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Sanitation technology library: details and data sources for appropriateness profiles and transfer coefficients

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Abbreviations

ABR	Anaerobic Baffled Reactor
AS	Appropriateness Score
bal.	Balanced results
CLUES	Community-Led Urban Environmental Sanitation Planning
EJ	Expert Judgement
FG	Functional Group
FS	Fixed Solids
HSSFCW	Horizontal Sub-Surface Flow Constructed Wetland
k	Concentration Factor
MCDA	Multi-criteria Decision Analysis
med. (R.)	Median (Range)
SAS	System Appropriateness Score
SBR	Sequencing Batch Reactor
SD	Standard Deviation
TAS	Technology Appropriateness Score
TC	Transfer Coefficient
TN	Total Nitrogen
TP	Total Phosphorus
TS	Total Solids
TSS	Total Suspended Solids
UDDT	Urine-Diverting Dry Toilet
VS	Volatile Solids
WSP	Waste Stabilization Pond

1 Introduction

This document provides supplementary information to apply the procedures described in:

> *Spuhler, D., Scheidegger, A. and Maurer, M. (2020) Ex-ante quantification of nutrient, total solids, and water flows in sanitation systems. Submitted to Water Research,*

which in turn builds on the system generator described in:

> *Spuhler, D., Scheidegger, A. and Maurer, M. (2018) Generation of sanitation system options for urban planning considering novel technologies. Water Research 145, 259-278.*

It provides the in-depth description of the methods, the raw data on their appropriateness profiles, the transfer coefficients including literature references and Factsheets for 41 sanitation technologies.

The methods were developed in the *GRASP project* ("Generation and Assessment of appropriate Sanitation Systems for Planning")[1] at the Eawag: Swiss Federal Institute of Aquatic Science and Technology. They have four steps:

1. Identifying all appropriate sanitation technologies by comparing the technology profiles to the application case profile.
2. Generating all valid sanitation system configurations from the toilet to the final reuse or disposal. The system configurations entail hardware only; services are not considered.
3. Selecting a diverse but manageable set of locally appropriate sanitation system options as input for the planning process.
4. Quantifying the nutrients (phosphorus and nitrogen), water, and total solids (as indicator for energy and organic matter).

The procedure is intended to support experts during the planning phase (ex-ante) in a structured decision-making process, such as Community-Led Urban Environmental Sanitation (Lüthi et al. 2011). The main output is a diverse set of locally appropriate sanitation system options that is of manageable size. This set is then to be further evaluated, regarding the main decision objectives (e.g. costs, operation and managements scheme, etc.), before it is handed over to the SDM process for the discussion of trade-offs and the selection of the preferred option, using any kind of multi-criteria decision analysis (MCDA) method. The required inputs are:

1. The set of potential technologies and data on their appropriateness and transfer coefficients (provided in this document)
2. The list of relevant and non-negotiable screening criteria (e.g. energy requirements) and the desired number of options given by the SDM process.

Four algorithm were implemented to perform the above steps: (i) the technology appropriateness assessment algorithm ("TechAppA"), (ii) the "SystemBuilder", (iii) the "OptionSelector", and (iv) a mass flow quantification algorithm using substance flow modelling ("MassFlows"). The SystemBuilder, OptionSelector, and MassFlow models are implemented in Julia (Bezanson et al. 2017) and are accessible at https://github.com/Eawag-SWW/SanitationSystemMassFlow.jl (v1.0). The TechAppA model is implemented in R (R Development Core Team 2018) and is accessible at https://github.com/Eawag-SWW/TechAppA (v1.0). A compact and machine-readable version of the technology data (the technology library) is available in data package 2 of Spuhler et al. (2020) at ERIC: https://doi.org/10.25678/0000ss.

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[1] https://www.eawag.ch/en/department/sww/projects/grasp-generation-assessment-of-sanitation-systems-for-strategic-planning/

1.1 Outline

Chapter 2 (p. 6ff): Clarification of terminology,

Chapter 3 (p. 8ff): Explanation and list of the appropriateness attributes used by the model.

Chapter 4 (p. 16ff): Details about the substances flow modelling, transfer coefficients, uncertainties, and implemented substances.

Chapter 5 (p. 26ff): Fact sheets for 41 technologies containing their appropriateness profiles and transfer coefficients.

2 Terminology

Appropriateness profile	The appropriateness profile contains the attributes and the functions that describe the given technology or case (Spuhler et al. 2018).
Appropriateness score	The appropriateness score expresses the confidence in how appropriate the technology is for a given application case. It is obtained by comparing the technology appropriateness profiles to the application case profile. Each attribute is compared individually resulting in an attribute score. The aggregation of all attribute appropriateness scores results in the overall technology appropriateness score for the given case. The score has a value between 0 and 1 (1 means 100% appropriate, 0 means not appropriate at all), (Spuhler et al. 2018). For example: Attribute appropriateness scores: frequency of O&M = 1, temperature range = 1, vehicular access = 0.8563 , slope = 1, O&M skills = 1, management = 0.1499 , spare parts supply = 0.85111 → technology appropriateness score (TAS) = 0.72884.
Attributes	Attributes are used to describe the screening criteria of technologies and cases. One example would be the “temperature range”. For the technology, it describes the performance of that technology given a specific temperature. For the case, the attribute describes the temperature variations in that location (case) (Spuhler et al. 2018).
Case	The case or context which the presented procedure is applied to. This could be a village or a district inside a bigger city (Spuhler et al. 2018).
Functional groups	Groupings of technologies that have similar functions. There are five different functional groups from which technologies can be chosen to build a system (Tilley et al. 2014): ▪ User Interface (e.g. pour flush toilet) ▪ Collection and storage/treatment (e.g. septic tank) ▪ Conveyance (e.g. solid free sewer) ▪ (Semi-) Centralised treatment (e.g. activated sludge) ▪ Reuse/disposal (e.g. biogas combustion).
Screening Criteria	The appropriateness of a technology is evaluated on the basis of screening criteria given by the local context. The evaluation of screening criteria is also highly context-dependent. Therefore, each screening criterion consists of a pair of technology and application case attributes, which characterise the criteria for the technology and the case, respectively. Each attribute is parametrised by a probability function. A pair of technology and case attributes consists of one probability density or distribution function (e.g. the water availability for a given case, *p(water availability)*) and one conditional probability (e.g. the performance of a technology given a certain water availability *P(performance | water availability)*). Whether the density or the conditional probability is used for the technology or the case attribute is not important as long as both types of functions are represented for one criterion.

(Sanitation) Products	Sanitation products are materials in sanitation systems that are also called 'wastes' or 'resources'. Some products are generated directly by humans (e.g. urine and faeces), others are required in the functioning of technologies (e.g. flush water to move excreta through sewers) and some are generated as a function of storage or treatment (e.g. sludge) (Tilley et al. 2014). See also the chapter "Definitions of sanitation products".
(Sanitation) System	A sanitation system (SanSys) is defined as a set of compatible technologies which, in combination, manage sanitation products from the point of generation to a final point of reuse or disposal (Maurer et al. 2012, Spuhler et al. 2018, Tilley et al. 2014).
(Sanitation) Technology	A sanitation technology (Tech) is defined as any process, infrastructure, method or service that is designed to contain, transform or transport sanitation products (Spuhler et al. 2018). It is characterised by its name, the input and output products and how they relate to each other (e.g. blackwater or greywater -> septic tank -> sludge and effluent), as well as the attributes describing its technology appropriateness profile (e.g. water and energy requirements, frequency of operation and maintenance, etc.), (Spuhler et al. 2018).
Transfer coefficient (TC)	The transfer coefficient gives the fraction of the total substance that enters a technology with all input products, which is transferred into a output product. The TC for the substance s and the i-th output of a Tech (TC_i) is the fraction of the sum of the input flows that leave the Tech through output i: $TC_{i,s} = \frac{out_{i,s}}{\sum_{j=1}^{n} in_{j},s}$, (1) For instance, a septic tank is fed with the product "blackwater", which contains a certain amount of the substance phosphorus (P). The output products of the septic tank are defined as "sludge" and "effluent". The TC defines how much of the phosphorus is transferred to the sludge and how much is transferred to the effluent (e.g. 80% and 20%, respectively). Additionally, there are also losses of substances into air, soil or water, which have to be accounted for. For every substance that is transferred into several output products, the sum of all TCs is equal to 1.

3 Technology appropriateness assessment

3.1 Approach

The first step to finding an appropriate sanitation system is to identify those technologies among all potential ones that are appropriate for a specific case. For example, if the provision of water is not possible in the case, all technologies that require water supply can be excluded immediately.
The appropriateness of technologies is evaluated on the basis of screening criteria derived from the overall decision objectives for sustainable sanitation as defined by (SuSanA 2008). Based on this definition, a sustainable sanitation system not only has to protect and promote human health by providing a clean environment and breaking the cycle of disease, but also has to be economically viable, socially and institutionally acceptable, technically appropriate, and protective of the environment and natural resources.
The process to identify the list of screening criteria to be used for a given case is described in Spuhler et al. (2018). In the following paragraphs, we describe how the screening criteria are evaluating using a technology and a case attribute and an appropriateness function for each of those attributes.

3.2 Appropriateness attributes

Each screening criteria consists of a pair of technology and case attributes, which characterise the technology and the case, respectively. To account for uncertainties, probability functions are used that parameterize the attributes. Each attribute is described by a probability density or distribution function (d-… function), e.g. the probability of an event at the case, and one conditional probability function (p-… function), e.g. the performance of a technology given a certain condition. Whether the density or the conditional probability is used for the technology or the case attribute is not important as long as both types of functions are always represented for one criterion.
General Example: the “Temperature range” would be described as a probability density function for the case (temperature variations in that location) and as a conditional probability function (performance) for the technology (how does the technology perform given a certain temperature).
In the following, the different types of functions will be described that have been used in the model.

3.3 Recommended attribute functions

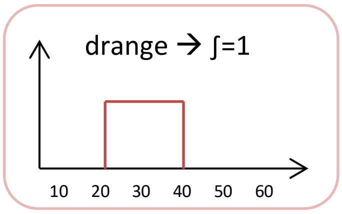
There exists a number of recommended probability functions that can serve as attribute functions. Which function is to be chosen depends on the type of available data and the judgement of the expert applying the procedure. In the following, we provide four different functions that should be enough to represent the data available in a typical application case. However, if more accuracy is needed, any other probability function could be used.

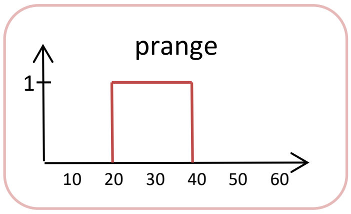
Range

The range function can describe a value range. It can be used if a range or a threshold is needed: →range (lower, upper), lower < upper

Example 1:

A technology only works with a temperature between 20 and 40 °C.
range(lower=20, upper=40)

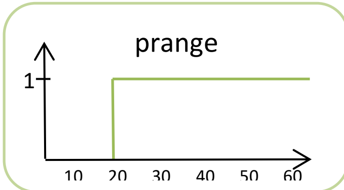




Example 2:

A minimal surface area of 20m² is required
range(lower=20, upper=+inf)

A density function does not make sense in this case (cannot have infinite values)

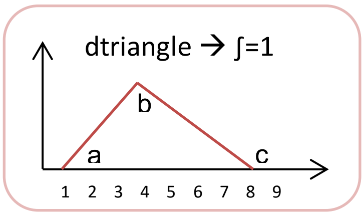


Triangle

The triangle function can describe values where a linear interpolation between three points is assumed → triangle(a, b, c) , a <= c <= b

Example 1:

The groundwater level varies between 2m and 8m with an average of 4m
triangle(a=2, b=8, c=4)

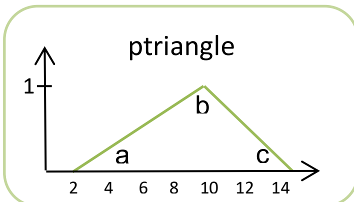


A performance function does not make sense under this statement

Example 2:

The technology works with a slope between 2% and 15% with an optimal slope of 10%
triangle(a=2, b=15, c=10)

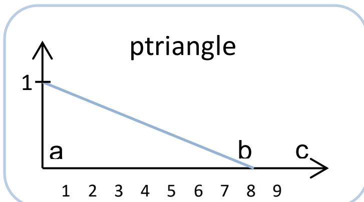
A density function does not make sense under this statement



Example 3:

Technology performance depending on electricity outages per month
triangle(a=0, b=8, c=0)

A density function does not make sense under this statement



Trapezium

The trapezium function can describe values where a linear interpolation between four data points (min, 1st optimum, 2nd optimum and max) is assumed.

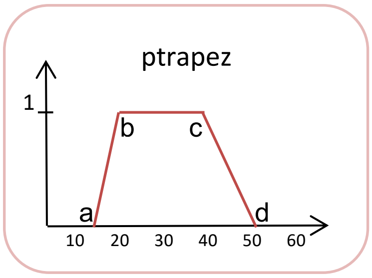
→ trapez(a,b,c,d) , a<b<c<d

Example1:

The technology starts working at 15°C, reaches its optimum at 20 to 40°C and does not work over 50°C

trapez(a=15, b=20, c=40, d=50)

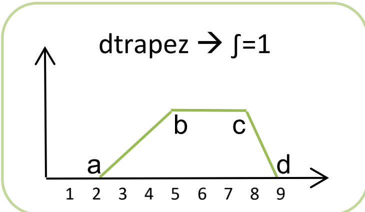
A density function does not make sense under this statement



Example 2:

The groundwater in this area is minimal 2m, mostly 5 to 8m and max. 9m deep.

trapez(a=2, b=5, c=8, d=9)



A performance function does not make sense under this statement

Category

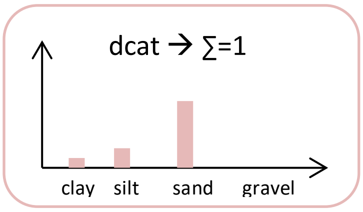
The category function allows us to give values to specific categories.

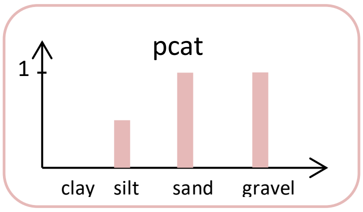
→ cat(category 1, category 2, category 3, …)

Example 1:

The soil in the area is 10% clay, 20% silt and 70% sand

cat(clay=0.1, silt=0.2, sand=0.7, gravel=0)





3.4 Calculation of technology appropriateness scores

The appropriateness score is calculated by checking how well the technology and the case functions match. The larger the overlap, the higher the score.
For a technology and a criterion c, the appropriateness score can be defined as

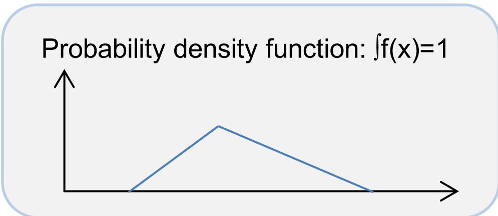
$$AS_{t,c} = P(p) = \int P(p|c)\, p(c)\, dc \qquad (2)$$

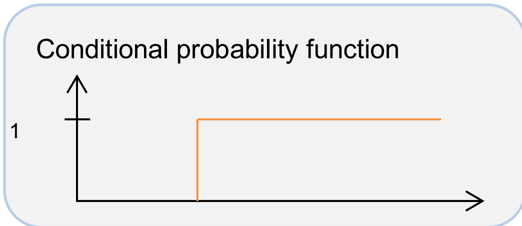
if p(c) is a probability density function, or

$$AS_{t,c} = P(p) = \sum_{c' \in \Omega} P(p|c)\, p(c') \qquad (3)$$

if p(c') is a probability distribution function.

Example:
Two functions,

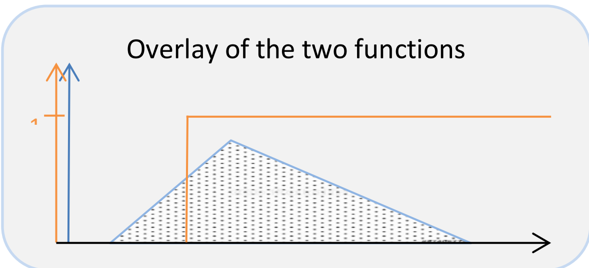




are overlaid and the appropriateness is the result of:

$$Attribute\ appropriateness\ score = \int density\ function \cdot performance\ function \qquad (4)$$

Visualizing it, the appropriateness score is calculated from the overlapping area under the two functions.



If a technology *t* has multiple criteria, the scores must be aggregated. The aggregation results in the technology appropriateness score (TAS), (Spuhler et al. 2018):

$$TAS_t = \sqrt[n]{\prod_{c=1}^{n} AS_{t,c}} \qquad (5)$$

3.5 Currently implemented appropriateness attributes

Currently, 27 screening criteria and corresponding attributes and probability functions are implemented. In **Table** 1, we provide a description as well as questions to be asked to quantify each of them. This information can be used to collect local data or to define appropriateness profiles of technologies not yet covered by this document and the technology library.

