lifetime expenses of the implemented systems, which are mostly covered by the users. As a result, many implemented WS&S systems are prematurely abandoned and fail to provide the intended service for the planned design period (Carter *et al.* 1999). This is also quite common in the rural and peri-urban areas of Ethiopia. If LCCs of a system are considered from the beginning of the planning phase, it is possible to set optimal and cost recovery user tariffs that allow sustainable operation and service provision.

This paper aims to develop cost functions for IIC, annual O&M cost, reinvestment cost and revenue value of commonly implemented WS&S technologies in Bahir Dar and Arba Minch vicinities. Prior to the cost function development, responsive input parameters need to be identified for each technology's cost values. These will assist service providers, planners and decision-makers to estimate LCC of WS&S systems.

METHODS

Study area description

The study was conducted in the vicinity of Bahir Dar and Arba Minch townships, which are located in the north-western (11°37'N and 37°10'E) and south-western (06°00'N and 37°30'E) regions of Ethiopia, respectively. The mean annual rainfall and temperature in the Bahir Dar vicinity range from 903 to 1,962 mm and 14 °C to 29 °C, respectively (Wondmagegne *et al.* 2012) and in Arba Minch vicinity the values range from 782 mm to 1,392 mm and 14 °C to 23 °C, respectively (Assefa & Bork 2014). The study areas encompass urban, peri-urban and rural towns sited within a radius of 200 km from Bahir Dar and Arba Minch townships.

Bahir Dar serves as the economic and political centre of the Amhara region and is categorized under towns enjoying a high living standard with very high development potential. Arba Minch is the administrative town of the Gamo Gofa zone of the Southern Nations-Nationalities and Peoples Region (SNNPR) and is categorized under towns having high development potential but lower living standards at present. In recent years, publicly and privately funded construction has been booming around Bahir Dar, which has resulted in considerable material and labour cost escalation of the surrounding market. Electric power interruption is a common phenomenon for most places in Ethiopia including Arba Minch and Bahir Dar vicinities, where a daily average of 4 and 1.5 hours of electric power cut occur, respectively. Hence, the presence of a standby diesel generator has been compulsory as a supplementary power source for energy-intensive WS&S technologies to assure the service reliability.

In Bahir Dar neighbourhoods, most of the government-funded water supply projects are directly awarded to Amhara Water Works Construction Enterprise irrespective of their costs. In contrast, competitive contract award has been practised in Arba Minch vicinity.

Urban and rural water supply coverage of the Bahir Dar vicinity was estimated at about 78% and 33% in 2013, respectively (BDWSSE 2013), while it is about 56% for the Arba Minch vicinity (AWSSE 2013). According to Ethiopian

standards, the daily domestic per capita water consumption for a house connection is 60–100 litres, for a yard connection it is 30–35 litres and for public water points it is 15–20 litres (EMWUD 1995). It is difficult to find study area-specific sanitation coverage information, although WHO and UNICEF estimate sanitation facilities coverage of 46% and 56% for the entire Amhara region and SNNPR in 2012, respectively (WHO/UNICEF 2014). Generally to improve the existing water supply, sanitation and hygiene (WASH) services level of the country, the Government of Ethiopia has set WASH strategic targets aligned with the country growth transformation plan of 2020 (GTP). These targets are: (1) 98.5% access to water supply, and reducing the proportion of non-functioning facilities to 10%; (2) 100% sanitation access, and 77% of the population to practise hand washing at critical times; and (3) 80% of communities to achieve open defecation-free status (OWNP 2013). The implementation of these policy directives has started in 2013 in all regions of the country including the study areas.