Table 1 List of currently implemented appropriateness attributes with description, case/technology questions and functions, as well as the scale of these. Attributes marked with a * behind the number were not included in the application presented in (Spuhler et al. 2020) “d-“ functions are characterised by a sum (or integral) of 1 (=<00%). “p-“ functions are characterised by [0<X<100%]. “continuous” functions include range, triangle and trapezium functions

No.	Attribute name	Description	Case question and function(s)	Technology question and function(s)	Scale
1	Water supply	Used if the technology requires water to work. The attribute applies only to technologies where water enters the system and not if it comes from a precedent technology (e.g. it applies to a flush toilet, but not to a sewer).	What type of water supply is available in the case? *Function:* dcat	How does the technology perform at a given water supply? *Function:* pcat	Categories (based on location of access): a-house b-yard c-public d-none
2	Energy supply	Used if electricity is essential for the technology (this includes electricity for possible features used during operation, e.g. pumps)	How many hours a day is electricity available at the household or facility level? *Function:* drange	How does the technology perform at a given energy availability? *Functions:* ptriangle, ptrapez	[hours/day]
3*	Water supply disruption	Used, if the technology uses the attribute "water supply"	How often does the water supply interrupt at the household level? *Functions:* drange, dcat	How does the technology perform at a specific water supply disruption? *Functions:* prange, pcat	frequency [hours/day, hours/week or hours/month] (e.g. 2h per week)
4*	Power supply disruption	Used, if the technology uses the attribute "energy supply"	How often does the energy supply interrupt in a household? *Function(s):* drange, dcat	How does the technology perform at a specific energy supply disruption? *Function(s):* prange, pcat	frequency [hours/day, hours/week or hours/month] (e.g. 2h per week)
5	Frequency of O&M	Used, if the technology needs human labour for operation and maintenance (O&M).	How feasible is it to find O&M labour for a specific workload? *Function:* prange	How many days of O&M are required to ensure performance of at household level? *Functions:* dtriangle, drange	[days/year/tech] or [days/ month/tech]
6	Tempera-ture range	Used, if the temperature can have an effect on the functionality of the technology.	What is the daily average temperature during one year? *Function:* dtriangle	How does the technology perform at a given temperature? *Functions:* prange, ptrapez, ptriangle	degree Celsius [°C]

No.	Attribute name	Description	Case question and function(s)	Technology question and function(s)	Scale
7	Flooding	Used, if flooding damages or compromises the technology.	How high are flooding levels at households or the facility?	What is the technology performance given a certain flooding height?	water height [cm]
			Function: drange	*Function:* ptrapez	
8	Vehicular access	Used, if the technology needs to be accessible with a vehicle for O&M.	What is the width of the access roads to the technologies?	How feasible is access to the technology given a certain road width?	street width [m]
			Function: dtrapez	*Function:* ptrapez	
9	Slope	Used, if the slope has an impact on the functionality of the technology.	What is the slope distribution in the settlement?	How does the technology perform if implemented on a specific slope?	[%]
			Function: dtriangle	*Function:* ptrapez	
10	Soil type/ hydraulic conducti-vity	Used, if the type of underlying soil or the hydraulic conductivity has an impact on the functionality of the technology.	What is the soil type in the case-area?	How appropriate is the technology given a specific soil type/permeability?	Categories: a=clay b=silt c=sand d=gravel
			Function: dcat	*Function:* pcat	
11	Ground-water depth	Used, if the technology is directly influenced by the groundwater table.	What is the groundwater depth at the households or the facility?	How appropriate is the technology given a groundwater depth?	water depth [m]
			Function: dtrapez	*Functions:* ptrapez, prange	
12	Excavation	Used, if the technology requires excavation.	How much of the area is easy/difficult to excavate?	How easy/difficult is excavation for this technology?	Categories: 1-easy 2-hard
			Function: dcat	*Function:* pcat	
13*	Population density	Describes how urbanised the area is.	What is the population density in this area?	What population density can be supported with this technology?	persons/km^2
			Function(s): drange	*Function(s):* prange	
14	Construc-tion skills	Describes the type of professions needed for the construction of this technology. Used for all technologies besides irrigation and surface water disposal.	What levels of professions for construction are available in this area?	What level of professions are needed for the construction of this technology?	Categories: 1-none 2-mason 3-specially trained mason 4-construction engineer 5-supervisor
			Function: ptrapez	*Function:* dtriangle	

No.	Attribute name	Description	Case question and function(s)	Technology question and function(s)	Scale
15	Design skills	Describes the type of professions which is needed for the design of this technology. Used for all technologies.	What levels of professions for design are available in this area?	What levels of professions are needed for the design of this technology?	Categories: 1-none 2-unskilled labour 3-mason 4-specially trained mason 5-planning engineer 6-supervisor
			Function: ptrapez	*Function:* drtiangle	
16	O&M skills	Describes the type of professions which is needed for the O&M of this technology. Used for all technologies.	What level of professions for O&M are available in this area?	What level of professions are needed for the O&M of this technology?	Categories: 1-none 2-unskilled labour 3-specially trained labour 4-technician 5-supervisor 6-administrator 7-engineer 8-scientist
			Function: ptrapez	*Function:* dtriangle	
17	Manage-ment	Describes the management level that is needed. Used for all technologies.	What kind of management is possible/preferred?	How appropriate is the technology given a certain management level?	Categories: 1-household 2-shared 3-public
			Function: dcat	*Function:* pcat	
18*	Pipe supply	Used, if pipes are essential for this technology	How available are pipes of a specific diameter?	What pipe diameters are used percentage-wise in the technology?	diameter [cm]
			Function(s): drange, dcat	*Function(s):* prange, pcat	
19*	Pump supply	Used, if the pumps are essential for this technology	How available are pumps of a specific pumping capacity?	What pumps are used percentage-wise in the technology?	Categories (based on power): small medium high
			Function(s): dcontinuous, dcat	*Function(s):* pcontinuous, pcat	
20*	Concrete supply	Used, if concrete is essential for this technology	How much concrete is available in one year? How accessible is concrete?	How much concrete is needed for this technology? [tonnes/household] How applicable is this technology with/without concrete?	[t]
			Function(s): drange, dcat	*Function(s):* prange, pcat	
21	Spare parts supply	Describes the possibility of replacing broken parts of the technology. Used for all technologies.	How accessible are spare parts of each category?	What parts are most likely to break?	Categories: 1- low-tech 2- technical parts 3- specially manufactured
			Function: pcat	*Function:* dcat	

No.	Attribute name	Description	Case question and function(s)	Technology question and function(s)	Scale
22*	Surface area	Refers to the plot area available at each household or construction site. Used, if space is "consumed" by this technology. Use two different attributes for on-site and (semi-) centralised technologies.	How much surface area (m2) is available between the houses or at the facility site?	How much area is needed for this technology (m2)?	[m^2/household]
			Function(s): dcontinuous, drange	*Function(s):* pcontinuous	
23*	Potential to accommod ate for changing water volumes	Use, if the technology interacts with water	How likely is an increased water volume?	How good does the technology perform given an increased water volume?	[l/capita/day]
			Function(s): drange, dcat	*Function(s):* prange, pcat	
24*	Potential to accommo-date for changing pollution load	Used, if the technology interacts with the pollution load	How likely is an increased pollution load?	How good does the technology perform given an increased pollution load?	BOD5 [mg/cap/day]
			Function(s): drange, dcat	*Function(s):* prange, pcat	
25*	User awareness require-ments (misuse)	Describes how respectful the people are towards sanitation technologies (proper use). Hereby, we are not considering the workers (O&M), but only the users of the technology. Used, if users have direct access to the technology	How likely are people to misuse a sanitation facility?	How does the technology perform under misuse?	Categories: 1-use as designed for 2-insufficient maintenance 3-occaisional disposal of small things 4-contineous disposal of waste 5-blocking through abnormal use 6-destruction
			Function(s): drange	*Function(s):* prange	
26*	Cleansing method	Describes what type of cleaning is recommended, only used for the user interface	What percentages of the population are comfortable with which cleansing method?	How applicable is each cleansing method for this technology?	Categories: 1- water 2- soft
			Function(s): dcat	*Function(s):* pcat	
27*	Odour	Refers to the odour to which the user/public is exposed during operation (not while maintenance) of a well-maintained technology	What level of odour is tolerated by the population?	How likely is a specific level of odour to occur at a household from this technology?	Categories: 1-no odour 2-few hours per month 3-few hours per week 4-few hours per day 5-contineous smell
			Function(s): prange	*Function(s):* drange	

4 System mass flows

4.1 Approach

For the evaluation of trade-offs and the selection of the preferred sanitation system option, detailed information regarding the performance of various options can be useful. Nutrient emission or recovery potentials, water reuse or loss, and energy recovery potential are performance indicators that can matter in a multi-criteria selection of the preferred option. To analyse and quantify the flows of matter and energy into, within and out of the defined borders of a system, material flow analysis (MFA) or substance flow modelling (SFM) has proven to be a good option (Villeneuve et al. 2004).
We apply a simplified SFM to quantify nutrient (phosphorus and nitrogen), total solids and water flows of the sanitation systems. The flow paths are defined by the sanitation products that connect technologies within a system. We implement four substances which exemplify different substance properties: total phosphorus (TP), total nitrogen (TN), total solids (TS), and water (H2O). All four substances are also relevant for decision making as indicators for resource recovery and pollution potentials. Water is a special case because not only the recovery potential, but also the absolute mass required/recovered varies depending on the system.

4.2 Mass flow calculations

The *SanitationSystemMassFlow* (Spuhler et al. 2020) model calculates substance mass flows for all potential systems, generated by the *SystemBuilder* (Spuhler et al. 2018). As initial input, inflows of substances are defined for each source technology. The model transfers the inflows of the source technologies into the respective output products (e.g. urine, faeces, excreta or blackwater) using the transfer coefficients (TCs). From then on, the flow of the substances through the system is calculated by multiplying the sum of all inflows to the technology by TCs in order to get the amount of substance in the output products. These are then transferred into inflows in the subsequent technology until the sink technologies are reached. Figure 1 is a schematic setup of a sanitation system from source to sink technology. The in- and output products are shown in different colours, implying their different compositions.

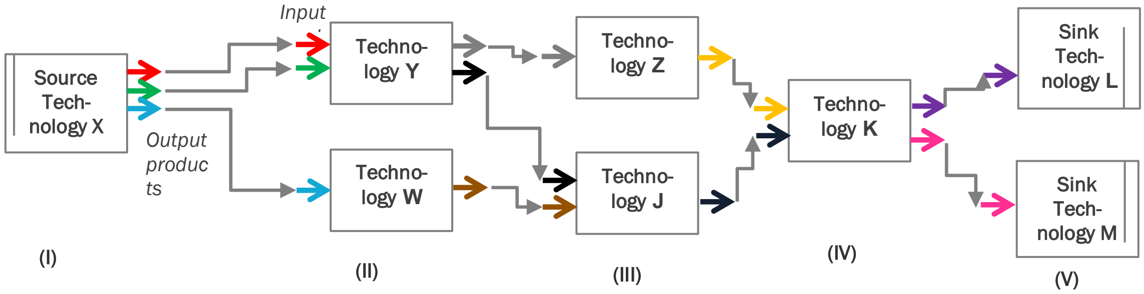


Figure 1 Schematic structure of a sanitation system with source, sink, and intermediate technologies. They are combined on the basis of their out- and input products and mass flows are calculated by the transfer coefficient in each technology.

The sink technologies (functional group D) define the mass flow that can be recovered for a system, as recovery occurs from these technologies only. To quantify the losses to air, soil, and water, the losses for all technologies within a system are summed up. Only the total recovery and loss potentials are saved and written out in both mass and in % of inflow to the system.
Because the model also allows for loops (e.g. an effluent of a drying bed going to a waste stabilisation pond and the sludge of the pond going back to the drying bed) all the mass flows have to be calculated at the same time assuming steady-state. Therefore, the flows within a given technology are not purely linear, but depend on the amounts of inflows. Yet, the recovery and loss potentials for the entire system are linear and, therefore, transferrable for one case to another.

4.3 Dirichlet distribution and Monte Carlo simulation

Assuming that mass is neither lost nor gained by the technologies (no biological fixation), the sum of all transfer coefficients for one technology and one substance is exactly 100%. Based on this assumption, the Dirichlet distribution, the multivariate generalisation of the beta distribution, can be used to model the uncertainty attached to the transfer coefficients.
To propagate the uncertainty, the model uses a Monte Carlo (MC) Simulation. The MC simulation repeats the mass flow calculation a defined number of times, sampling different TCs from the Dirichlet distribution of the given TC. The results are again distributions for the output values for recoveries and losses.

4.4 Concentration factors *k*

Varying environmental conditions, different study set-ups, design characteristics and product compositions result in a range of values found in the literature from which transfer coefficients were calculated. For novel technologies, ignorance of performance under different conditions is a limitation. To reflect the uncertainty, every TC is equipped with a concentration factor (*k*), the basis of the Dirichlet distribution. The lower the factor, the less certain are the TCs and the higher is the variability.
To translate the variability from literature ranges into concentration factors used by the model, we developed Table 2. If, for example, literature values for a technology and substance, have a range of 0.18, *k* is set to 25. The TCs of all pathways of a substance have the same concentration factor and the largest range of one of the pathways (into an output product or a loss) is taken. Spuhler et al. (2020) describes, how the *k*s were determined to correspond with the ranges.

Table 2 The range of TCs found in literature was translated into an concentration factor using this table.

Range	Uncertainty factor
0- 0,1	100
0,11-0,2	25
0,21-0,4	5
0,41-0,6	2
0,61-0,8	1
0,81-1	0.5

For TCs where no literature was available, we developed Table 3 to define the concentration factors based on the experts' confidence in two dimensions: (i) knowledge about the technology, and (ii) confidence in the specific substance.

Table 3 Matrix to translate confidence in knowledge about technologies and substance into an uncertainty factor

		Confidence in knowledge about technology		
		low	medium	high
Confidence in substance	low	1	2	5
	medium	2	5	25
	high	5	25	100

4.5 Currently implemented substances

There are two main general interests in the *SanitaitonSystemMassFlow* model. First, knowledge on the substance flow and emissions to the environment is gained. And secondly, options and potentials of the different sanitation systems for recovery and reuse of these substances are better understood.
In the following, the interest in the used substances, their sources, fates in the treatment process, and transfer coefficients are described in more detail.

Phosphorus

Interest and reuse potential

Phosphorus (P) is an essential nutrient for plant growth and may cause algae bloom in water bodies, leading to excessive oxygen consumption and oxygen free zones (Tchobanoglous et al. 2009). As phosphates are not reduced like organic matter, but remain in the cycle, the discharge of effluents from sanitation systems containing P can be problematic. Because P is an important plant nutrient, the recovery of P from sanitation systems can be financially attractive and achieved through different methods (e.g. irrigation with effluent, composting of sludge, or struvite product (Etter et al. 2011, Jönsson et al. 2004).

Sources of P in wastewater and chemical characteristics

In raw wastewater P is found in different forms as organic phosphates, inorganic orthophosphates, and polyphosphates. While organic phosphates have physiological origin, inorganic phosphates originate mainly from detergents and other household chemicals (Sperling 2007). Humans excrete 30 to 50% of P in faeces and the other 50 to 70% in urine (Montangero and Belevi 2007, Rose et al. 2015). As detergents can account for up to 50% of P in wastewater, it is vital to know if greywater enters a treatment system or not (Sperling 2007).
Orthophosphates, such as PO_3^-, HPO_4^{2-}, $H_2PO_4^-$ and H_3PO_4, are directly available for biological metabolism, in which of these forms they occur depends on the pH (Montangero and Belevi 2007). Polyphosphates are complex molecules, which slowly transform to the orthophosphate forms through hydrolysis and can then be consumed by microorganisms (Sperling 2007, Tchobanoglous et al. 2009).
The bigger part (~75%) of phosphorus in raw domestic sewage is soluble, comprised of the inorganic forms, as well as part of P bound to soluble organic matter. The remaining ~25% are organic P bound to particulate organic matter (Sperling 2007, Tchobanoglous et al. 2009).

Treatment process

Phosphorus is required as a growth nutrient for microorganisms that stabilise organic matter during treatment (Sperling 2007). Consequently, biological removal of phosphorus is based on the removal of phosphate accumulating organisms. Removal of phosphorus by physical-chemical processes after biological treatment can polish the effluent and result in very low P (Sasse 1998, Sperling 2007). Transformation or storage of P (e.g. in compost) are additional ways of treatment, with the aim of recovery.

Determination of transfer coefficients for P

For the *SanitationSystemMassFlow* model, we use Total phosphorus (TP) to describe the flows of P through sanitation systems because most of the consulted research literature on the TCs for P in sanitation technologies uses TP as a measurement. A few literature examples also look at another type of phosphorus. In these cases, estimations were transformed to TP. The uncertainties that come with this procedure are considered in the corresponding concentration factor.

Nitrogen

Interest and reuse potential

Just like phosphorus, nitrogen (N) is a fundamental nutrient for plant growth and a potential pollutant of water bodies, leading to algae growth and eutrophication (Mudrack and Kunst 2003). Adverse impacts on humans are caused by nitrite (NO_2^-) in drinking water, as it can cause illness (methemoglobinemia). In the form of free ammonia gas (NH_3), it is toxic to fish (Sperling 2007). During nitrogen conversions in wastewater treatment processes, nitrous oxide (N_2O) is produced (Kampschreur et al. 2009). N_2O emission are not discussed further here but accounted for by air losses of total nitrogen.
Nitrogen is also a valuable fertiliser. During composting and drying of faeces and sludge, a high percentage of nitrogen volatises (Meinzinger 2010). The rest remains retained in the biosolid. High N recoveries can be achieved by direct recovery from urine.

Sources of N in wastewater and chemical characteristics

Nitrogen can take on different oxidation stages in water, the changes between which are often brought about by bacteria. Additionally, the changes in oxidation stages vary with the availability of free oxygen in the water, i.e. aerobic or anaerobic conditions (Tchobanoglous et al. 2009). The chemistry of nitrogen in wastewater treatment is, thus, fairly complex.
In domestic wastewater, N is mainly found as organic nitrogen and ammonia. About 80 to 90% of N in domestic wastewater originates from urine as urea; the remaining 10 to 20% come from faeces and are mainly in the form of proteinaceous matter (Montangero and Belevi 2007, Rose et al. 2015). Urea is rapidly hydrolysed to ammonia and is detectable in small quantities only in sewage. In aquatic solutions, ammonia exists in two forms: ammonium ions (NH_4^+) and ammonia (NH_3) as shown in the equilibrium reaction in:

$$NH_4^+ \leftrightarrow NH_3 + H^+ \qquad (6)$$

The distribution of ammonia forms here is dependent on the pH. At pH = 9.25, the reaction is in equilibrium, while, at a higher pH, it is displaced to the right and more gaseous ammonia is released (Tchobanoglous et al. 2009). In typical raw domestic sewage., the pH ranges around 7 and consequently ammonia is predominantly present as NH_4^+ (Sperling 2007).

Treatment process

Nitrogen from wastewater undergoes two main processes during treatment, i.e. nitrification and denitrification. Nitrification is a two-step process in which ammonia is first oxidised to nitrite and then to nitrate (Tchobanoglous et al. 2009). The oxidation is carried out by two groups of autotrophic bacteria under aerobic conditions as they consume oxygen. Denitrification occurs under anoxic conditions. Consequently, if essential nitrogen removal is required, the treatment needs to comprise a mixture of aerobic and anaerobic conditions (Sasse 1998).