Data collection and analysis

Eight water supply and eleven sanitation technologies' design documents, bill of quantities (BoQs) and payment certificates were collected from different stakeholders. All sampled projects were financed by the Ethiopian Government from its own capital and support from the African Development Bank and World Bank, in which very limited financial provision was allocated for capacity building programmes (OWNP 2013). Discussions with service providers and users were held to understand annual O&M practices and corresponding expenses of various technologies, since it was difficult to find recorded O&M tasks and costs. Viability of collected information was evaluated using country-specific and international design standards. Consequently, an organized database of recorded design parameters, initial and recurrent cost values and service lifetime for each technology was established. For example, a database for distribution network included design parameters such as pipe length, pipe diameter, pipe material, lifetime and corresponding initial and recurrent cost values. All cost values of implemented WS&S projects were collected in Ethiopian currency (birr; €1 = 25.87 birr as of November 2013) and

these costs were converted into euros (€) for analysis and international representation.

Statistical analyses at 95% confidence level were applied to assess the significance level of design parameters for respective technologies' initial and recurrent costs, and then responsive independent parameters were identified. For cost function development, linear-multiple regression and best-fit regression models were employed for technologies with multiple and single responsive independent parameters, respectively.

Technology assessment

Ground water sources, such as spring development, boreholes and shallow wells were found to be the predominant water supply sources in both study areas. This is because of abundant ground water potential and quite turbid surface water quality (Tiruneh 2005; Tilahun *et al.* 2013). At both sites, disinfection by chlorination was identified as the principal purification method. Moreover, surface and/or elevated reservoirs, pumping stations, and pipe networks (ductile cast iron [DCI], high-density polyethylene [HDPE], galvanized iron [GI] and polyvinyl chloride [PVC] materials) were commonly implemented in the areas.

Residents in the vicinities practice simple, low-cost sanitation solutions, since the average monthly household income was only about 1,395 birr (€55) in 2012 and 727 birr (€30) in 2009 at Bahir Dar and Arba Minch, respectively (Adedimeji *et al.* 2012; Awoke & Seleshi 2013). Ventilated pit latrines (VIPs), urine-diversion-dehydration toilets (UDDTs), fossa alterna type composting toilets, septic tanks, gravity sewers, composting and sludge drying beds were identified as feasible waste collection and treatment technologies.

RESULTS AND DISCUSSION

The IIC, O&M cost functions and the lifetime of the main parts of WS&S technologies are presented in Tables 1 and 2. All cost functions cover material, labour and machinery expenses needed to implement and operate the technology for the intended purpose. The reinvestment cost of a technology depends on the lifetime of the

Table 1 | Developed cost functions for total IIC, annual O&M cost and lifetime of the major components of water supply technologies for Bahir Dar and Arba Minch

Technology	Township ^a	Sample number (n)	Total initial investment cost ^b (IIC) in €	Annual O&M cost ^{b,d} in €	Validity range ^e	Major part (lifetime in years) and present value of reinvestment cost ^f
Spring development	BD	15	$1,392.5 (Q_{Md})^{1.05}$	2% of IIC , if $Q_{Md} \leq 81.5\%$ of IIC , if $Q_{Md} < 8$	Q_{Md} [4, 216]	Pipes & fittings (20) = 5% of IIC Civil work (40) = 95% of IIC
	AM	10	$706 (Q_{Md})^{0.91}$			
Borehole (203 mm) with submersible pump	BD	23	$IIC_{WD} + IIC_{EMC} (6.804 + 246d_w) + (580Q_{Md} + 255H_t)$	$185Q_{Md} + 44H_t$	Q_{Md} [8, 145] & H_t [60, 293] & d_w [60, 200]	Civil work (40) = IIC_{WD} Electro-mechanical (20) = IIC_{EM}
	AM	6	$IIC_{WD} + IIC_{EM} (39,654 + 162d_w) + (334Q_{Md} + 490H_t)$	$4Q_{Md}H_t$		
Shallow well with hand pump	BD	10	$2,528 + 69d_w$	2% of IIC	d_w [50, 70]	Hand pump (10) = 8.5% of IIC Civil work (40) = 91.5% of IIC
	AM	8	$2,598 + 65d_w$			
Disinfection by chlorination	BD & AM	10	If $Q_{Md} \leq 180 = 31,092$ If $180 < Q_{Md} \leq 270 = 41,151$ If $270 < Q_{Md} \leq 360 = 50,067$ If $360 < Q_{Md} \leq 450 = 58,983$ If $450 < Q_{Md} \leq 540 = 67,899$	$76Q_{Md}$, if the disinfectant agent is Ca(OCl) ₂ & $115Q_{Md}$, if the disinfectant agent is Na(OCl)	Q_{Md} [4, 540]	Whole parts (20) = IIC
Concrete surface reservoir	BD	24	$4,464(Q_{Md})^{0.65}$	1% of IIC	Q_{Md} [6,125]	Whole parts (40) = IIC
	AM	16	$1,646(Q_{Md})^{0.93}$			
Concrete elevated reservoir	BD	10	$652H(Q_{Md})^{0.83}$	1% of IIC	Q_{Md} [2.5,12.5] & H [8, 31]	Whole parts (40) = IIC
	AM	6	$6,581(Q_{Md}) + 717H - 12,906$			
Pumping station	BD	12	$957Q_{Md} + 438H_t$	$3Q_{Md}H_t$	Q_{Md} [5,580] & H_t [45,250]	Pump house (40) = 7% of IIC Electro-mechanical (20) = 93% of IIC
	AM	8	$846Q_{Md} + 109H_t$	$4Q_{Md}H_t$		
Pipe network	BD	54	$L(0.0005 D^2 + 0.2D)$	1.5% of IIC	D [25, 500]	Fitting & valves (20) = 5% of IIC Pipes (40) = 95% of IIC
	AM	52	$L(0.0008 D^2 - 0.03D + 8.4)$			

^aThe cost functions are valid for: BD: Bahir Dar vicinity; AM: Arba Minch vicinity; BD & AM: both Bahir Dar and Arba Minch.

^bTotal IIC and annual O&M cost were formulated as the function of identified responsive input parameters, which are: Q_{Md} : designed maximum daily demand in m³/h; H_t : total pumping head in m; d_w : well depth in m; H : tower height in m; D : pipe diameter in mm; L : pipe length in m.

^c IIC_{WD} : portion of total IIC of borehole for well development (civil work); IIC_{EM} : portion of total IIC of borehole for electro-mechanical work.

^dAnnual O&M cost function of energy and/or chemical intensive technologies (i.e. 'Borehole with submersible pump', 'Pumping station' and 'Disinfection by chlorination') was formulated based on implemented projects data in the study areas; while for other technologies lacking enough O&M data the costs were estimated as a certain percentage of their total IIC that is based on field observation, workers' and experts' opinions.

^eValidity range: refers to the upper and lower boundary of input parameters in which the respective cost functions are valid.

^fMajor part (lifetime in years) and present value of reinvestment cost: refers to the timing of reinvestment of the major parts of the technology: for example for 'shallow well with hand pump' the civil work (the well itself) can last for 40 years and its reinvestment cost present value is about 91.5% of the total IIC, while the hand pump lasts for 10 years and its reinvestment cost present value is about 8.5%.

Table 2 | Developed cost functions for total initial investment cost, annual O&M cost, annual revenue and lifetime of the major components of sanitation technologies for Bahir Dar and Arba Minch