Determination of transfer coefficients for N

Different forms of nitrogen can be and are measured in wastewater treatment monitoring, often according to the treatment process and prevailing form of N. A short overview of the commonly measured forms of N is given here (Sperling 2007):

Organic nitrogen (No):	Nitrogen in the form of proteins, amino acids and urea
Ammonia:	Ammonium ions (NH_4^+) and ammonia gas (NH_3), produced by the decomposition of organic nitrogen
Nitrite:	NO_2^-, product of first oxidation stage of ammonia, basically not found in raw sewage
Nitrate:	NO_3^-, final product of ammonia oxidation, basically not found in raw sewage
Total Nitrogen:	Includes organic nitrogen, ammonia, nitrite and nitrate
Total Kjeldahl nitrogen (TKN):	Organic nitrogen and ammonia together

For the *SanitationSystemMassFlow* model, Total nitrogen (TN) is used to describe the flows of N through sanitation systems. Many of the studies considered for the determination of TCs, however, did not measure TN, but did measure other forms of N. If TN and an additional form of N were measured in one literature source, the ratio of these two was determined and applied to other literature for the same or similar treatment processes in order to convert all values found in the literature to TN. Ratio estimations were made based on the measured form of N and personal knowledge of the nitrogen pathway in the respective technology. The uncertainties that come with this procedure are represented by the corresponding concentration factor.

Total Solids

Interest and reuse potential

Excessive discharge of total solids (TS) into water bodies induces microbial growth and can, thus, lead to a lowering of the dissolved oxygen availability in water. Aquatic life is negatively impacted and eutrophication may occur. Because of this, determining flows of TS in sanitation systems is important. Moreover, TS can be used as indicator for energy content or for organic carbon content, which is a valuable soil amendment. For both relationships, TS-energy and TS-organics, other factors, especially the volatile and fixed matter content are important. The subchapter "*Energy in wastewater*" goes into detail about the relation of TS and energy.

Sources of Total Solids in wastewater and chemical characteristics

The term Total Solids (TS) comprises all matter in wastewater which is not water and which remains after evaporation and drying (Hauser 1996). Besides faeces, urine and paper from toilet usage, food residues and wash waters have to be considered.

Total solids can be further divided by size and state into Total Suspended Solids (TSS) and Total Dissolved Solids (TDS) (Sasse 1998). TSS includes settleable, as well as non-settleable suspended solids retained by filtration and is often used as an indicator for the performance of wastewater treatment plants (Tchobanoglous et al. 2009). An alternative way of describing the different fractions of TS is by distinguishing them into Volatile Solids (VS) and Fixed Solids (FS). VS burn off or volatilise when heating up to temperatures of around 550°C and are considered the organic matter fraction of wastewater

(Tchobanoglous et al. 2009). FS still contains a combustible part (inorganic solids) and inert mineral (ash), see also Figure 2.

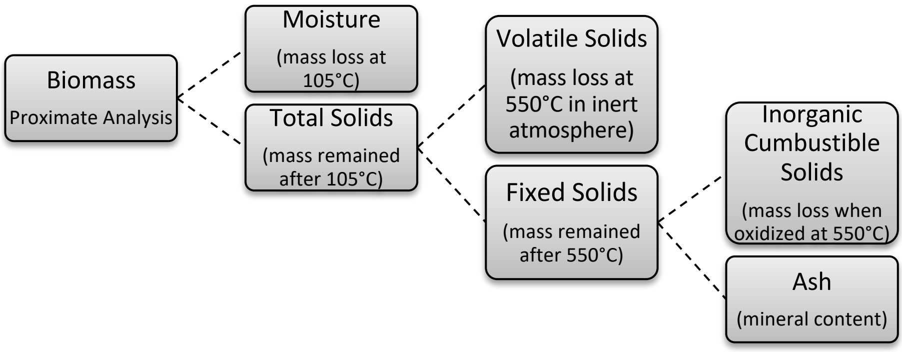


Figure 2 Procedure for determination of biomass volatile solids, fixed solids and ash (Sahito et al. 2013)

Treatment process

In primary treatment especially, suspended solids get removed through the physical process of sedimentation (50 to 70% of TSS) (Scholz 2006). A major part of this is organic matter in suspension. As a result, primary sludge contains a big VS fraction, which is the fraction interesting for fertilisation or energy recovery. In secondary treatment, the solids content in wastewater is further reduced through biochemical processes carried out by different kinds of microorganisms (Hauser 1996, Sperling 2007). There are different setups for secondary treatment, all aiming at establishing contact of the microorganisms with the wastewater through biofilms, mixing or guided flow paths (Sperling 2007).

Determination of transfer coefficients for TS

The literature mostly reports on measurements of the removal efficiencies of TSS. To obtain values for TS pathways, studies measuring TS, as well as TSS removal ratios, were used to establish a "removal ratio" between these. The ratios were then applied to other data to calculate transfer coefficients for TS (see, for example, the calculation in "*S8. Septic* "). The uncertainties that results from this procedure are represented by the corresponding uncertainty factor.

Another difficulty that was encountered relates to the consumption of solids by microorganisms. As the used concept of transfer coefficients does not include a "removal" of substance but only describes their transfer into output products, compromises had to be made. In most cases the amount of solids taken up by microorganism was considered as transferred to sludge. In composting and dehydration technologies, it was considered as air loss.

Energy from wastewater

There are different ways energy can be gained from wastewater. Biogas is produced in anaerobic digestion of wastewater sludge and can be used for electricity production or as heating energy. Other technologies for thermal processing of faeces or faecal sludge in mono- and co-combustion include pelletising or briquetting (Werther and Ogada 1999).

To estimate the energy that can be gained through the combustion of biomass solid fuels, the composition of the fuel is of importance. While volatile and fixed solids contribute to the calorific value, high ash and moisture content have a negative effect (Sheng and Azevedo 2005, Yin 2011).

Equation 10 can be used to calculate the gross calorific value (GCV) of biomass, based on the amount of fixed and volatile solid content minus ash (Sahito et al. 2013).

$$\mathrm{GCV}\,[\mathrm{MJ/kg}] = 0.21575\,(\mathrm{VS}) + 0.07492\,(\mathrm{FS}) - 0.08426\,(\mathrm{ash}) \quad (7)$$

In the case of faecal sludge, ash originates, for example, from indigestible nutrients and sand from pit linings and increases slagging and fouling (Hafford et al. 2017, Rose et al. 2015). The moisture content of the fuel again depends on the drying technology.

The heating value of faecal sludge varies considerably, depending on initial composition, storage duration and containment types (Strande et al. 2014). It has, for example, been shown that anaerobic digestion of faecal sludge reduces the readily degradable organic fraction into ash and lowers the calorific value (Andriessen et al. 2019). Dried faeces or sewage sludge, therefore, have a higher calorific value than anaerobic digested sludge (Hafford et al. 2017).

In the same way, energy recovery in the form of biogas, which is based on methane production from anaerobic digestion, works best from primary sludge. Most organic matter is contained in settable solids, collects here and can be digested (Shizas and Bagley 2004, Zhang and Li 2017).

Water

Interest and reuse potential

Wastewater reuse is an important part of urban water cycles. In about 80% of the towns in Africa, Asia and Latin America, use wastewater, non- or partially treated, for irrigation (Meinzinger 2010). This due to the scarcity of fresh water, high prices, or convenience. Fertilisers are also expensive, and the nutrients and organic matter contained in the wastewater is an added value. Moreover, the availability can be linked to water consumption (Meinzinger 2010). As treated wastewater still contains pathogens, it should be handled with care (Sasse 1998) and treated according to the purpose (e.g. if used for irrigation, nutrient content is not a problem). Guidelines on the usage of treated wastewater are published by various organisations, such as the WHO (Sperling 2007). To plan the irrigation options with reclaimed water, the quantities available after losses in the sanitation systems are important to know better.

Sources of water and chemical characteristics

Water in sanitation systems can originate from various sources within households: toilet flushing, bathing, wash water, kitchen sinks and so on. Depending on the country, type of toilet, culture and habit, different flows are to be expected. Additionally, there is stormwater, which may infiltrate into sanitation systems and influence the flow rates. In this study, only flush water is considered as entering the system.

Treatment process

In most treatment technologies considered in this study, there is little change in the amount of water flow. Some is retained when solid and liquid phase are separated. The biggest losses of water are due to evapotranspiration and infiltration.

Determination of transfer coefficients for water

Little data was found on the pathway of water in sanitation technologies, most likely because as mentioned before, there is almost no change in quantity. If technologies are open to the atmosphere, evaporation may occur. Infiltration into soil due to leakages is another pathway, but is not well documented. Consequently, a lot of TC used in this study are based on expert judgement.

4.6 Definitions of sanitation products

The definitions given here are based on those given in the *Compendium of Sanitation Systems and Technologies* (Tilley et al. 2014). Some are more refined, and some (denoted with a *) were added to increase process precision or if the technologies that produce them are not included in the Compendium.

Aurin*	The product of a series of urine treatment processes. A highly concentrated nutrient solution that compares well to commercial liquid fertilisers in terms of nutrient concentrations (Etter et al. 2015).
Biogas	The common name for the mixture of gases released from anaerobic digestion. Biogas is comprised of methane (50 to 75%), carbon dioxide (25 to 50%) and varying quantities of nitrogen, hydrogen sulphide, water vapour and other components. Biogas can be collected and burned for fuel (like propane).
Blackwater	The mixture of urine, faeces and flushwater along with anal cleansing water (if water is used for cleansing) and/or dry cleansing materials. Blackwater contains the pathogens of faeces and the nutrients of urine that are diluted in the flushwater.
Briquettes*	The product of a process developed by Sanivation in Naivasha, Kenia. Consisting of a mixture of dried, ground faecal matter and coal-dust, the briquettes are round and black in colour. They burn longer than normal charcoal and produce less smoke (Jones 2017).
Compost	Decomposed organic matter that results from a controlled aerobic degradation process. In this biological process, microorganisms (mainly bacteria and fungi) decompose the biodegradable waste components and produce an earth-like, odourless, brown/black material. Compost has excellent soil-conditioning properties and a variable nutrient content. Because of leaching and volatilisation, some of the nutrients may be lost, but the material is still rich in nutrients and organic matter. Generally, excreta or sludge should be composted long enough (2 to 4 months) under thermophilic conditions (55 to 60 °C) in order to be sanitised sufficiently for safe agricultural use. This temperature is not guaranteed in most composting chambers, but considerable pathogen reduction can normally be achieved.
Dried faeces	Faeces that have been dehydrated until they become a dry, crumbly material. Dehydration takes place by storing faeces in a dry environment with good ventilation, high temperatures and/or the presence of absorbent material. Very little degradation occurs during dehydration and this means that the dried faeces are still rich in organic matter. However, the faeces reduce by around 75% in volume during dehydration and most pathogens die off. There is a small risk that some pathogenic organisms can be reactivated under the right conditions, particularly, in humid environments.

Effluent	The general term for a liquid that leaves a technology, typically after blackwater, sludge or urine has undergone solids separation or some other type of treatment. Effluent originates at either collection and storage or a (semi-) centralised treatment technology. Depending on the type of treatment, the effluent may be completely sanitised or may require further treatment before it can be used or disposed of.
Excreta	Excreta consists of urine and faeces that is not mixed with any flushwater. Excreta is small in volume, but concentrated in both nutrients and pathogens. Depending on the quality of the faeces, it has a soft or runny consistency.
Faeces	The (semi-solid) human excrement, not mixed with urine or water. Depending on diet, each person produces approximately 50 L per year of faecal matter. Fresh faeces contain about 80% water. Of the total nutrients excreted, faeces contain about 12% N, 39% P, 26% K and have 107 to 109 faecal coliforms in 100 mL.
Greywater	Water generated from washing food, clothes and dishes, as well as from bathing, but not from toilets. It may contain traces of excreta (e.g., from washing diapers) and, therefore, also pathogens. Greywater accounts for approximately 65% of the wastewater produced in households with flush toilets.
Organics	Biodegradable plant material (general organic waste) that can be added to some technologies. Organic degradable material can include, but is not limited to, leaves, grass and market waste. Although other products contain organic matter, the term organics here refers to undigested plant material.
Pellets*	The product of the LaDePa (Latrine Dehydration and Pasteurization) machine, is brown in colour and brittle. They are produced from faecal sludge and have a similar nutrient content to manure and compost, and similar calorific value to wood. As such they have suitable characteristics for reuse in agriculture and as a biofuel (Septien et al. 2018).
Pit humus	A nutrient rich, hygienically improved, humic material that is generated in double pit technologies (e.g. a twin-pit) through dewatering and degradation. This earth-like product is also referred to as *EcoHumus*, a term conceived by Peter Morgan in Zimbabwe. The various natural decomposition processes taking place in alternating pits can be both aerobic and anaerobic in nature, depending on the technology and operating conditions. The main difference between pit humus and compost is that the degradation processes are passive and are not subjected to a controlled oxygen supply, C:N ratio, humidity and temperature. Therefore, the rate of pathogen reduction is generally slower and the quality of the product, including its nutrient and organic matter content, can vary considerably. Pit humus can look very similar to compost and have good soil conditioning properties, although pathogens may still be present.
Processed sludge*	Sludge that was further processed in drying beds, SBRs, biogas reactors.
Secondary effluent*	Effluent that has undergone treatment for stabilisation and is expected to have a better quality, than for example, septic tank effluent. Examples are aurin production, WSP and HSSFCW.

Sludge	A mixture of solids and liquids, containing mostly excreta and water, in combination with sand, grit, metals, trash and/or various chemical compounds. A distinction can be made between faecal sludge and wastewater sludge. Faecal sludge comes from onsite sanitation technologies, i.e., it has not been transported through a sewer. It can be raw or partially digested, a slurry or semisolid, and results from the collection and storage/treatment of excreta or blackwater, with or without greywater. Wastewater sludge (also referred to as sewage sludge) is sludge that originates from sewer-based wastewater collection and (semi-)centralized treatment processes. The sludge composition will determine the type of treatment required.
Stabilized urine*	Urine that was kept in a urine bank and has been hydrolysed naturally over time, i.e., the urea has been converted by enzymes into ammonia and bicarbonate. Stabilized urine has a pH of approximately 9. Most pathogens cannot survive at this pH. After 6 months of storage, the risk of pathogen transmission is considerably reduced. (In compendium regarded as “Stored Urine”)
Stored faeces*	Faeces that were collected in a faeces storage chamber to be collected and transported to a treatment facility.
Stored urine*	Urine that was collected in a urine storage tank to be collected and transported to a treatment facility.
Stormwater	Rainfall runoff collected from roofs, roads, and other surfaces before flowing towards low-lying land. It is the portion of rainfall that does not infiltrate into the soil.
Transported … *	For offsite treatment facilities, sanitation products require prior conveyance. The differentiation between transported and not transported products is made to ensure a correct assembly of technologies by the sanitation system builder; for more information refer to Spuhler et al. (2018).
Urine	The liquid produced by the body to rid itself of urea and other waste products. In this context, the Urine product refers to pure Urine that is not mixed with faeces or water. Depending on diet, human urine collected from one person during one year (approx. 300 to 550 L) contains 2 to 4 kg of nitrogen. With the exception of some rare cases, urine is sterile when it leaves the body.

5 Fact sheets

5.1 Structure Overview

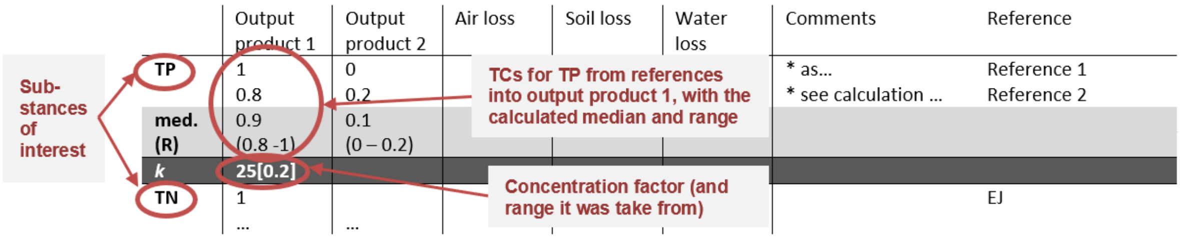
Definition:	Short explanation of the technology as understood in this study
FG:	Functional Group (see chapter "2. Terminology"): user interface (U), collection and storage/treatment (S), conveyance (C), (semi-)centralized treatment (T), use and/or disposal (D)
Products:	In- and output products of the technologies; for an overview of all products and more information see chapter "Definitions of sanitation products"
Relations:	Describes the relation between the input and between the output products: 'OR': any possible combination 'XOR': a mutual exclusion 'AND': a compulsory co-existence For technologies in the FG C (conveyance): the order of output products separated by "**>**" indicates which output product is most/more dominant in case different products get mixed during conveyance. For example if blackwater AND greywater enter a conventional sewer, the output product will be considered to be transported blackwater (as blackwater > greywater).

Appropriateness attributes

	Attribute	Function	Value	Comment
5	**Frequency of O&M**	dtriangle	a=0, b=2, c=1	
…	**…**	…	…	

Lists the appropriateness attributes, the used function, its values and comments. For an overview and explanation of the attributes and the functions, see chapter 3 "Technology appropriateness assessment". Attributes marked with a * were not considered in the case presented in (Spuhler et al. 2020).

Transfer coefficients



Abbreviations:	TP:	Total Phosphorus
	TN:	Total Nitrogen
	H2O:	Water
	TS:	Total Solids
	med.:	Median
	(R):	Range
	bal.:	balanced Results
	k : ... []	concentration factor [Range it was taken from]
	EJ:	Expert Judgement
	Comment: *as...	Chemical form in which the substance was described in the reference

Calculations

The TCs were calculated using equation (1).

$$TC_{i,s} = \frac{out_{i,s}}{\sum_{j=1}^{n} in_{j,s}} , \qquad (1)$$

Where:

out = mass in output product *i*

in = mas in input product *j*

s = substance of interest

U1. Cistern flush toilet

Definition: The flush toilet consists of a water tank that supplies the water for flushing the excreta and a bowl into which the excreta are deposited (Tilley et al. 2014).
FG: User interface (U)
Products: -> blackwater
Relations: Input: NA
Output: NA

Appropriateness

	Attribute	Function	Value	Comment
1	**Water supply**	pcat	a=1, b=0.5, c=0 , d=0	
5	**Frequency of O&M**	dtriangle	a=0, b=2, c=1	
6	**Temperature range**	prange	lower=-5, upper=50	
14	**Construction skills**	dtriangle	a=1, b=3, c=2	
15	**Design skills**	dtriangle	a=2, b=4, c=3	
16	**Operation and maintenance skills**	dtriangle	a=1, b=3, c=2	
17	**Management**	pcat	household=1, shared=0.7, public=0.5	
21	**Spare parts supply**	dcat	low tech=0.5, technical parts=0.5 , specially manufactured=0	

Transfer coefficients

	Blackwater	Air loss	Soil loss	Water loss	Comments	Reference
TP	1					EJ
med.	1.00					
k	**100 [EJ]**					
TN	1					EJ
med.	1.00					
k	**100 [EJ]**					
H2O	1					EJ
med.	1.00					
k	**100 [EJ]**					
TS	1					EJ
med.	1.00					
k	**100 [EJ]**					

U2. Pour flush toilet

Definition: The flush toilet consists of a bowl into which the excreta are deposited. Water for flushing is poured in by the user (Tilley et al. 2014).
FG: user interface (U)
Products: -> blackwater
Relations: Input: NA
Output: NA

Appropriateness

	Attribute	Function	Value	Comment
1	**Water supply**	pcat	a=1, b=0.5, c=0.5 , d=0	
3*	**Water supply disruption**	ptriangle	a=0, b=0, c=24	
5	**Frequency of O&M**	dtriangle	a=0, b=2, c=1	
6	**Temperature range**	prange	lower=-5, upper=50	
14	**Construction skills**	dtriangle	a=1, b=3, c=2	
15	**Design skills**	dtriangle	a=2, b=4, c=3	
16	**Operation and maintenance skills**	dtriangle	a=1, b=3, c=2	
17	**Management**	pcat	household=1, shared=0.7, public=0.5	
20*	**Concrete supply**	pcat	easy=1, medium=1, hard=0.5	
21	**Spare parts supply**	dcat	low tech=0.5, technical parts=0.5, specially manufactured=0	
22*	**Surface area**	prange	lower=1, upper=10000	
25*	**User awareness requirements (misuse)**	ptrapez	a=1, b=1, c=3, d=5	
26*	**Cleansing method**	pcat	water=1, soft=1	
27*	**Odour**	dtriangle	a=1, b=3, c=5	

Transfer coefficients

	Blackwater	Air loss	Soil loss	Water loss	Comments	Reference
TP	1					EJ
med.	1.00					
k	**100 [EJ]**					
TN	1					EJ
med.	1.00					
k	**100 [EJ]**					
H2O	1					EJ
med.	1.00					
k	**100 [EJ]**					
TS	1					EJ
med.	1.00					
k	**100 [EJ]**					

U3. Dry toilet

Definition: A dry toilet operates without flush water, the excreta falls through a drophole. Different user interfaces include raised pedestal on which the user can sit, or a squat pan (Tilley et al. 2014).

FG: user interface (U)

Products: -> excreta

Relations: Input: NA
Output: NA

Appropriateness

	Attribute	Function	Value	Comment
5	**Frequency of O&M**	dtriangle	a=0, b=2, c=1	
6	**Temperature range**	prange	lower=-10, upper=50	
14	**Construction skills**	dtriangle	a=1, b=3, c=2	
15	**Design skills**	dtriangle	a=2, b=4, c=3	
16	**Operation and maintenance skills**	dtriangle	a=1, b=3, c=2	
17	**Management**	pcat	household=1, shared=0.7, public=0.5	
20*	**Concrete supply**	pcat	easy=1, medium=1, hard=0.5	
21	**Spare parts supply**	dcat	low tech=0.5, technical parts=0.5, specially manufactured=0	
22*	**Surface area**	prange	lower=1, upper=10000	
25*	**User awareness requirements (misuse)**	ptrapez	a=1, b=1, c=4, d=5	
26*	**Cleansing method**	pcat	water=1, soft=1	
27*	**Odour**	dtriangle	a=2, b=3, c=5	

Transfer coefficients

	Excreta	Air loss	Soil loss	Water loss	Comments	Reference
TP	1					EJ
med.	1.00					
k	**100 [EJ]**					
TN	0.99	0.01				EJ
med.	0.99	0.01				
k	**25 [EJ]**					
H2O	1					EJ
med.	1.00					
k	**100 [EJ]**					
TS	1					EJ
med.	1.00					
k	**100 [EJ]**					

U4. Urine-diverting dry toilet (UDDT)

Definition: A urine-diverting dry toilet (UDDT) is a toilet that operates without water and has a divider so that the user, with little effort, can divert the urine away from the faeces (Tilley et al. 2014).

FG: user interface (U)

Products: -> urine, faeces

Relations: Input: NA
Output: AND

Appropriateness attributes

	Attribute	Function	Value	Comment
5	**Frequency of O&M**	dtriangle	a=0, b=2, c=1	
6	**Temperature range**	prange	lower=-10, upper=50	
14	**Construction skills**	dtriangle	a=2, b=4, c=3	
15	**Design skills**	dtriangle	a=2, b=4, c=3	
16	**Operation and maintenance skills**	dtriangle	a=1, b=3, c=2	
17	**Management**	pcat	household=1, shared=0.7, public=0.5	
20*	**Concrete supply**	pcat	easy=1, medium=1, hard=0.5	
21	**Spare parts supply**	dcat	low tech=0.5, technical parts=0.5, specially manufactured=0	
22*	**Surface area**	prange	lower=1, upper=10000	
23*	**User awareness requirements (misuse)**	ptrapez	a=1, b=1, c=2, d=5	
24*	**Cleansing method**	pcat	water=1, soft=1	
25*	**Odour**	dtriangle	a=2, b=3, c=5	

Transfer coefficients

	Urine	Faeces	Air loss	Soil loss	Water loss	Comments	Reference
TP	0.61	0.39				* as P	(Eawag 2014)
	0.68	0.32				* see calculation 1	(Kirchmann and Pettersson 1995)
	0.5	0.5				* as P	(Conradin et al. 2010)
	0.62	0.38				* as P	(Schouw et al. 2002)
med. (R)	0.61 (0.5 - 0.7)	0.39 (0.3- 0.5)					
k	**25 [0.2]**						
TN	0.88	0.12				* as N	(Eawag 2014)
	0.85	0.15				* see calculation 1	(Kirchmann and Pettersson 1995)
	0.8	0.2				* as N	(Conradin et al. 2010)
	0.87	0.13				* as N	(Schouw et al. 2002)
med. (R)	0.86 (0.8 - 0.9)	0.14 (0.1 - 0.2)					
k	**100 [0.1]**						
H2O	0.86	0.14				* see calculation 2	(Rose et al. 2015)
	0.93	0.07				* see calculation 3	(Vinnerås et al. 2006)
med. (R)	0.90 (0.86-0.93)	0.1 (0.07 - 0.14)					
k	**100 [0.07]**						
TS	0.61	0.39				* see calculation 2	(Rose et al. 2015)
	0.66	0.34				* see calculation 3	(Vinnerås et al. 2006)
med. (R)	0.64 (0.61-0.66)	0.36 (0.34-0.39)					
k	**100 [0.05]**						

Calculations

1.

	N [kg/P*a]		P[kg/P*a]		TN	TP
	med.	**Range**	**med.**	**Range**		
Urine	3.4	2.5 - 4.3	0.85	0.7 - 1.0	0.85	0.68
Faeces	0.6	0.5-0.7	0.4	0.3 - 0.5	0.15	0.32
	Data from: (Kirchmann and Pettersson 1995)				Calculation: *Input*= Urine+Faeces , *output*= Urine or Faeces	

2.

	Wet weight [g/cap*d]	Dry weight [g/cap*d]	Water content [g]	Water content %	H2O	TS	Comments
Faeces	250	38	212	0.85	0.14	0.39	*For low income countries; in high income countries values are about half
Urine	1400	59	1341	0.96	0.86	0.61	* "total urine solids" are used for dry weight
Total		97	1553				
	Data from: (Rose et al. 2015)				Calculation: *m*= Water content [g] *input*= Total	*m*= dry weight [g/cap*d] *Input*= Total	

3.

	Wet weight [kg/cap*a]	Dry weight [kg/cap*a]	Water content [kg/cap*a]	Water content %	H2O	TS
Faeces	51	11	40	0.78	0.07	0.34
Urine	550	21	529	0.96	0.93	0.66
Total		32	569			
	Data from: (Vinnerås et al. 2006)				Calculation: *m*= Water content [g] *input*= Total	*m*= dry weight [g/cap*d] *Input*= Total

S1. Urine storage tank

Definition: Containers for primary onsite urine storage, that are then either moved or emptied into other containers for transport (Tilley et al. 2014).
FG: collection and storage/treatment (S)
Products: urine -> stored urine
Relations: Input: NA
Output: NA

Appropriateness

	Attribute	Function	Value	Comment
5	**Frequency of O&M**	drange	lower=0, upper=1	
6	**Temperature range**	ptrapez	a=2, b=20, c=50, d=50	
8	**Vehicular access**	ptrapez	a=1, b=3, c=100, d=100	
14	**Construction skills**	dtriangle	a=1, b=3, c=2	
15	**Design skills**	dtriangle	a=1, b=3, c=2	
16	**Operation and maintenance skills**	dtriangle	a=1, b=3, c=2	
17	**Management**	pcat	household=1, shared=1, public=1	
20*	**Concrete supply**	pcat	easy=1, medium=1, hard=0.5	
21	**Spare parts supply**	dcat	low tech=1, technical parts=0, specially manufactured=0	
22*	**Surface area**	ptrapez	a=1, b=2, c=10000, d=10000	
25*	**User awareness requirements (misuse)**	ptrapez	a=1, b=1, c=3, d=5	
27*	**Odour**	dtriangle	a=0, b=3, c=5	

Transfer coefficients

	Stored urine	Air loss	Soil loss	Water loss	Comments	Reference
TP	1				* 28% of P settle in storage, see considerations	(Etter et al. 2011)
	1				* 20% of P settle in storage, see considerations	(Maurer et al. 2006)
med.	1.00					
k	**100 [0]**					
TN	0.98	0.02			* 10% of N precipitate/volatize in storage	(Etter et al. 2011)
	0.99	0.01			* 1% of N precipitates/volatizes in storage	(Maurer et al. 2006)
	0.98	0.02			* “volatilization is marginal”	(Udert et al. 2006)
med. (R)	0.98 (0.98-0.99)	0.02				
k	**100 [0,01]**					
H2O	0.98	0.02				(Maurer et al. 2006)
med.	0.98	0.02				
k	**100 [0]**					
TS	1				*2% of TS settle in storage, see considerations	(Maurer et al. 2006)
med.	1					
k	**100 [0]**					

Considerations for TCs

In theory, precipitation of struvite occurs in primary urine storage, however it can be assumed. that the precipitated struvite is not collected as a rule. The reported TCs for struvite are therefore neglected and included in the TCs for stabilized urine.

S2. Dehydration vault

Definition: Dehydration vaults are used with UDDTs to collect, store and dehydrate the separated faeces. Faeces will only dehydrate when the vaults are well ventilated, watertight to prevent external moisture from entering (Tilley et al. 2014).

FG: collection and storage/treatment (S)

Products: faeces -> dried faeces

Relations: Input: NA
Output: NA

Appropriateness

	Attribute	Function	Value	Comment
5	**Frequency of O&M**	drange	lower=0, upper=1	
6	**Temperature range**	ptrapez	a=2, b=20, c=50, d=50	
7	**Flooding**	ptrapez	a=0, b=0, c=3, d=30	
8	**Vehicular access**	ptrapez	a=1, b=3, c=100, d=100	
14	**Construction skills**	dtriangle	a=1, b=3, c=2	
15	**Design skills**	dtriangle	a=2, b=4, c=3	
16	**Operation and maintenance skills**	dtriangle	a=1, b=3, c=2	
17	**Management**	pcat	household=1, shared=1, public=0.5	
20*	**Concrete supply**	pcat	easy=1, medium=1, hard=0.5	
21	**Spare parts supply**	dcat	low tech=1, technical parts=0, specially manufactured=0	
22*	**Surface area**	ptrapez	a=1, b=2, c=10000, d=10000	
27*	**Odour**	dtriangle	a=0, b=3, c=5	

Transfer coefficients

	Dried faeces	Air loss	Soil loss	Water loss	Comments	Reference
TP	1				* as P	(Jönsson et al. 2004)
med.	1.00					
k	**100 [0]**					
TN	0.5	0.5			* as N	(Jönsson et al. 2004)
med.	0.50	0.50				
k	**25 [EJ]**					
H2O	0.2 0.25	0.8 0.75				(Esrey et al. 1998) (Rieck et al. 2011)
med. (R)	0.23 (0.2-0.25)	0.77				
k	**100 [0.05]**					
TS	0.85	0.15			*Organic matter containment: 70% (assumption for TS= 85%)	(Regmi 2005)
med.	0.85	0.15				
k	**5 [EJ]**					

S3. Faeces storage chamber

Definition: A faeces storage chamber is a container with little air circulation but potential leaching where faeces are stored for further treatment. An example is buckets lined with plastic bags and placed under UDDTs.

FG: collection and storage/treatment (S)

Products: faeces -> stored faeces

Relations: Input: NA
Output: NA

Appropriateness

	Attribute	Function	Value	Comment
5	**Frequency of O&M**	drange	lower=0, upper=1	
6	**Temperature range**	ptrapez	a=2, b=20, c=50, d=50	
7	**Flooding**	ptrapez	a=0, b=0, c=3, d=30	
8	**Vehicular access**	ptrapez	a=1, b=3, c=100, d=100	
14	**Construction skills**	dtriangle	a=1, b=3, c=2	
15	**Design skills**	dtriangle	a=2, b=4, c=3	
16	**O&M skills**	dtriangle	a=1, b=3, c=2	
17	**Management**	pcat	household=1, shared=1, public=0.5	
21	**Spare parts supply**	dcat	low tech=1, technical parts=0, specially manufactured=0	

Transfer coefficients

	Stored Faeces	Air loss	Soil loss	Water loss	Comments	Reference
TP	1				* Nutrients besides N are contained	(Jönsson et al. 2004)
med.	1.00					
k	**25 [EJ]**					
TN	0.8	0.2			* at constant air moisture, loss of N is low	(Jönsson et al. 2004)
med.	0.80	0.20				
k	**5 [EJ]**					
H2O	0.7	0.3				
med.	0.7	0.3				
k	**5 [EJ]**					
TS	0.9	0.1			*Assumption: similar to dehydration vault	(Regmi 2005)
med.	0.9	0.1				
k	**5 [EJ]**					

S4. Single pit

Definition: Excreta, along with anal cleansing materials (water or solids) are deposited into a pit for storage. Urine and water percolate into the soil through the bottom of the pit and wall, while microbial action degrades part of the organic fraction. Lining the pit prevents it from collapsing and provides support to the superstructure (Tilley et al. 2014).

FG: collection and storage/treatment (S)

Products: faeces, excreta, blackwater -> sludge

Relations: Input: OR
Output: NA

Appropriateness

No.	Attribute name	Function	Value	Comment
5	**Frequency of O&M**	drange	lower=0, upper=1	
6	**Temperature range**	ptrapez	a=10, b=20, c=50, d=50	
7	**Flooding**	ptrapez	a=0, b=0,c=6, d=60	
8	**Vehicular access**	ptrapez	a=1, b=3, c=100, d=100	
10	**Soil type/ hydraulic conductivity**	pcat	clay=0.5, silt=1, sand=1, gravel=0.5	
11	**Ground-water depth**	ptrapez	a=4, b=8, c=100, d=100	
12	**Excavation**	pcat	easy=1, hard=0.5	
14	**Construction skills**	dtriangle	a=1, b=3, c=2	
15	**Design skills**	dtriangle	a=2, b=4, c=3	
16	**O&M skills**	dtriangle	a=1, b=3, c=2	
17	**Management**	pcat	household=1, shared=1, public=0	
21	**Spare parts supply**	dcat	low tech=1, technical parts=0 , specially manufactured=0	
22*	**Surface area**	ptrapez	a=1, b=2, c=10000, d=10000	
27*	**Odour**	dtriangle	a=3, b=4, c=5	

Transfer coefficients

	Sludge	Air loss	Soil loss	Water loss	Comments	Reference
TP	0.29 (0,18 - 0,4)	0	0.71 (0.6 - 0.82)		* as P	(Montangero and Belevi 2007)
med. (R)	0.29 (0.18 - 0.4)	0	0.71			
k	**5 [0.22]**					
TN	0.18 (0.09-0.27) 0.18 (0.15 - 0.2) 0.2	0 0.55 (0.3 - 0.8) 0.6	0.82 (0.73 - 0.91) 0.27 (0.01 -0.5) 0.2 (0.02 – 0.2)		* as N * as N * TC Soil loss: N reaching the groundwater	(Montangero and Belevi 2007) (Jacks et al. 1999) (Nyenje et al. 2013)
med. (R)	0.18 (0.09-0.27)	0.55 (0 - 0.8)	0.27 (0.01 - 0.91)			
k	**0.5 [0.9]**					
H2O	0.15 (0.05 - 0.25)	0.15	0.7		*high variability depending on soil permeability	EJ
med. (R)	0.15 (0.05 - 0.25)	0.15	0.70			
k	**5 [0.2]**					
TS	0.6 (0.5 - 0.7)	0	0.4		*TSS retainment range: 0.7-0.9 (Assumption for TS: 0.5 - 0.7)	(Montangero and Belevi 2007)
med. (R)	0.60 (0.5 - 0.7)	0.00	0.40			
k	**5 [0.2]**					

S5. Twin pit

Definition: Two alternatingly used pits that are connected to a pour flush toilet. The water slowly infiltrates into the surrounding soil of the active pit while in the resting pit the remains transform into a partially sanitized, soil-like material that can be manually excavated (Tilley et al. 2014).

FG: collection and storage/treatment (S)

Products: blackwater -> pit humus

Relations: Input: OR
Output: NA

Appropriateness

No.	Attribute name	Function	Value	Comment
5	**Frequency of O&M**	drange	lower=1, upper=4	
6	**Temperature range**	ptrapez	a=10, b=20, c=50, d=50	
7	**Flooding**	ptrapez	a=0, b=0, c=6, d=30	
8	**Vehicular access**	ptrapez	a=1, b=3, c=100, d=100	
9	**Slope**	ptrapez	a=0, b=0, c=70, d=100	
10	**Soil type/ hydraulic conductivity**	pcat	clay=0, silt=0.5, sand=1, gravel=1	
11	**Ground-water depth**	ptrapez	a=3.5, b=6, c=100, d=100	
12	**Excavation**	pcat	easy=1, hard=0.5	
14	**Construction skills**	dtriangle	a=1, b=3, c=2	
15	**Design skills**	dtriangle	a=3, b=5, c=4	
16	**O&M skills**	dtriangle	a=2, b=4, c=3	
17	**Management**	pcat	household=1, shared=1, public=0	
21	**Spare parts supply**	dcat	low tech=1, technical parts=0 , specially manufactured=0	

Transfer coefficients

	Pit Humus	Air loss	Soil loss	Water loss	Comments	Reference
TP	0.8		0.2			EJ
med.	0.80		0.20			
k	**5**					
TN	0.6	0.1	0.3			EJ
med.	0.60	0.10	0.30			
k	**5**					
H2O	0.05	0.1	0.85			EJ
med.	0.05	0.10	0.85			
k	**5**					
TS	0.85	0.05	0.1			EJ
med.	0.85	0.05	0.10			
k	**5**					

Underlying considerations

In alternating pits decomposition processes can be anaerobic as well as aerobic, depending on technology, operating conditions and resting time for excreta. Consequently, the quality of the product, including its nutrient and organic matter content, can vary considerably (Conradin et al. 2010). This is reflected by low concentration factors corresponding to a big range.