Technology	Township ^a	Sample number (n)	Total initial investment cost ^b (IIC) in €	Annual O&M cost ^{b,c} in €	Annual revenue ^b in €	Validity range ^d	Major part (lifetime in years) and present value of reinvestment cost ^e
VIP	BD	20	$N(1,353)$	1.5% of IIC	–	N [1, ∞]	Whole part (20) = 100% of IIC
	AM	20	$N(1,216)$				
UDDT	BD	10	$N(146 PE_i^{0.55})$	1% of IIC	–	N [1, ∞] & PE _i [5, 25]	Whole part (20) = 100% of IIC
	AM	40	$N(93 PE_i^{0.67})$				
Fossa alterna		15	$N(58 PE_i)$	1.5% of IIC	$N(2.3PE_i)$	N [1, ∞] & PE _i [5, 25]	Movable super structure (10) = 30% of IIC Chambers (20) = 70% of IIC
		250	$N(34 PE_i)$		$N(1.5PE_i)$		
Faeces collection (ST) ^f	BD & AM	75	$0.57PE + 19,160$	$0.03PE + D_{ct} + 0.013 D_{ct} + 3,834$	0.83PE	PE [15, 8,600] & D_{ct} [0.5, 10]	Machinery (15) = 100% of IIC
Faeces collection (BT) ^g	BD & AM	50	$2.75PE + 18.901$	$0.01PE D_{ct} + 0.3PE + 0.16D_{ct} + 2,328$	0.83PE	PE [8,600, 50,000] & D_{ct} [10, 20]	Machinery (15) = 100% of IIC
Urine collection (VT) ^h	BD & AM	50	$0.62PE D_{ct} + 36PE + 72,340$	$0.12PE D_{ct} + 5.4PE$	5PE	PE [15, 50,000] & D_{ct} [0.5, 20]	Machinery (15) = 100% of IIC
Septic tank	BD	12	$N(43PE_i - 0.006PE_i^2 + 1,634)$	$N(0.4PE_i)$	–	N [1, ∞] & PE _i [5, 360]	Whole part (40) = 100% of IIC
	AM	10	$N(0.026PE_i^2 + 18.2PE_i + 1,308)$	$N(0.35PE_i)$			
Faecal sludge collection ^h	BD & AM	80	$72,340$; if $PE \leq 15,000$ & $(0.15 PE D_{ct} + 2.3PE - 132D_{ct} + 25,630)$; if $15,000 < PE \leq 200,000$	$0.05PE D_{ct} + 0.4PE$	0.4PE	PE [20, 200,000] & D_{ct} [0.5, 20]	Machinery (15) = 100% of IIC
Gravity sanitary sewer	BD	12	$L (0.004 D^2 + 0.1 D)$	1.2% of IIC	–	L [1, ∞] & D [150, 350]	Fitting & valves (20) = 5% of IIC Pipes (40) = 95% of IIC
	AM	10	$L (2D^2 - 0.0005 D^2 + 88)$	1% of IIC	–		
Sludge drying bed	BD	9	$90 PE^{0.96}$	$5.1PE^{0.65}$	–	PE [5,000, 16,000]	Whole part (20) = 100% of IIC
	AM	10	$83 PE^{0.96}$	$4.6PE^{0.65}$	–		
Composting	BD & AM	10	$10,441 (2V_f + V_o)^{0.8}$	$1,012 (2V_f + V_o)^{0.75} + 73V_f$	$11,140 (V_f + V_o)$	V_f [1, 100] & V_o [1, 100]	Machinery (15) = 28% of IIC Civil work (40) = 72% of IIC

^aThe cost functions are valid for: BD: Bahir Dar vicinity; AM: Arba Minch vicinity; BD & AM: both Bahir Dar and Arba Minch.

^bTotal IIC, annual O&M cost and annual revenue were formulated as a function of identified responsive input parameters, which are: PE: person equivalent; PE_i: person equivalent per one facility; N: number of facility (PE/PE_i); D_{ct} : transport distance in km; D : pipe diameter in mm; L : pipe length in m; V_f : collected faeces volume in m³/d; V_o : collected other municipal bio waste volume in m³/d.

^cAnnual O&M cost of technologies lacking enough O&M data were estimated as a percentage of their total IIC that is based on field observation, workers' and experts' opinion.

^dValidity range: refers to the upper and lower boundary of input parameters in which the respective cost functions are valid.

^eMajor part (lifetime in years) and present value of reinvestment cost: refers to the timing of reinvestment of the major parts of the technology: for example for 'gravity sanitary sewer' technology has two main costing parts, the first is the pipes that can last for 40 years and its reinvestment cost present value is about 95% of the total IIC of the technology and the second part is fitting & valves which need to be replaced after 20 years' service with the reinvestment cost present value of 5% of the total IIC.

^fFaeces collection with small truck (1,200 kg loading capacity).

^gFaeces collection with big truck (10,000 kg loading capacity).