S6. Composting chamber

Definition: A composting chamber is designed to convert excreta and organics into compost, through biological decomposition by microorganisms (mainly bacteria and fungi) under aerobic conditions (Tilley et al. 2014).

FG: collection and storage/treatment (S)

Products: faeces, excreta, organics -> compost, effluent

Relations: Input: OR

Output: AND

Appropriateness

No.	Attribute name	Function	Value	Comment
5	**Frequency of O&M**	drange	lower=0, upper=2	
6	**Temperature range**	ptrapez	a=10, b=20, c=50, d=50	
7	**Flooding**	ptrapez	a=0, b=0, c=3, d=30	
8	**Vehicular access**	ptrapez	a=1, b=3, c=100, d=100	
14	**Construction skills**	dtriangle	a=1, b=3, c=2	
15	**Design skills**	dtriangle	a=2, b=4, c=3	
16	**O&M skills**	dtriangle	a=2, b=4, c=3	
17	**Management**	pcat	household=1, shared=1,public=0.5	
20*	**Concrete supply**	pcat	easy=1, medium=1, hard=0.5	
21	**Spare parts supply**	dcat	low tech=1, technical parts=0 , specially manufactured=0	
22*	**Surface area**	ptrapez	a=1.5, b=3, c=10000, d=10000	
26*	**Cleansing method**	pcat	water=0, soft=1	
27*	**Odour**	dtriangle	a=2, b=3, c=5	

Transfer coefficients

	Compost	Effluent	Air loss	Soil loss	Water loss	Comments	Reference
TP	0.95	0.05				* as P	(Jönsson et al. 2004)
	1	0				* see calculations in 1.	(Yadav et al. 2012)
	0.99	0.01				* as P	(Meinzinger 2010)
med. (R)	0.99 (0.95 -1)	0.01					
k	**100 [0.05]**						
TN	0.7 (0,5-0,9)		0.3			* as N	(Jönsson et al. 2004)
	0.67		0.33			* see calculations in 1.	(Yadav et al. 2012)
	0.65		0.35			* as N	(Meinzinger 2010)
	0.3		0.7			* max N losses through volatilization	(Heinonen-Tanski and van Wijk-Sijbesma 2005)
		0.05					EJ
med. (R)	0.66 (0.3-0.9)	0.05	0.34				
bal.	0.63	0.05	0.32				
k	**2 [0.6]**						
H_2O	0.65 (0.59 - 0.7)		0.35			* moisture content should be 50- 60%, see calculations in 2.	(Esrey et al. 1998)
	0.54		0.46			*faecal slurry, see calculations in 1.	(Yadav et al. 2012)
	0.7		0.3			*moisture content should be 60%, see calculation in 2.	(Zavala and Funamizu 2005)
		0.05					EJ
med. (R)	0.65 (0.54-0.7)	0.05	0.35				
bal.	0.63	0.05	0.32				
k	**25 [0.16]**						
TS	0.33 (0.1- 0.6)	0.05	0.62			*reduction is achieved by organic matter consumption by bacteria	(Zavala and Funamizu 2005)
med. (R)	0.33 (0.1 -0.6)	0.05	0.62				
k	**2**						

Calculations

1.

	Faecal Slurry	**Bulking material***	**Compost**	**TC compost from slurry**
Moisture %	92	45	50	0.54
TN [mg/g dry weight]	42	20	28	0.67
P as P_2O_5 [mg/g dry weight]	12	11	14	1.17
	Data from (Yadav et al. 2012) * The bulking material is an optional additive and ignored here.			Calculation: *Input:* Slurry *Output:* Compost

	Moisture Content	
Faeces	85%	(Rose et al. 2015)

Compost	60%	(Zavala and Funamizu 2005)
TC Water	0.7	Calculation: H2O to compost = Moisture content Compost / Moisture Content Faeces

2.

S7. Vermi-composting

Definition: Vermicomposting refers to on-site faecal matter treatment, for example from biofil toilets (Amoah et al. 2016) or urine diverting vermicomposting toilets (UDVT) (Lalander et al. 2013). Both microorganisms and macro-invertebrates such as earthworms and cockroaches are used to process waste into a stable, homogeneous material. The earthworms ingest, grind and digest organic matter with the help of aerobic and anaerobic microflora in their gut, and convert it into a much finer, humified, microbially active material (Gupta and Garg 2008).

FG: collection and storage/treatment (S)

Products: faeces, excreta, blackwater, organics -> compost, effluent

Relations: Input: OR
Output: NA

Appropriateness

No.	Attribute name	Function	Value	Comment
5	**Frequency of O&M**	drange	lower=0, upper=2	
6	**Temperature range**	ptriangle	a=10, b=30, c=20	
7	**Flooding**	ptrapez	a=0, b=0, c=6, d=60	
8	**Vehicular access**	ptrapez	a=1, b=3, c=100, d=100	
14	**Construction skills**	dtriangle	a=1, b=3, c=2	
15	**Design skills**	dtriangle	a=2, b=4, c=3	
16	**O&M skills**	dtriangle	a=2, b=4, c=3	
17	**Management**	pcat	household=1, shared=1, public=0.5	
20*	**Concrete supply**	pcat	easy=1, medium=1, hard=0.5	
21	**Spare parts supply**	dcat	low tech=1, technical parts=0 , specially manufactured=0	
22*	**Surface area**	ptrapez	a=1.5, b=3, c=10000, d=10000	
26*	**Cleansing method**	pcat	water=0, soft=1	
27*	**Odour**	dtriangle	a=2, b=3, c=5	

Transfer coefficients

	Compost	Effluent	Air loss	Soil loss	Water loss	Comments	Reference
TP	1					* see calculations in 2	(Yadav et al. 2010)
	1					* includes prior composting, see calculations in 1	(Yadav et al. 2012)
	1					* increase of TP content	(Hait and Tare 2011)
med.	1.00						
k	**100**						
TN	0.68		0.32			* see calculations in 2	(Yadav et al. 2010)
	0.64		0.36			* as TN	(Benitez et al. 1999)
	0.5		0.5			* includes prior composting, see calculations in 1	(Yadav et al. 2012)
	1.00		0			* increase of TN content	(Hait and Tare 2011)
	1.00		0			* increase of TN content	(Gupta and Garg 2008)
med. (R)	0.68 (0.5-1)		0.32				
k	**2 [0.5]**						
H2O	0.49		0.51			* includes prior composting, see calculations in 1	(Yadav et al. 2012)
	0.53		0.47			* see calculations in 2	(Yadav et al. 2010)
	0.7		0.3			* moisture is contained at 70%	(Gupta and Garg 2008)
med. (R)	0.53 (0.49-0.7)		0.47				
k	**5 [0.21]**						
TS	0.5		0.5			* see calculations in 2	(Yadav et al. 2010)
	0.541		0.459			* Manure	(Lalander et al. 2015)
med. (R)	0.52 (0.5 - 0.54)		0.48				
k	**100 [0.04]**						

Calculations

1.

	Faecal Slurry	Bulking Mat	Compost	Vermi-compost	TC vermicompost from slurry
Moisture %	92%	45%	50%	45%	0.49
VS [mg/g dry weight)	780	220	527	340.00	0.44
TN [mg/g dry weight]	42	20	28	21.00	0.50
P as P2O5 [mg/g dry weight]	12	11	14	21.00	1.75
	Data from: (Yadav et al. 2012)				Calculation: *Input* = slurry *Output*= vermicompost

2.

	Faeces	Vermi-compost	TC Vermicompost
Moisture %	80 %	43 %	0.5375
TN [mg/g dry weight]	0.41	0.28	0.682926829
P as P2O5 [mg/g dry weight]	0.11	0.235	2.136363636
	Data from: (Yadav et al. 2010)		Calculation: *Input*= slurry *Output*= vermicompost

S8. Septic tank

Definition: A septic tank is a watertight chamber made of concrete, fibreglass, PVC or plastic, through which blackwater and greywater flows for primary treatment. Settling and anaerobic processes reduce solids and organics, but the treatment is only moderate (Tilley et al. 2014).

FG: collection and storage/treatment (S)

Products: blackwater, greywater -> sludge, effluent

Relations: Input: OR
Output: AND

Appropriateness

No.	Attribute name	Function	Value	Comment
5	**Frequency of O&M**	drange	lower=0, upper=1	
6	**Temperature range**	ptrapez	a=-5, b=15, c=50, d=50	
7	**Flooding**	ptrapez	a=0, b=0, c=6, d=60	
8	**Vehicular access**	ptrapez	a=1, b=3, c=100, d=100	
14	**Construction skills**	dtriangle	a=1, b=3, c=2	
15	**Design skills**	dtriangle	a=2, b=4, c=3	
16	**O&M skills**	dtriangle	a=2, b=4, c=3	
17	**Management**	pcat	household=1, shared=1, public=1	
20*	**Concrete supply**	pcat	easy=1, medium=1, hard=0.5	
21	**Spare parts supply**	dcat	low tech=1, technical parts=0 , specially manufactured=0	
22*	**Surface area**	ptrapez	a=1, b=2, c=10000, d=10000	
27*	**Odour**	dtriangle	a=1, b=2, c=3	

Transfer coefficients

	Sludge	Effluent	Air loss	Soil loss	Water loss	Comments	Reference
TP	0.19 (0.11 – 0.27)	0.81 (0.73 – 0.89)				* general P pathways	(Montangero and Belevi 2007)
	0.23	0.77				* general TP removal	(Hamader and Javorszky 2014)
	0.4	0.6				* general TP removal	(Polprasert and Rajput 1982)
	0.1	0.9				* P removal at HRT 24 - 48h	(Siegrist 2017)
	0.256	0.7444				* P removal at HRT 24h	(Nasr and Mikhaeil 2013)
	0.3	0.7				* PO4 at HRT 20h	(Rahman et al. 1999)
	0.6	0.4				* TP removal at HRT 48h	(Wanasen 2003)
	0.269	0.731				* P removal at HRT 48h	(Nasr and Mikhaeil 2013)
	0.33	0.67				* PO4 at HRT 46h	Rahman et al. (1999)
	0.47	0.53				* TP removal at HRT 24h	(Wanasen 2003)
	0.293	0.707				* P removal at HRT 72h	(Nasr and Mikhaeil 2013)
	0.33	0.67				* PO4 at HRT 73h	(Rahman et al. 1999)
	0.65	0.35				* PO4 at HRT 114h	(Rahman et al. 1999)
med. (R)	0.30 (0.1 – 0.65)	0.70 (0.35-0.9)					
k	**2 [0,55]**						
TN	0.095 (0.5 – 0.14)	0.905 (0.86 – 0.95)				* general N pathways	(Montangero and Belevi 2007)
	0.08	0.92				* general TN removal	(Polprasert and Rajput 1982)
	0	1				* N removal at HRT 24 - 48h	(Siegrist 2017)

	0.177	0.823				* TKN removal at HRT 24h, increase of ammonia concentration	(Nasr and Mikhaeil 2013)
	0.16	0.84				* NO3 removal at HRT 20h	(Rahman et al. 1999)
	0.24	0.76				* TKN removal at HRT 24h	(Wanasen 2003)
	0.208	0.792				* TKN removal at HRT 48h, increase of ammonia concentration	(Nasr and Mikhaeil 2013)
	0.2	0.8				* NO3 removal at HRT 46h	(Rahman et al. 1999)
	0.44	0.56				* TKN removal at HRT 48h	(Wanasen 2003)
	0.268	0.732				* TKN removal at HRT 72h, increase of ammonia concentration	(Nasr and Mikhaeil 2013)
	0.35	0.65				* NO3 removal at HRT 67h	(Rahman et al. 1999)
	0.48	0.52				* general TN pathways	(Hamader and Javorszky 2014)
	0.46	0.54				* NO3 removal at HRT 114h	(Rahman et al. 1999)
			0.02 (0.0 - 0.1)				EJ
med. (R)	0.21 (0 – 0.48)	0.79 (0.52 – 1)	0.02				
bal.	0.20	0.78	0.02				
k	**2 [0,48]**						
H2O	0.05 (0.0 -0.1)	0.93 (0.85 - 1.0)	0.02 (0.0 - 0.05)			*EJ based on:	(Howard 2007)
med. (R)	0.05 (0.0 - 0.1)	0.93 (0.85 - 1.0)	0.02 (0.0 - 0.05)				
k	**25 [EJ]**	**[0.15]**					
TS	0.30 (0.25- 0.35)	0.70 (0.65- 0.75)				* TSS removal of 50–70% (~ TS removal 25-35%, estimated with 1.)	(Álvarez et al. 2008)
	0.51	0.49				* Average TSS removal of single& double chamber: 65% (~ TS removal 51%, estimated with 1.)	(Seabloom et al. 2004)
	0.46	0.56				* TS removal	(Polprasert and Rajput 1982)
	0.35 (0.30 – 0.40)	0.65 (0.60-0.70)				* at HRT 24 - 48h; TSS removal 60–80% (TS removal 30-40%, estimated with 1.),	(Siegrist 2017)
	0.33	0.68				* single baffle septic tank; TSS removal at HRT 24h: 65% (~TS 32,5%, estimated with 1.)	(Nasr and Mikhaeil 2014)
	0.25	0.75				* TS removal at HRT 24h	(Nasr and Mikhaeil 2013)
	0.25	0.75				* TSS removal at HRT 20h: 50% (~TS 25%, estimated with 1.)	(Rahman et al. 1999)
	0.24	0.76				* TSS removal of conventional septic tank at HRT 24h: 47% (~TS 24%, estimated with 1.)	(Wanasen 2003)
	0.34	0.66				* single baffle septic tank; TSS removal: 69% (~TS 34%, estimated with 1.)	(Nasr and Mikhaeil 2014)
	0.27	0.73				* TS removal at HRT 48h	(Nasr and Mikhaeil 2013)
	0.18	0.82				* TSS removal at 46h: 36% (~TS 18%, estimated with 1.)	(Rahman et al. 1999)
	0.38	0.62				* TSS removal of conventional septic tank at	(Wanasen 2003)

						HRT 48h: 76% (~TS 38%, estimated with 1.)	
	0.37	0.63				* single baffle septic tank; TSS removal: 73% (~TS 0,37, estimated with 1.)	(Nasr and Mikhaeil 2014)
	0.38	0.62				* TS removal at HRT 72h	(Nasr and Mikhaeil 2013)
	0.35	0.65				* TSS removal at HRT 73h: 70% (~TS 35%, estimated with 1.)	(Rahman et al. 1999)
	0.20	0.80				* TSS removal at HRT 114h: 40% (~TS 20%, estimated with 1.)	(Rahman et al. 1999)
med. (R)	0.33 (0.18 – 0.51)	0.67 (0.49-0.82)					
k	**5 [0.33]**						

Calculations

In most studies on septic tanks the considered parameters are not TS but TSS. TSS are only a fraction of TS. Septic tanks work mainly as primary settlers and consequently especially the suspended solids load of wastewater is reduced by them. To be able to also utilize data from case studies measuring TSS, a ratio was established: between TS and TSS removal. Many of the above used TS TCs were established based on this ratio.

1.

Relationship TS:TSS removal in septic tanks

TS removal	38%	27%	24.60%	46%		
TSS removal	65.30%	58.30%	55%	70%		
Ratio TS:TSS removal	58.19%	46.31%	44.73%	65.71%	**AVERAGE:**	**53.74%**
Reference	(Nasr and Mikhaeil 2013)	(Nasr and Mikhaeil 2013)	(Nasr and Mikhaeil 2013)	(Polprasert and Rajput 1982)		

C1. Motorized transport urine

Definition:	A vehicle equipped with a motorized pump and a storage tank for emptying and transporting urine (Tilley et al. 2014).
FG:	conveyance (C)
Products:	stored urine, stabilized urine
Relations:	Input: OR Output: stored urine > stabilized urine

Appropriateness

No.	Attribute name	Function	Value	Comment
5	**Frequency of O&M**	dtriangle	a=0, b=2, c=1	
6	**Temperature range**	prange	lower=-20, upper=50	
8	**Vehicular access**	prange	lower=3, upper=100	
9	**Slope**	ptrapez	a=0, b=0, c=20, d=35	
16	**O&M skills**	dtriangle	a=2, b=4, c=3	
17	**Management**	pcat	household=0, shared=0.5, public=1	
21	**Spare parts supply**	dcat	low tech=0.5, technical parts=0.5, specially manufactured=0	

Transfer coefficients

	Urine	Air loss	Soil loss	Water loss	Comments	Reference
TP	0.98			0.02		EJ
med.	0.98			0.02		
k	**100 [EJ]**					
TN	0.96	0.02		0.02	* Ammonia volatilization	(Udert et al. 2006)
med.	0.96	0.02		0.02		
k	**100 [EJ]**					
H2O	0.97	0.01		0.02		EJ
med.	0.97	0.01		0.02		
k	**100 [EJ]**					
TS	0.98	0		0.02		EJ
med.	0.98	0.00		0.02		
k	**100 [EJ]**					

C2. Human-powered transport of urine

Definition:	Refers to different ways by which people can manually empty and/or transport urine generated in onsite sanitation facilities (Tilley et al. 2014).
FG:	conveyance (C)
Products:	urine, stored urine, stabilized urine
Relations:	Input: OR Output: urine > stored urine > stabilized urine

Appropriateness

No.	Attribute name	Function	Value	Comment
5	**Frequency of O&M**	dtriangle	a=0, b=2, c=1	
6	**Temperature range**	prange	lower=-20, upper=50	
8	**Vehicular access**	ptrapez	a=0, b=1, c=100, d=100	
9	**Slope**	ptrapez	a=0, b=0, c=50, d=100	
16	**O&M skills**	dtriangle	a=1, b=3, c=2	
17	**Management**	pcat	household=1, shared=1,public=1	
21	**Spare parts supply**	dcat	low tech=1, technical parts=0 , specially manufactured=0	

Transfer coefficients

	Urine	Air loss	Soil loss	Water loss	Comments	Reference
TP	0.98			0.02		EJ
med.	0.98			0.02		
k	**100 [EJ]**					
TN	0.95	0.03		0.02	* Ammonia volatilization	(Udert et al. 2006)
med.	0.95	0.03		0.02		
k	**100 [EJ]**					
H2O	0.97	0.01		0.02		EJ
med.	0.97	0.01		0.02		
k	**100 [EJ]**					
TS	0.98	0		0.02		EJ
med.	0.98	0.00		0.02		
k	**100 [EJ]**					

C3. Motorized transport of dry material

Definition: A vehicle equipped with a motorized pump and a storage tank for emptying and transporting of sanitation products other than urine and blackwater (Tilley et al. 2014).