^hUrine and faecal sludge collected with vacuum truck.

technology's main parts and planning horizon of the system. If the planning horizon is longer than the lifetime of specific parts of a technology, replacement of the part is compulsory at the end of its respective lifetime. Hence, during reinvestment the planner must consider the growing demand during the years from the lifetime to the end of the planning year.

From the analyses of collected data, the cost value of WS&S technologies in the Bahir Dar vicinity is comparatively higher than in the Arba Minch areas. This might be justified by higher living standards and non-competitive contract award practices in the vicinity of Bahr Dar.

Water supply technologies

In this section, the obtained results for water supply technologies are presented and the developed cost functions are summarized in [Table 1](#).

Spring protection/development

Spring development with collection chambers is the most common state-of-the-art practice in the study areas. From the multiple regression analysis, maximum daily demand (Q_{Md}) was found to be the statistically predominant parameter ($P < 0.05$, $n = 25$) for initial investment cost of spring development (IIC_{SP}) but chamber volume and hydraulic conductivity were not statistically significant parameters. Similar studies conducted by [OECD \(2007\)](#) for countries in Eastern Europe, Caucasus and Central Asia show the importance of daily water demand as the dominant parameter for IIC_{SP} . The annual O&M cost function was also developed as a fraction of IIC_{SP} as shown in [Table 1](#) and it includes all expenses for scheduled water quality testing, collection chamber cleaning and accessories maintenance.

Borehole with submersible pump

A 203 mm (8 inch) diameter borehole with PVC pipe casing was observed as the most common ground water extraction technology in the two regions. The technology is equipped with a submersible pump, standby diesel generator and generator house. The cost value of the borehole incorporated all expenditures incurred by these parts. The total IIC of a

borehole is therefore the summation of the cost for well development (IIC_{WD}) and electro-mechanical parts (IIC_{EM}).

Borehole drilling depth (d_w), maximum daily demand (Q_{Md}) and total pumping head (H_t) were found to be statistically influential variables ($P < 0.05$, $n = 29$) for the total IIC of the 203 mm diameter borehole. Results also revealed the importance of Q_{Md} and H_t for the O&M cost of a borehole. In line with the obtained results, previously conducted research findings in Palestine and five African countries (i.e. Ethiopia, Kenya, Burkina Faso, Morocco and South Africa) confirm the importance of well yield, aquifer depth and well diameter for IIC of a borehole ([Abu-Madi 2009](#); [Ketema & Langergraber 2015](#)). Unlike previous study findings, H_t was identified as an important parameter in this study.

Shallow well with hand pump

In the rural vicinity of the study areas, a machine drilled 127 mm (5 inch) diameter shallow well equipped with a hand pump (Afridev type) was found to be a typical ground water extraction technology. Unlike boreholes, neither the initial investment cost (IIC_{SW}) nor the O&M cost of shallow wells was influenced by the well yield ($P = 0.73$, $n = 15$), rather only influenced by the well depth (d_w) ($P < 0.05$, $n = 15$). This is because the hand pump technology is the same for all shallow wells irrespective of the yield from the well.

Disinfection by chlorination

Disinfection in the region has been mainly done by adding either calcium hypochlorite ($Ca(OCl)_2$) with 60% free chlorine or sodium hypochlorite ($NaOCl$) with 12% free chlorine at the inlet of service reservoirs. In most of the observed disinfection processes in the study areas, an average concentration of 1.5 mg/L of pure chlorine was added to maintain the minimum residual chlorine concentration of 0.1–0.3 mg/L at every end user point. For this average concentration, the IIC cost of a chlorination plant was significantly influenced only by maximum daily demand (Q_{Md}), while the O&M cost was influenced by Q_{Md} and type of disinfectant agent ($P < 0.05$, $n = 10$). Previously conducted research has confirmed the significant influence of

discharge, type and dose of disinfectant on the running cost of a disinfection process (Rogers 2008).

Reservoir

From the regression analysis result, the maximum daily demand (Q_{Md}) was found to be influential for IIC and O&M costs of both surface and elevated reservoirs besides the tower height (H) for an elevated reservoir ($P < 0.05$, $n = 56$). Previous research findings also revealed the importance of the reservoir volume, which is a function of Q_{Md} , for IIC and O&M cost of surface and elevated reservoirs for a predefined tower height (OECD 2007).

Pumping station

The formulated cost function of the pumping station comprises electrically driven active and standby centrifugal pumps, a diesel generator, pump and generator house, and other electro-mechanical accessories. Owing to the presence of a standby pump and diesel generator in the station, pumping was possible for 24 hours per day. Pumping discharge (Q_{Md}) and pumping total head (H_t) were found to be the most influential factors for both IIC and O&M cost ($P < 0.05$, $n = 20$). Previous research has also acknowledged the major influence of flow rate, total head and efficiency for the lifetime cost of pumps (Frenning 2001).

Pipe network

The formulated pipe network cost function comprises UPVC, HDPE, DCI and GI pipe materials. The regression analysis result of the distribution networks implemented in small and large towns revealed the importance of pipe length (L) and pipe diameter (D) for both IIC and O&M cost ($P < 0.05$, $n = 106$). Likewise, previous research results show the dependency of the pipe network's cost on pipe length and diameter (Zhou & Tol 2005), which are linearly correlated with the IIC of the pipe network (OECD 2007; Lamei *et al.* 2008). In contrast, a study conducted for a small water supply system stated that the capital cost of the pipe network is mostly independent of pipe diameter (Jagals & Rietveld 2011). This is because in a small system there is no significant variation of pipe diameter within the network.

Sanitation technologies

Cost function results for sanitation technologies are discussed in this section and summarized in Table 2.

Ventilated improved pit latrine (VIP)

The VIP is widely utilized as a sanitation facility, since the ground water table is deeper than 30 m and average infiltration rate of the soil is greater than $0.025 \text{ m}^3/\text{m}^2/\text{day}$ in both study areas (EMoH *et al.* 2010). The analyses of 40 household-owned VIPs, with 5–10 person equivalent (PE) per VIP, showed insignificant influence of PE on the investment cost of VIPs ($PE > 0.05$, $n = 40$). The major operation cost of VIP is associated with pit emptying frequency of about 5 years in the study areas.

UDDT

Single, double and triple vault types of UDDTs were analysed with average user numbers of 5–25 per toilet. The number of users per UDDT (PE_i) was found to be the responsive variable ($P < 0.05$, $n = 50$) for IIC and annual O&M cost. The produced faeces and urine were temporarily stored in a separated 100-litre tank and collected every 4–5 months and 14 days, respectively, which are the major components of annual O&M cost of UDDT. Average collection rates of €0.001/kg of faeces and €0.01/litre of urine were charged in the region. The collected faeces were used for compost production and the urine for direct agricultural application at the household level after one month storage and dilution.

Composting toilet/fossa alterna

The fossa alterna was observed as a typical type of double pit composting toilet in the regions. The number of users per toilet (PE_i) was identified as the most responsive variable ($P < 0.05$, $n = 250$) for costing the fossa alterna. The superstructure was constructed with light materials to make it movable from one pit to another. The annual revenue gained from the fossa alterna was estimated based on the current market price of €0.10/kg of partially cured compost in the area.

Urine and faeces collection

The results for urine collection from UDDT with 8-m³ and 5-m³ vacuum trucks have shown the significant influence of PE and average distance from collection point to treatment site (D_{ct}) for both IIC and annual O&M cost ($P < 0.05$, $n = 50$). For faeces collection, PE and loading capacity of the truck were identified as influential parameters for both IIC and O&M cost ($P < 0.05$, $n = 125$). Moreover, the influence of D_{ct} was reflected in the O&M cost ($P < 0.05$). The analysis of faeces collection demonstrated the economic benefit of using a small truck (i.e. 1,200 kg loading capacity) rather than a big truck (i.e. 10,000 kg loading capacity), if the total PE and D_{ct} are less than 8,600 km and 10 km, respectively. The revenue from urine and faeces collection was calculated based on the existing collection fee of €0.20 per 20 litres of urine and €0.60 per 50 kg of faeces. The revenue can also be expressed in terms of PE.