FG: conveyance (C)

Products: stored faeces, dried faeces, pit humus, compost, organics, sludge, processed sludge

Relations: Input: OR

Output: stored faeces > pit humus > organics > sludge > processed sludge > dried faeces > compost

Appropriateness

No.	Attribute name	Function	Value	Comment
5	**Frequency of O&M**	dtriangle	a=0, b=2, c=1	
6	**Temperature range**	prange	lower=-20, upper=50	
8	**Vehicular access**	prange	power=3, upper=100	
9	**Slope**	ptrapez	a=0, b=0, c=20, d=35	
16	**O&M skills**	dtriangle	a=2, b=4, c=3	
17	**Management**	pcat	household=0, shared=0.5, public=1	
21	**Spare parts supply**	dcat	low tech=0.5, technical parts=0.5 , specially manufactured=0	

Transfer coefficients

	Urine	Air loss	Soil loss	Water loss	Comments	Reference
TP	0.98			0.02		EJ
med.	0.98			0.02		
k	**100 [EJ]**					
TN	0.96	0.02		0.02	* Ammonia volatilization	(Udert et al. 2006)
med.	0.96	0.02		0.02		
k	**100 [EJ]**					
H2O	0.97	0.01		0.02		EJ
med.	0.97	0.01		0.02		
k	**100 [EJ]**					
TS	0.98	0		0.02		EJ
med.	0.98	0.00		0.02		
k	**100 [EJ]**					

C4. Human powered transport of dry material

Definition: Refers to different ways by which people can manually empty and/or transport sanitation products other than urine and blackwater generated in onsite sanitation facilities (Tilley et al. 2014).

FG: conveyance (C)

Products: stored faeces, dried faeces, pit humus, compost, organics, sludge, processed sludge

Relations: Input: OR

Output: stored faeces > pit humus > organics > sludge > processed sludge > dried faeces > compost

Appropriateness

No.	Attribute name	Function	Value	Comment
5	**Frequency of O&M**	dtriangle	a=0, b=2, c=1	
6	**Temperature range**	prange	lower=-20, upper=50	
8	**Vehicular access**	ptrapez	a=0, b=1, c=100, d=100	
9	**Slope**	ptrapez	a=0, b=0, c=50, d=100	
16	**O&M skills**	dtriangle	a=1, b=3, c=2	
17	**Management**	pcat	household=1, shared=1,public=1	
21	**Spare parts supply**	dcat	low tech=1, technical parts=0 , specially manufactured=0	

Transfer coefficients

	Urine	Air loss	Soil loss	Water loss	Comments	Reference
TP	0.98			0.02		EJ
med.	0.98			0.02		
k	**100 [EJ]**					
TN	0.96	0.02		0.02	* Ammonia volatilization	(Udert et al. 2006)
med.	0.96	0.02		0.02		
k	**100 [EJ]**					
H2O	0.97	0.01		0.02		EJ
med.	0.97	0.01		0.02		
k	**100 [EJ]**					
TS	0.98	0		0.02		EJ
med.	0.98	0.00		0.02		
k	**100 [EJ]**					

C5. Conventional sewer

Definition: Conventional gravity sewers are large networks of underground pipes that convey blackwater, greywater and, in many cases, stormwater from individual households to a (semi-) centralized treatment facility, using gravity (and pumps when necessary) (Tilley et al. 2014).
FG: conveyance (C)
Products: blackwater, greywater, effluent, stormwater
Relations: Input: OR
Output: blackwater > greywater > effluent > stormwater

Appropriateness

No.	Attribute name	Function	Value	Comment
5	**Frequency of O&M**	dtriangle	a=0, b=2, c=1	
6	**Temperature range**	prange	lower=-10, upper=50	
7	**Flooding**	ptrapez	a=0, b=0, c=20, d=365	
8	**Vehicular access**	ptrapez	a=1, b=4, c=100, d=100	
9	**Slope**	ptrapez	a=0.5, b=4, c=100, d=100	
11	**Ground-water depth**	ptrapez	a=3, b=7, c=100, d=100	
12	**Excavation**	pcat	easy=1, hard=0.5	
14	**Construction skills**	drange	lower=3, upper=5	
15	**Design skills**	dtriangle	a=4, b=6, c=5	
16	**O&M skills**	drange	lower=3, upper=7	
17	**Management**	pcat	household=0, shared=0, public=1	
18*	**Pipe supply**	drange	lower=7, upper=60	
20*	**Concrete supply**	pcat	easy=1, medium=0.6, hard=0.2	
21	**Spare parts supply**	dcat	low tech=1, technical parts=0 , specially manufactured=0	
23*	**Potential to accommodate for changing water volumes**	prange	lower=-100, upper=200	
27*	**Odour**	dtriangle	a=1, b=1, c=3	

Transfer coefficients

	Blackwater	Air loss	Soil loss	Water loss	Comments	Reference
TP	0.9		0.1		* EJ based on H2O, assuming P in particulate form is contained in solids	
med.	0.90		0.10			
k	**5 [EJ]**					
TN	0.85	0.05	0.10		*EJ based on H2O	
med.	0.85	0.05	0.10			
k	**5 [EJ]**					
H2O	0.8 0.95 0.95 0.70		0.2 0.05 0.05 0.3		*Italy *Germany *UK * EJ for developing countries	(Howard 2007) (Reynolds and Barrett 2003) (Howard 2007)
med. (R)	0.87 (0.7 - 0.95)		0.13			
k	**5 [0.25]**					
TS	0.9		0.1		*EJ based on H2O	
med.	0.90		0.10			
k	**5 [EJ]**					

C6. Solids-free sewer

Definition: A solids-free sewer is a network of small-diameter pipes that transports pre-treated and solids-free wastewater (such as septic tank effluent). It can be installed at a shallow depth and does not require a minimum wastewater flow or slope to function (Tilley et al. 2014).

FG: conveyance (C)

Products: effluent, secondary effluent

Relations: Input: OR

Output: effluent > secondary effluent

Appropriateness

No.	Attribute name	Function	Value	Comment
5	**Frequency of O&M**	dtriangle	a=0, b=2, c=1	
6	**Temperature range**	prange	lower=-10, upper=50	
7	**Flooding**	ptrapez	a=0, b=0, c=20, d=365	
8	**Vehicular access**	ptrapez	a=1, b=3, c=100, d=100	
9	**Slope**	ptrapez	a=1, b=5, c=100, d=100	
11	**Ground-water depth**	ptrapez	a=1, b=3, c=100, d=100	
12	**Excavation**	pcat	easy=1, hard=0.8	
14	**Construction skills**	drange	lower=3, upper=5	
15	**Design skills**	dtriangle	a=4, b=6, c=5	
16	**O&M skills**	drange	lower=3, upper=5	
17	**Management**	pcat	household=0.5, shared=1, public=1	
18*	**Pipe supply**	drange	75mm+	
20*	**Concrete supply**	pcat	easy=1, medium=0.8, hard=0.5	
21	**Spare parts supply**	dcat	low tech=1, technical parts=0 , specially manufactured=0	
23*	**Potential to accommodate for changing water volumes**	prange	lower=-100, upper=200	
27*	**Odour**	dtriangle	a=1, b=1, c=2	

Transfer coefficients

	Effluent	Air loss	Soil loss	Water loss	Comments	Reference
TP	0.9		0.1			EJ
med.	0.90		0.10			
k	**25 [EJ]**					
TN	0.85	0.05	0.1			EJ
med.	0.85	0.05	0.10			
k	**25 [EJ]**					
H2O	0.9		0.1			EJ
med.	0.90		0.10			
k	**25 [EJ]**					
TS	0.9		0.1			EJ
med.	0.90		0.10			
k	**25 [EJ]**					

T1. Urine bank

Definition: Centralized collection or storage unit for urine before it receives further treatment.
FG: (semi-)centralized treatment (T)
Products: transported urine, transported stored urine -> transported stabilized urine
Relations: Input: OR
Output: NA

Appropriateness

No.	Attribute name	Function	Value	Comment
5	**Frequency of O&M**	drange	lower=0, upper=1	
6	**Temperature range**	prange	lower=4, upper=50	
8	**Vehicular access**	ptrapez	a=1, b=3, c=100, d=100	
14	**Construction skills**	dtriangle	a=1, b=3, c=2	
15	**Design skills**	dtriangle	a=1, b=3, c=2	
16	**O&M skills**	dtriangle	a=1, b=3, c=2	
17	**Management**	pcat	household=1, shared=1, public=1	
20*	**Concrete supply**	pcat	easy=1, medium=1, hard=0.5	
21	**Spare parts supply**	dcat	low tech=1, technical parts=0 , specially manufactured=0	
22*	**Surface area**	ptrapez	a=((0.5*1*30*5)/1000)^(2/3), b=((2.5*6*30*5)/1000)^(2/3), c=10000, d=10000	
24*	**Potential to accommodate for changing pollution load**	prange	lower=-100, upper=200	
27*	**Odour**	dtriangle	a=1, b=1, c=5	

Transfer coefficients

	urine	Air loss	Soil loss	Water loss	Comments	Reference
TP	1				*EJ from urine storage	
med.	1.00					
k	**25 [EJ]**					
TN	0.95 (0.92 - 0.98)	0.05			*EJ from urine storage	
med. (R)	0.95 (0.92 - 0.98)	0.05				
k	**100 [0.06]**					
H2O	0.96	0.04			*EJ from urine storage	
med.	0.96	0.04				
k	**25 [EJ]**					
TS	1	0			*EJ from urine storage	
med.	1.00	0.00				
k	**100 [EJ]**					

T2. Aurin production

Definition: Aurin is produced in a series of processes: nitrification to stabilize and bind the nutrients, filtration with activated carbon to remove unwanted trace elements and finally a distiller is used to receive a concentrated fertilizer (Etter et al. 2015, Udert et al. 2015).

FG: (semi-)centralized treatment (T)

Products: transported urine, transported stored urine -> transported aurin, transported secondary effluent

Relations: Input: OR
Output: NA

Appropriateness

No.	Attribute name	Function	Value	Comment
2	**Energy supply**	ptriangle	a=23, b=24, c=24	
5	**Frequency of O&M**	drange	lower=4, upper=16	
14	**Construction skills**	drange	lower=4, upper=5	
15	**Design skills**	dtriangle	a=1, b=3, c=2	
16	**O&M skills**	dtriangle	a=3, b=7, c=4	
17	**Management**	pcat	household=0, shared=1, public=1	
21	**Spare parts supply**	dcat	low tech=0.3, technical parts=0.6, specially manufactured=0.1	

Transfer coefficients

	Aurin	Effluent	Air loss	Soil loss	Water loss	Comments	Reference
TP	1 0.99		0 0.01				(Udert et al. 2015) PC with Bastian Etter
med.	1.00		0				
k	**100 [0.01]**						
TN	0.97 0.99		0.03 0.01				(Udert et al. 2015) PC with Bastian Etter
med. (R)	0.98 (0.97-0.99)		0.02				
k	**100 [0.02]**						
H2O	0.04 0.075	0.96 0.925				95 - 97% of water are removed	(Udert et al. 2015) PC with Bastian Etter
med. (R)	0.06 (0.04-0.075)	0.94					
k	**100 [0.035]**						
TS	0.35 0.4		0.65 (0.58-0.76) 0.6			* up to 90% of organic matter content is degraded; Organic matter makes up 65- 85% of urine dry solids (Rose et al. 2015)-> TC airloss range 0.58 - 0.76	(Udert et al. 2015) PC with Bastian Etter
med. (R)	0.38 (0.35 -0.4)		0.63 (0.58-0.76]				
k	**5**		**[0.28]**				

T3. Sludge drying bed

Definition: A simple, permeable bed that, when loaded with sludge, collects percolated leachate and allows the sludge to dry by evaporation. The sludge is not effectively stabilized or sanitized (Tilley et al. 2014).

FG: (semi-)centralized treatment (T)

Products: sludge, transported sludge -> processed sludge , transported processed sludge , effluent, transported effluent

Relations: Input: OR
Output: NA

Appropriateness

No.	Attribute name	Function	Value	Comment
5	**Frequency of O&M**	drange	lower=1, upper=3	
6	**Temperature range**	ptrapez	a=5, b=15, c=50, d=50	
7	**Flooding**	ptrapez	a=0, b=0, c=6, d=12	
8	**Vehicular access**	ptrapez	a=1, b=3, c=100, d=100	
9	**Slope**	ptrapez	a=0, b=0, c=10, d=100	
11	**Ground-water depth**	prange	lower=2, upper=100	
12	**Excavation**	pcat	easy=1, hard=0.8	
14	**Construction skills**	dtriangle	a=1, b=3, c=2	
15	**Design skills**	dtriangle	a=3, b=5, c=4	
16	**O&M skills**	dtriangle	a=2, b=4, c=3	
17	**Management**	pcat	household=0, shared=0, public=1	
20*	**Concrete supply**	pcat	easy=1, medium=1, hard=0.5	
21	**Spare parts supply**	dcat	low tech=1, technical parts=0 , specially manufactured=0	
22*	**Surface area**	prange	lower=0.4, upper=10000	
23*	**Potential to accommodate for changing water volumes**	prange	lower=-100, upper=200	
24*	**Potential to accommodate for changing pollution load**	prange	lower=-100, upper=200	
27*	**Odour**	dtriangle	a=2, b=2, c=5	

Transfer coefficients

	Dried sludge	Effluent	Air loss	Soil loss	Water loss	Comments	Reference
TP	0.7 0.53 (0.48-0.58)	0.3 0.46 (0.42-0.52)				* TP recovery in paved drying beds * TP removal given	(Nikiema et al. 2014) (Kuffour 2015)
med. (R)	0.62 (0.48 - 0.7)	0.38 (0.3 - 0.52)					
k	**5 [0.22]**						
TN	0.6 0.61 0.5 0.70 0.52 0.55	0.3 0.39 (0.28 - 0.51) 0.2 0.3 (0.2-0.4) 0 0.15 (0.1-0.2)	0.1 0.3 0.1 0.48 (0.22-0.74) 0.3 (0.2-0.4)			* TN recovery in paved drying beds * see calculations in 1 * NH4 removal rates given (0.4 - 0.6) * Removals of different N compounds given, average is used * Net TN loss due to volatilization, solar drying, no effluent, differences due to tillage and temp * TN of sludges decreased by 30-59% through air drying	(Nikiema et al. 2014) (Cofie et al. 2006) (Montangero and Strauss 2002) (Kuffour 2015) EJ (O'Shaughnessy et al. 2008) (Ryan and Keeney 1975)
med. (R)	0.58 (0.5-0.7)	0.40 (0.2 - 0.6)	0.10				
bal.	0.53	0.37	0.10				
k	**5**	**[0.4]**					
H2O	0.2 0.58 (0.32-0.79) 0.14	0.55 (0.4-0.7) 0.22	0.25 (0.1-0.4) 0.2 0.86 (0.73-0.99)			* Estimated from: volume reduction: 90%, of that 20 -50% evaporation and 50-80% percolation; ratio depends on sludge thickness * see calculations in 2. * solar drying, no effluent	(Strande et al. 2014) (Montangero and Strauss 2002) (O'Shaughnessy et al. 2008)
med. (R)	0.2 (0.14 -0.79)	0.39 (0.22-0.7)	0.25				
bal.	0.31	0.39	0.3				
k	**2 [EJ]**						
TS	0.8 0.78	0.2 (0.19-0.2) 0.22	 0.04			* see calculations in 1. * 95% removal SS (TS=0.78, estimated from ratio in 3.)	(Cofie et al. 2006) (Montangero and Strauss 2002) EJ
med. (R)	0.79 (0.78 -0.8)	0.21 (0.2-0.22)	0.04				
bal.	0.75	0.21	0.04				
k	**100 [0.05]**						

Calculations

1.

	FS	Percolate		TC effluent	
		Min	Max	Min	Max
TS [mg/L]	30450	5700	6100	0.19	0.20
TSS[mg/L]	14600	290	600	0.02	0.04
NH3-N [mg/L]	1500	260	520		
NO3		50	170		
TKN		370	590		
TN (TKN + NO3)		420	760	0.28	0.51
	Data from: (Cofie et al. 2006)			Calculated: TC_Effluent= Value in Effluent (TS/TSS/N) / Value in FS	

2.

	Moisture content	H2O Sludge
Incoming	0.95	
Dried sludge high moisture	0.75	0.79
Dried sludgemed.ium moisture	0.6	0.63
Dried sludge low moisture	0.3	0.32
		0.58
	Data from: (Montangero and Strauss 2002)	Calculated: H2O sludge = Moisture content in dried sludge/ moisture content in incoming sludge

3.