Septic tank

Septic tanks were commonly implemented by middle-income residences, institutions and business centres in the regions, where there is an adequate water supply. The septic (faecal) sludge was mostly desludged every two years and transported into a sludge drying bed. The cement plastered masonry-wall type of septic tank was found as the typical type in both study areas. A faecal sludge collection fee is the major expense of septic tank operation. The obtained result revealed that the PE per septic tank (PE_i) was the most responsive variable ($P < 0.05$, $n = 22$) for IIC and annual O&M cost.

Faecal sludge collection

Government and private companies were involved in the faecal sludge collection business using 8-m³ and 5-m³ vacuum trucks. The regression analysis result determined the importance of PE and D_{ct} for both IIC and annual O&M cost ($P < 0.05$, $n = 80$). However, the IIC of the faecal sludge collection remained constant, if the value of PE and D_{ct} are below 15,000 m and 20 m, respectively. The average collection fee of €17.50 per emptying is the source of the revenue, irrespective of the vacuum truck capacity.

Gravity sanitary sewer

In the study area, a few gravity-aided sanitary sewers were implemented by institutions, universities, and condominiums to convey wastewater from a numbers of blocks to communal septic tanks. The results for these sewers show the importance of pipe diameter and length ($P < 0.05$, $n = 22$) for IIC and O&M cost.

Sludge drying bed

The sludge drying beds owned by institutions and public universities were constructed to treat faecal sludge collected from septic tanks. PE was found to be the most responsive parameter ($P < 0.05$, $n = 19$) for IIC and O&M cost. Expenses for dried sludge removal every 5 years and inspection work were considered for O&M costs of the drying bed. As current practice in the area showed, dried sludge was simply disposed of at the nearby landfill or surrounding bush areas, but it can be reused for soil conditioning after further composting.

Composting

Small, labour-intensive windrow composting was practised in the regions for composting a mixture of municipal organic waste and faeces from UDDT. The observed composting practices in the regions were unhygienic and traditional. Hence, modified standard composting designs were prepared and cost estimation was performed accordingly. The modified design includes the required civil works, equipment and basic machinery such as tractors to minimize the health risk to the employees. From the obtained result, the volume of compostable faeces (V_f) and municipal organic waste (V_o) were identified as statistically responsive parameters for IIC, O&M cost and revenue ($P < 0.05$, $n = 10$). The revenue was estimated based on the current market price of €0.14/kg of cured compost.

CONCLUSION

The economic analyses of eight water supply and eleven sanitation technologies show the importance of the

maximum daily water demand (Q_{Md}) and the number of people connected (as PE) for costing them, respectively. Q_{Md} can also be expressed in the form of flow rate or pipe diameter. Operation costs for energy- and/or chemically intensive technologies (e.g. Disinfection and Pumping stations) were considerably influenced by the type and rate of energy and/or chemical consumption.

The developed cost functions for initial investment, annual O&M, annual revenue and reinvestment can be used to help the planners to estimate the LCC of WS&S systems. This leads to fair economic comparison among feasible water supply or sanitation alternatives.

The obtained cost values of WS&S technologies for the Bahir Dar vicinity are comparatively higher than for Arba Minch. This may be justified by the higher living standard, non-competitive contract award practices and high excavation cost because of relatively sound geological formation in Bahir Dar neighbourhoods. Hence, the authors recommend a further study on the pros and cons of non-competitive and competitive contract awards on WS&S project costing. Generally, the study findings can assist planners to make a comprehensive economic analysis of WS&S systems at an early stage of planning. Furthermore, the presented cost functions help to improve the commonly practised IIC-focussed WS&S system selection in the study areas and can contribute towards reducing the proportion of non-functioning WS&S facilities aligned with the Ethiopian Government's GTP targets.

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