	Removal	Ratio TS:SS removal
TS	80%	
TSS	97%	82%
	Data from (Cofie et al. 2006)	Calculated: Ratio= TS removal/ TSS removal

T4. Faeces drying bed

Definition: Simple, impermeable drying beds to dry solid sanitation products.
FG: (semi-)centralized treatment (T)
Products: pit humus, transported pit humus, stored faeces, transported stored faeces -> dried faeces, transported dried faeces
Relations: Input: OR
Output: NA

Appropriateness

No.	Attribute name	Function	Value	Comment
5	**Frequency of O&M**	drange	lower=1, upper=3	
6	**Temperature range**	ptrapez	a=5, b=15, c=50, d=50	
7	**Flooding**	ptrapez	a=0, b=0, c=6, d=12	
8	**Vehicular access**	ptrapez	a=1, b=3, c=100, d=100	
9	**Slope**	ptrapez	a=0, b=0, c=10, d=100	
11	**Ground-water depth**	prange	lower=2, upper=100	
12	**Excavation**	pcat	easy=1, hard=0.8	
14	**Construction skills**	dtriangle	a=1, b=3, c=2	
15	**Design skills**	dtriangle	a=3, b=5, c=4	
16	**O&M skills**	dtriangle	a=2, b=4, c=3	
17	**Management**	pcat	household=0, shared=0, public=1	
21	**Spare parts supply**	dcat	low tech=1, technical parts=0 , specially manufactured=0	

Transfer coefficients

	Dried faeces	Air loss	Soil loss	Water loss	Comments	Reference
TP	1					EJ
med.	1.00					
k	**25 [EJ]**					
TN	0.8	0.2				EJ
med.	0.80	0.20				
k	**5 [EJ]**					
H2O	0.4	0.6				EJ
med.	0.40	0.60				
k	**5 [EJ]**					
TS	0.9	0.1				EJ
med.	0.90	0.10				
k	**5 [EJ]**					

T5. Briquetting

Definition:	The process was developed and implemented by Sanivation in Naivasha, Kania. The process was designed for a container-based waste-to-fuel concept, using separated faecal waste. It is currently scaled up to work also for sludge and pit humus. The solid sanitation products are treated thermally for pathogen inactivation, before they are ground and mixed with charcoal dust and water to a thick paste. A roller press agglutinates it to briquettes which are dried before being sold for combustion in cooking stoves (Jones 2017).
FG:	(semi-)centralized treatment (T)
Products:	transported dried faeces, transported stored faeces, transported pit humus, transported sludge -> transported briquettes
Relations:	Input: OR Output: NA

Appropriateness

No.	Attribute name	Function	Value	Comment
2	**Energy supply**	ptrapez	a=0, b=4, c=24, d=24	
5	**Frequency of O&M**	drange	lower=4, upper=8	
14	**Construction skills**	dtriangle	a=2, b=5, c=4	
15	**Design skills**	drange	lower=5, upper=6	
16	**O&M skills**	drange	lower=2, upper=3	
17	**Management**	pcat	household=0, shared=0, public=1	
21	**Spare parts supply**	dcat	low tech=0.7, technical parts=0.2, specially manufactured=0.1	

Transfer coefficients

	Briquettes	Air loss	Soil loss	Water loss	Comments/Specifications	Reference
TP	**1**					PC with Sanivation
med.	1.00					
k	**100 [0]**					
TN	0.95 0.9	0.05 0.1			* N volatilization is related to air temperature	PC with Sanivation EJ
med. (R)	0.92 (0.9 – 0.95)	0.08				
k	**25 [0.05]**					
H2O	0 0.14	1 0.86 (0.75 - 0.93)			Moisture content briquettes ~5%. Dried faeces with moisture 20% -> 5% = TC Air loss 0.75. FS with moisture 80% -> 5% = TC Air loss 0.9325	PC with Sanivation EJ
med. (R)	0.07 (0 – 0.14)	0.93 (0.75 - 1)				
k	**5 [0.25]**					
TS	**0.99**	**0.01**				PC with Sanivation
med.	0.99	0.01				
k	**100 [0]**					

T6. LaDePa pelletizing

Definition: In a LaDePa (Latrine Dehydration Pasteurization) machine, faecal sludge or pit humus is extruded for the formation of pellets. The pellets are then exposed to infrared radiation that provides effective heat transmission for drying, in the course of which also pathogens are inactivated. The final product is dried and pasteurized pellets that can be used as a fertilizer (Septien et al. 2018). Current research also looks into the use of pellets as fuel.

FG: (semi-)centralized treatment (T)

Products: transported sludge, transported processed sludge, transported pit humus -> transported pellets

Relations: Input: OR

Output: NA

Appropriateness

No.	Attribute name	Function	Value	Comment
2	**Energy supply**	ptrapez	a=0, b=4, c=24, d=24	
5	**Frequency of O&M**	drange	lower=4, upper=16	
14	**Construction skills**	dtriangle	a=3, b=5, c=4	
15	**Design skills**	drange	lower=5, upper=6	
16	**O&M skills**	dtriangle	a=2, b=5, c=2	
17	**Management**	pcat	household=0, shared=1, public=1	
21	**Spare parts supply**	dcat	low tech=0.3, technical parts=0.6, specially manufactured=0.1	

Transfer coefficients

	Pellets	Air loss	Soil loss	Water loss	Comments	Reference
TP	0.99	0.01			*Drying did not affect the nutrient content and calorific value of the dry bone of faecal sludge	(Septien et al. 2018)
	0.99	0.01				PC with Rein Buisman
med.	0.99	0.01				
k	**100 [0]**					
TN	0.95	0.05			*Drying did not affect the nutrient content and calorific value of the dry bone of faecal sludge	(Septien et al. 2018)
	0.99	0.01				PC with Rein Buisman
med. (R)	0.97 (0.95-0.99)	0.03				
k	**100 [0.04]**					
H2O	0.25	0.75			*Moisture from 80% to 20%	(Septien et al. 2018)
	0.225	0.775				PC with Rein Buisman
med. (R)	0.24 (0.225 -0.25)	0.76				
k	**100 [0.025]**					
TS	0.99	0.01			*Drying did not affect the nutrient content and calorific value of the dry bone of faecal sludge	(Septien et al. 2018)
	0.99	0.01				PC with Rein Buisman
med.	0.99	0.01				
k	**100 [0]**					

T7. Anaerobic baffled reactor (ABR)

Definition: An anaerobic baffled reactor (ABR) is an improved Septic Tank with a series of baffles under which the wastewater is forced to flow. The increased contact time with the active biomass (sludge) results in improved treatment (Tilley et al. 2014).

FG: (semi-)centralized treatment (T)

Products: blackwater, transported blackwater, greywater, transported greywater -> sludge, transported sludge, effluent, transported effluent

Relations: Input: OR
Output: AND

Appropriateness

No.	Attribute name	Function	Value	Comment
5	**Frequency of O&M**	drange	lower=1, upper=2	
6	**Temperature range**	ptrapez	a=5, b=15, c=35, d=50	
7	**Flooding**	ptrapez	a=0, b=0, c=6, d=60	
8	**Vehicular access**	ptrapez	a=1, b=3, c=100, d=100	
9	**Slope**	ptrapez	a=0, b=0, c=50, d=100	
14	**Construction skills**	dtriangle	a=2, b=4, c=3	
15	**Design skills**	dtriangle	a=3, b=5, c=4	
16	**O&M skills**	dtriangle	a=2, b=4, c=3	
17	**Management**	pcat	household=0.5, shared=1, public=1	
20*	**Concrete supply**	pcat	easy=1, medium=1, hard=0.5	
21	**Spare parts supply**	dcat	low tech=1, technical parts=0 , specially manufactured=0	
22*	**Surface area**	prange	lower=0.5, upper=10000	
23*	**Potential to accommodate for changing water volumes**	ptrapez	a=-100, b=-50, c=50, d=100	
24*	**Potential to accommodate for changing pollution load**	ptrapez	a=-100, b=-50, c=50, d=100	
27*	**Odour**	dtriangle	a=1, b=1, c=2	

Transfer coefficients

	Sludge	Effluent	Air loss	Soil loss	Water loss	Comments	Reference
TP	0.31 0.45 (0.39 - 0.51) 0.33 (0.3 - 0.36)	0.69 0.55 0.67				* TP pathways * TP removal, range depends on number of baffles * TP removal, depends on HRT	(Hamader and Javorszky 2014) (Koottatep et al. 2018) (Nasr et al. 2009)
med. (R)	0.33 (0.3-0.51)	0.67					
k	**5 [0.21]**						
TN	0.32 0.28 (0.15 - 0.41) 0.29 (0.21 - 0.37)	0.68 0.72 0.71				* TKN pathways * TKN removal, range depends on number of baffles * TKN removal, depends on HRT; Ammonia concentration increases	(Hamader and Javorszky 2014) (Koottatep et al. 2018) (Nasr et al. 2009)
med. (R)	0.29 (0.15 - 0.41)	0.71					
k	**5 [0.26]**						
H2O	0.04	0.95	0.01				EJ
med.	0.04	0.95	0.01				
k	**25 [EJ]**						
TS	0.57 0.65 (0.63 - 0.66) 0.58 (0.53 - 0.63)	0.43 0.35 0.42				* TSS Removal 73%; TC Effluent TS=0.57 estimated with ratio from calculations in 1. * TS removal, range depends on number of baffles *TSS Removal: 69 – 82%; TC Effluent TS=0.53 - 0.63 estimated with ratio from calculations in 1.	(Hamader and Javorszky 2014) (Koottatep et al. 2018) (Nasr et al. 2009)
med. (R)	0.58 (0.53 -0.66)	0.42					
k	**25 [0.13]**						

Calculations

1.

	TS	**TSS**	**Ratio TS:TSS removal**
Removal	66%	86%	77%
	65%	83%	78%
	55%	71%	77%
med.			77%
	Data from: (Koottatep et al. 2018)		Calculation: Ratio = Removal TS / Removal TSS

T8. Sequencing batch reactor (SBR)

Definition: A sequencing batch reactor is a single tank in which activated sludge treatment happens in cycles with phases of filling, reaction, settling, and drawing. Through the alternation of anaerobic and oxic/anoxic phases, nutrients such as nitrogen and phosphorus are removed through biological activities (Zhu et al. 2006).

FG: (semi-)centralized treatment (T)

Products: sludge, transported sludge, blackwater, transported blackwater, greywater, transported greywater -> processed sludge , transported processed sludge, effluent, transported effluent

Relations: Input: OR
Output: AND

Appropriateness

No.	Attribute name	Function	Value	Comment
2	**Energy supply**	ptriangle	a=0, b=24, c=24	
4*		ptriangle	a=0, b=0, c=24	
5	**Frequency of O&M**	drange	lower=1, upper=2	
6	**Temperature range**	ptrapez	a=5, b=10, c=40, d=50	
7	**Flooding**	ptrapez	a=0, b=0, c=6, d=60	
8	**Vehicular access**	ptrapez	a=1, b=3, c=100, d=100	
9	**Slope**	ptrapez	a=0, b=0, c=50, d=100	
14	**Construction skills**	dtriangle	a=3, b=5, c=4	
15	**Design skills**	dtriangle	a=4, b=6, c=5	
16	**O&M skills**	dtriangle	a=2, b=4, c=3	
17	**Management**	pcat	household=0, shared=0, public=1	
20*	**Concrete supply**	pcat	easy=1, medium=1, hard=0.5	
21	**Spare parts supply**	dcat	low tech=0.5, technical parts=0.4, specially manufactured=0.1	
22*	**Surface area**	prange	lower=2, upper=10000	
23*	**Potential to accommodate for changing water volumes**	ptrapez	a=-100, b=-50, c=50, d=100	
24*	**Potential to accommodate for changing pollution load**	ptrapez	a=-100, b=-50, c=50, d=100	
27*	**Odour**	dtriangle	a=1, b=1, c=4	

Transfer coefficients

	Sludge	Effluent	Air loss	Soil loss	Water loss	Comments	Reference
TP	0.88	0.12				* pathways for PO4-P	(Hamader and Javorszky 2014)
	0.74	0.26				* see calculations 1.	(Wilderer et al. 2000)
	0.74 (0.44 - 0.98)	0.26 (0.02 - 0.56)				* PO4-P removal see calculations in 2.	(Bernal-Martínez et al. 2000)
med. (R)	0.74 (0.44 - 0.98)	0.26 (0.02 - 0.56)					
k	**2 [0.54]**						
TN	0.22	0.14	0.64			* pathways for TN	(Hamader and Javorszky 2014)
	0.26	0.06	0.68			* Effluent TC: calculations in 1.; other values estimated with removal distribution ratio in 5.	(Wilderer et al. 2000)
	0.23	0.19 (0 - 0.52)	0.58			* removal see calculations in 2; other values estimated with removal distribution ration in 5.	(Bernal-Martínez et al. 2000)
	0.25	0.05	0.7			* Aerobic granular sludge SBR; TN pathways given	(Lochmatter et al. 2014)
	0.29 (0.27 - 0.3)	0.1 (0.055 - 0.17)	0.61 (0.53 - 0.66)			* continuous influent SBR, calculations see 4.	(Xylem 2015)
med. (R)	0.25 (0.22 - 0.32)	0.1 (0 - 0.52)	0.64 (0.48 - 0.7)				
bal.	0.25	0.1	0.65				
k	**2 [0.52]**						
H2O	0.02 (0 - 0.05)	0.93	0.05 (0 - 0.1)				EJ
med. (R)	0.02	0.93 (0.85 – 1)	0.05				
k	**25**	**[0.15]**					
TS	0.64	0.36				*Given is TSS to sludge: 0.82; TS estimated from ratio in 6.	(Hamader and Javorszky 2014)
	0.75	0.25				* TSS to sludge: calculation 3.; TS estimated from ratio in 6.	(Keller et al. 2001)
	0.78	0.22				* PIG SLURRY	(Zhu et al. 2006)
med. (R)	0.75 (0.64 - 0.78)	0.25 (0.22-0.36)					
k	**25 [0.14]**						

Calculations

1.

	TN [mg/L]		TP [mg/L]		TC Effluent	
	Influent	Effluent	Influent	Effluent	TN	TP
Min	25	4.5	5	0.6	0.18	0.12
Ave	62	12.5	10.8	2.8	0.20	0.26
Max	87	20.0	17	4.5	0.23	0.26
	Data from: (Wilderer et al. 2000)			**TC med.:**	**0.20**	**0.26**

2.

Sludge Age days	PO4-P removal [%]	NH4- N removal [%]
3	0.53	-
6	0.44	0.48
16	0.95	1
23	0.98	0.94
Mean	**0.73**	**0.81**
Data from: (Bernal-Martínez et al. 2000)		

3.

	Influent [mg/L]	Effluent [mg/L]	TC effluent
TSS	260	13	0.05
	Data from: (Keller et al. 2001)		

4.

	0h	4h	6h	Average
TN to effluent	0.17	0.087	0.055	0.10
TN to sludge	0.3	0.27	0.29	0.29
TN to Gas	0.53	0.65	0.66	0.61
	Data from: (Xylem 2015)			

5.

Ratio TC_Sludge: TC_Air loss (for TN pathway estimations)		
Data from:	**TC Sludge**	**TC Air loss**
(Hamader and Javorszky 2014)	0.22	0.64
(Lochmatter et al. 2014)	0.25	0.7
(Xylem 2015)	0.29	0.61
Mean	0.25	0.65
Removal Distribution (%)	0.28	0.72

6.

TS removal [%]	TSS removal [%]	Ratio
0.782	0.995	0.786
Data from: (Zhu et al. 2006)		Calculated: Ratio= TS Removal/ TSS removal

T9. Co-composting

Definition: The controlled aerobic degradation of organics, using more than one feedstock (faecal sludge and organic solid waste) in a centralized facility. By combining the two, the benefits of each can be used to optimize the process and the product (Tilley et al. 2014).
FG: (semi-)centralized treatment (T)
Products: stored faeces, transported stored faeces, pit humus, transported pit humus, sludge, transported sludge, organics, transported organics -> compost, transported compost
Relations: Input: OR
Output: NA

Appropriateness

No.	Attribute name	Function	Value	Comment
5	**Frequency of O&M**	drange	lower=1, upper=2	
6	**Temperature range**	ptrapez	a=10, b=20, c=50, d=50	
7	**Flooding**	ptrapez	a=0, b=0, c=6, d=12	
8	**Vehicular access**	ptrapez	a=1, b=3, c=100, d=100	
9	**Slope**	ptrapez	a=0, b=0, c=50, d=100	
14	**Construction skills**	dtriangle	a=1, b=3, c=2	
15	**Design skills**	dtriangle	a=3, b=5, c=4	
16	**O&M skills**	dtriangle	a=2, b=4, c=3	
17	**Management**	pcat	household=1, shared=1, public=1	
21	**Spare parts supply**	dcat	low tech=1, technical parts=0 , specially manufactured=0	
22*	**Surface area**	prange	lower=0.3, upper=10000	
24*	**Potential to accommodate for changing pollution load**	prange	lower=-100, upper=200	
27*	**Odour**	dtriangle	a=1, b=2, c=4	

Transfer coefficients

	Compost	Air loss	Soil loss	Water loss	Comments	Reference
TP	0.99 0.99 0.99		0.01 0.01 0.01		* full P pathways * full P pathways * see calculation in 1	(Belevi 2002) (Meinzinger 2010) (Leitzinger 2001)
med.	0.99		0.01			
k	**100 [0]**					
TN	0.69 0.65 0.65 0.30	0.3 0.35 0.28 0.6	0.01 0 0.07 0.1	 0.01 	* full N pathways * full N pathways * see calculation in 1 * N loss as high as 70%	(Belevi 2002) (Meinzinger 2010) (Leitzinger 2001) (Heinonen-Tanski and van Wijk-Sijbesma 2005)
med. (R)	0.65 (0.3-0.69)	0.33	0.04	0.01		
bal.	0.63	0.32	0.04	0.01		
k	**5 [0.39]**					
H2O	0.9	0.05	0.05		EJ: moisture content is to be maintained throughout	
med.	0.90	0.05	0.05			
k	**5 [EJ]**					
TS	0.61	0.36	0.03		* Derived from pathways for masses	(Belevi 2002)
med.	0.61	0.36	0.03			
k	**5 [EJ]**					

Calculations

1.

	Incoming N [t/year]	**Outgoing N [t/year]**	**Incoming P [t/year]**	**Outgoing P [t/year]**	**TN**	**TP**
From Markets	534		267			
From Households	1005		182			
From Poultry Farms	7		6			
From Breweries	177		44			
From Sawmills	172		3			
To Atmosphere- Air loss		534		0	0.28	0.00
To Urban Agriculture - Compost		1227		495	0.65	0.99
To Surface water- Water loss		18		7	0.01	0.01
To Effluent (covers discrepancy)		116		0	0.06	0.00
Sum	1895	1895	502	502		
	Data from:					

T10. Biogas reactor

Definition: A biogas reactor or anaerobic digester is an anaerobic treatment technology that produces (a) a digested slurry (digestate) that can be used as a fertilizer and (b) biogas that can be used for energy (Tilley et al. 2014).

FG: (semi-)centralized treatment (T)

Products: organics, transported organics, blackwater, transported blackwater, sludge, transported sludge -> biogas, transported biogas, processed sludge , transported processed sludge

Relations: Input: OR
Output: AND

Appropriateness

No.	Attribute name	Function	Value	Comment
5	**Frequency of O&M**	drange	lower=0, upper=3	
6	**Temperature range**	ptrapez	a=15, b=30, c=40, d=50	
7	**Flooding**	ptrapez	a=0, b=0, c=6, d=12	
8	**Vehicular access**	ptrapez	a=1, b=3, c=100, d=100	
9	**Slope**	ptrapez	a=0, b=0, c=50, d=100	
14	**Construction skills**	dtriangle	a=2, b=4, c=3	
15	**Design skills**	dtriangle	a=3, b=5, c=4	
16	**O&M skills**	dtriangle	a=2, b=4, c=3	
17	**Management**	pcat	household=1, shared=1, public=1	
20*	**Concrete supply**	pcat	easy=1, medium=1, hard=0.5	
21	**Spare parts supply**	dcat	low tech=0.5, technical parts=0.5 , specially manufactured=0	
22*	**Surface area**	prange	lower=0.3, upper=10000	
23*	**Potential to accommodate for changing water volumes**	ptrapez	a=-100, b=-50, c=50, d=100	
24*	**Potential to accommodate for changing pollution load**	prange	lower=-100, upper=200	
27*	**Odour**	dtriangle	a=1, b=1, c=2	

Transfer coefficients

	Processed Sludge	Biogas	Air loss	Soil loss	Water loss	Comments	Reference
TP	1						(Bachmann et al. 2015)
med.	1						
k	**25 [EJ]**						
TN	0.97	0.03					EJ
med.	0.97	0.03					
k	**100 [EJ]**						
H2O	0.99	0.01					EJ
med.	0.99	0.01					
k	**100 [EJ]**						
TS	0.5	0.5				* at least 50% of the dry matter content is converted to methane (CH_4) and carbon dioxide (CO_2)	(Al Seadi et al. 2013)
	0.6	0.4 (0.25-0.5)				*Organic matter combustion 40-90%; TS assumption 25-50%	(Rose et al. 2015)
	0.66	0.34					(Minale and Worku 2014)
	0.71	0.29 (0.25-0.33)				* anaerobic digestion leads to a reduction in total dry matter of about 25-33%	(Bachmann et al. 2015)
med. (R)	0.62	0.38 (0.25-0.5)					
k	**5 [0.25]**						

T11. Waste stabilization pond

Definition: Waste stabilization ponds (WSPs) are large, manmade water bodies. The ponds can be used individually, or linked in a series for improved treatment. There are three types of ponds, (1) anaerobic, (2) facultative and (3) aerobic (maturation), each with different treatment and design characteristics (Tilley et al. 2014).

FG: (semi-)centralized treatment (T)

Products: transported blackwater, transported stormwater, transported effluent, transported greywater -> transported sludge, transported secondary effluent

Relations: Input: OR
Output: NA

Appropriateness

No.	Attribute name	Function	Value	Comment
5	**Frequency of O&M**	drange	lower=1, upper=2	
6	**Temperature range**	ptrapez	a=0, b=15, c=50, d=50	
7	**Flooding**	ptrapez	a=0, b=0, c=6, d=100	
8	**Vehicular access**	ptrapez	a=1, b=3, c=100, d=100	
9	**Slope**	ptrapez	a=0, b=0, c=0, d=100	
14	**Construction skills**	dtriangle	a=1, b=3, c=2	
15	**Design skills**	dtrianlge	a=3, b=5, c=4	
16	**O&M skills**	dtriangle	a=2, b=5, c=3	
17	**Management**	pcat	household=0, shared=0.5, public=1	
20*	**Concrete supply**	pcat	easy=1, medium=1, hard=0.5	
21	**Spare parts supply**	dcat	low tech=1, technical parts=0 , specially manufactured=0	
22*	**Surface area**	prange	lower=0.4, upper=10000	
23*	**Potential to accommodate for changing water volumes**	ptrapez	a=-100, b=-50, c=50, d=100	
24*	**Potential to accommodate for changing pollution load**	prange	lower=-100, upper=200	
27*	**Odour**	dtriangle	a=1, b=2, c=5	

Transfer coefficients

	Sludge	Effluent	Air loss	Soil loss	Water loss	Comments	Reference
TP	0.56	0.44				* TP pathways	(Hamader and Javorszky 2014)
	0.37 (0.32 - 0.41)	0.63					(Xian-Hua 1994)
med. (R)	0.47 (0.32- 0.56)	0.53					
k	**5 [0.24]**						
TN	0.24	0.28	0.48			* TN pathways	(Hamader and Javorszky 2014)
	0.2	0.2	0.6			* TN removal=80%, others estimated with removal distribution ration in 2	(Conradin et al. 2010)
	0.22	0.33 (0.11 - 0.56)	0.45			* N removal 44 -89%, other estimated with removal distribution ration in 2	(Ho et al. 2017)
	0.25	0.24 (0.2 - 0.27)	0.51			* Ammonia removal 73-80%, others values estimated with removal distribution ration in 2	(Soares et al. 1996)
med. (R)	0.23 (0.24-0.5)	0.26 (0.11 - 0.56)	0.49				
bal.	0.24	0.26	0.50				
k	**2**	**[0.45]**					
H2O	0.05	0.9	0.05			*EJ	
med.	0.05	0.90	0.05				
k	**5 [EJ]**						
TS	0.43	0.57				* TSS removal: 78%, TS removal estimated from ratio in 1	(Hamader and Javorszky 2014)
	0.35	0.65				*TSS removal 90%, TS removal estimated from ratio in 1	(Conradin et al. 2010)
	0.45	0.55				* TS removal efficiency given	(Alcocer et al. 1993)
med. (R)	0.43 (0.35 -0.45)	0.57					
k	**25 [0.1]**						

Calculations

1.

	Removal Efficiency	TC Effluent	Ratio TS:TSS removal
TS	45%	0.55	
TSS	60%	0.40	75%
TDS	43%	0.57	
	Data from: (Alcocer et al. 1993)	Calculation: TC Effluent = 1- Removal efficiency	Calculation: Ratio= Removal TS / Removal TSS

2.

		Removal Distribution (%)
TC Sludge	0.24	33%
TC Effluent	0.28	
TC Air loss	0.48	67%
	Data from: (Hamader and Javorszky 2014)	Calculated: Removal to sludge= TC Sludge / (TC Sludge + TC Air loss) Removal to airloss= TC Air loss / (TC Sludge + TC Air loss)

T12. Horizontal subsurface flow constructed wetland (HSSFCW)

Definition: A large gravel and sand-filled basin that is planted with wetland vegetation. As wastewater flows horizontally through the basin, the filter material filters out particles and microorganisms degrade the organics (Tilley et al. 2014).

FG: (semi-)centralized treatment (T)

Products: transported blackwater, transported stormwater, transported effluent, transported greywater -> transported sludge, transported secondary effluent

Relations: Input: OR
Output: AND

Appropriateness

No.	Attribute name	Function	Value	Comment
5	**Frequency of O&M**	drange	lower=0, upper=1	
6	**Temperature range**	ptrapez	a=-5, b=10, c=30, d=50	
7	**Flooding**	ptrapez	a=0, b=0, c=6, d=100	
8	**Vehicular access**	ptrapez	a=1, b=3, c=100, d=100	
9	**Slope**	ptrapez	a=0, b=0, c=10, d=100	
11	**Ground-water depth**	prange	lower=2, upper=100	
14	**Construction skills**	dtriangle	a=1, b=3, c=2	
15	**Design skills**	dtriangle	a=3, b=5, c=4	
16	**O&M skills**	dtriangle	a=1, b=4, c=3	
17	**Management**	pcat	household=0.5, shared=1, public=1	
20*	**Concrete supply**	pcat	easy=1, medium=1, hard=0.5	
21	**Spare parts supply**	dcat	low tech=1, technical parts=0 , specially manufactured=0	
22*	**Surface area**	prange	lower=0.4, upper=10000	
23*	**Potential to accommodate for changing water volumes**	ptrapez	a=-100, b=-50, c=50, d=100	
24*	**Potential to accommodate for changing pollution load**	ptrapez	a=-100, b=-50, c=50, d=100	
27*	**Odour**	dtriangle	a=1, b=2, c=4	

Transfer coefficients

	Sludge	Effluent	Air loss	Soil loss	Water loss	Comments	Reference
TP	0.37 (0.3 - 0.45)	0.63				* TP removal efficiency given	(Conradin et al. 2010)
	0.5	0.5				* TP removal efficiency given	(Vymazal 2010)
	0.41	0.59				* TP removal efficiency given	(Vymazal 2007)
med. (R)	0.41 (0.3 - 0.5)	0.59					
k	**25 [0.2]**						
TN		0.73 (0.6 - 0.85)				* TN removal efficiency given	(Conradin et al. 2010)
		0.62 (0.57 - 0.67)				* TN removal efficiency given	(Vymazal 2010)
		0.577				* TN removal efficiency given	(Vymazal 2007)
			0.12 (0.07-0.16)			* NH3 volatilization of CW treating swine manure	(Poach et al. 2002)
	0.26						EJ
med. (R)	0.26	0.62 (0.57 - 0.85)	0.12				
k	**5**	**[0.28]**					
H2O		0.8 (0.95-0.73)	0.16 (0.05 - 0.27)			* ET rates given	(Headley et al. 2012)
		0.82 (0.75- 0.97)	0.15 (0.03–0.25)			* ET rates given	(Consoli et al. 2018)
	0.02			0.02			EJ
med. (R)	0.02	0.81 (0.71 - 0.95)	0.16 (0.03 - 0.27)	0.02			
bal.	0.02	0.80	0.16	0.02			
k	**5 [0.24]**	**[0.24]**	**[0.24]**				
TS	0.34 (0.31 - 0.37)					* TSS removal = 80 - 95 %, TS estimated from ratio in 1	(Conradin et al. 2010)
	0.29					* TSS removal 75%; TS estimated from ratio in 1	(Vymazal 2010)
		0.63	0.05				EJ
med. (R)	0.32 (0.29 - 0.37)	0.63	0.05				
k	**25 [EJ]**						

Calculations

1.

Relation TS - TSS – TDS in lab scale experiment CW		**Ratio to TS**
Removal TS	15.63%	
Removal TSS	40%	39%
Removal TDS	11.11%	141%
Data from Chandrakanth et al. (2016)		

D1. Application of urine

Definition: Stored urine is applied as a liquid fertilizer with a high concentration of nutrients and can replace all or some commercial chemical fertilizers (Tilley et al. 2014).
FG: use and/or disposal (D)
Products: stored urine, transported stored urine, stabilized urine, transported stabilized urine ->
Relations: Input: OR
Output: NA

Appropriateness

No.	Attribute name	Function	Value	Comment
5	**Frequency of O&M**	drange	lower=1, upper=2	
6	**Temperature range**	ptrapez	a=-5, b=5, c=30, d=40	
7	**Flooding**	ptrapez	a=0, b=0, c=6, d=60	
14	**Construction skills**	dtriangle	a=1, b=3, c=2	
15	**Design skills**	dtriangle	a=2, b=4, c=3	
16	**O&M skills**	dtriangle	a=2, b=4, c=3	
17	**Management**	pcat	household=1, shared=1, public=1	
21	**Spare parts supply**	dcat	low tech=1, technical parts=0 , specially manufactured=0	
22*	**Surface area**	prange	lower=0.5, upper=10000	
24*	**Potential to accommodate for changing pollution load**	prange	lower=-100, upper=200	
27*	**Odour**	dtriangle	a=1, b=1, c=2	

Transfer coefficients

	Recovered	Air loss	Soil loss	Water loss	Comments	Reference
TP	0.97		0.02	0.01		EJ
med.	0.97		0.02			
k	**100 [EJ]**					
TN	0.94 (0.9 - 0.99)	0.05 (0.01 - 0.1)			* sophisticated spreading techniques	(Udert et al. 2006)
	0.89	0.11 (0.04 -0.18)			* Cattle manure	(Vertregt and Rutgers 1987)
			0.01	0.01		EJ
med. (R)	0.90 (0.89-0.99)	0.08 (0.01 -0.18)	0.01	0.01		
k	**25 [0.17]**	**[0.17]**				
H2O	0.98		0.01	0.01		EJ
med.	0.98		0.01	0.01		
k	**100 [EJ]**					
TS	0.98		0.01	0.01		EJ
med.	0.98		0.01	0.01		
k	**100 [EJ]**					

D2. Application of Aurin

Definition: Aurin is applied to plants as a safe, stabilized fertilizer that has a high concentration of valuable nutrients (http://www.vuna.ch/aurin/)

FG: use and/or disposal (D)

Products: transported aurin ->

Relations: Input: NA
Output: NA

Appropriateness

No.	Attribute name	Function	Value	Comment
5	**Frequency of O&M**	drange	lower=1, upper=2	
6	**Temperature range**	ptrapez	a=-5, b=5, c=30, d=40	
7	**Flooding**	ptrapez	a=0, b=0, c=6, d=60	
14	**Construction skills**	dtriangle	a=1, b=3, c=2	
15	**Design skills**	dtriangle	a=2, b=4, c=3	
16	**O&M skills**	dtriangle	a=2, b=4, c=3	
17	**Management**	pcat	household=1, shared=1, public=1	
21	**Spare parts supply**	dcat	low tech=1, technical parts=0 , specially manufactured=0	

Transfer coefficients

	Recovered	Air loss	Soil loss	Water loss	Comments	Reference
TP	0.98		0.01	0.01		EJ
med.	0.98		0.01	0.01		
k	**100 [EJ]**					
TN	0.96	0.02	0.01	0.01	*"low volatilization due to prior nitrification"	Bastian Etter, 5th SEI Webinar "VUNA - Valorisation of Urine Nutrients in Africa"
med.	0.96	0.02	0.01	0.01		
k	**100 [EJ]**					
H2O	0.98		0.01	0.01		EJ
med.	0.98		0.01	0.01		
k	**100 [EJ]**					
TS	0.98		0.01	0.01		EJ
med.	0.98		0.01	0.01		
k	**100 [EJ]**					

D3. Application of faeces

Definition: Dried faeces are a crumbly, white-beige, coarse, flaky material or powder. It is mixed into soil for agriculture and improve the structure and water holding capacity (Tilley et al. 2014).
FG: use and/or disposal (D)
Products: dried faeces, transported dried faeces ->
Relations: Input: XOR
Output: NA

Appropriateness

No.	Attribute name	Function	Value	Comment
5	**Frequency of O&M**	drange	lower=1, upper=2	
6	**Temperature range**	ptrapez	a=-5, b=5, c=30, d=40	
7	**Flooding**	ptrapez	a=0, b=0, c=12, d=50	
14	**Construction skills**	dtriangle	a=1, b=3, c=2	
15	**Design skills**	dtriangle	a=2, b=4, c=3	
16	**O&M skills**	dtriangle	a=2, b=4, c=3	
17	**Management**	pcat	household=1, shared=1, public=0.5	
21	**Spare parts supply**	dcat	low tech=1, technical parts=0 , specially manufactured=0	
22*	**Surface area**	prange	lower=0.5, upper=10000	
24*	**Potential to accommodate for changing pollution load**	prange	lower=-100, upper=200	
27*	**Odour**	dtriangle	a=1, b=1, c=2	

Transfer coefficients

	Recovered	Air loss	Soil loss	Water loss	Comments	Reference
TP	0.98		0.01	0.01	* higher losses with surface application than incorporation into soil	(Dunigan and Dick 1980)
med.	0.98		0.01	0.01		
k	**100 [EJ]**					
TN	0.94	0.04	0.01	0.01	* higher losses with surface application than incorporation into soil	(Dunigan and Dick 1980)
med.	0.94	0.04	0.01	0.01		
k	**100 [EJ]**					
H2O	0.98		0.01	0.01		EJ
med.	0.98		0.01	0.01		
k	**100 [EJ]**					
TS	0.69		0.3	0.01	EJ based on: Effects are comparable to processed sludge application	(Lima et al. 2009)
med.	0.69		0.3	0.01		
k	**5 [EJ]**					

D4. Application of compost/pit humus

Definition: Compost is a soil-like substance, while the appearance of pit humus depends on materials added to the faeces initially. Both can be added to agricultural soils to improve the structure and water-holding capacity and reduce the use of chemical fertilizers (Tilley et al. 2014).

FG: use and/or disposal (D)

Products: compost, transported compost, pit humus, transported pit humus ->

Relations: Input: OR
Output: NA

Appropriateness

No.	Attribute name	Function	Value	Comment
5	**Frequency of O&M**	drange	lower=1, upper=2	
6	**Temperature range**	ptrapez	a=-5, b=5, c=30, d=40	
7	**Flooding**	ptrapez	a=0, b=0, c=12, d=50	
14	**Construction skills**	dtriangle	a=1, b=3, c=2	
15	**Design skills**	dtriangle	a=2, b=4, c=3	
16	**O&M skills**	dtriangle	a=2, b=4, c=3	
17	**Management**	pcat	household=1, shared=1, public=0.5	
21	**Spare parts supply**	dcat	low tech=1, technical parts=0 , specially manufactured=0	
22*	**Surface area**	prange	lower=0.5, upper=10000	
24*	**Potential to accommodate for changing pollution load**	prange	lower=-100, upper=200	
27*	**Odour**	dtriangle	a=1, b=1, c=2	

Transfer coefficients

	Recovered	Air loss	Soil loss	Water loss	Comments	Reference
TP	0.98		0.01	0.01		EJ
med.	0.98		0.01	0.01		
k	**100 [EJ]**					
TN	0.94	0.04	0.01	0.01		EJ based on (He et al. 2003)
med.	0.94	0.04	0.01	0.01		
k	**100 [EJ]**					
H2O	0.98		0.01	0.01		EJ
med.	0.98		0.01	0.01		
k	**100 [EJ]**					
TS	0.69		0.3	0.01	EJ based on: Effects are comparable to processed sludge application	(Lima et al. 2009)
med.	0.69		0.3	0.01		
k	**5 [EJ]**					

D5. Application of processed sludge

Definition: Digested or stabilized sludge can be applied to public or private lands for landscaping or agriculture (Tilley et al. 2014).

FG: use and/or disposal (D)

Products: processed sludge, transported processed sludge, pit humus, transported pit humus, transported pellets ->

Relations: Input: OR
Output: NA

Appropriateness

No.	Attribute name	Function	Value	Comment
5	**Frequency of O&M**	drange	lower=1, upper=2	
6	**Temperature range**	ptrapez	a=-5, b=5, c=30, d=40	
7	**Flooding**	ptrapez	a=0, b=0, c=12, d=50	
14	**Construction skills**	dtriangle	a=1, b=3, c=2	
15	**Design skills**	dtriangle	a=2, b=4, c=3	
16	**O&M skills**	dtriangle	a=2, b=4, c=3	
17	**Management**	pcat	household=1, shared=1, public=1	
21	**Spare parts supply**	dcat	low tech=1, technical parts=0 , specially manufactured=0	
22*	**Surface area**	prange	lower=0.5, upper=10000	
24*	**Potential to accommodate for changing pollution load**	prange	lower=-100, upper=200	
27*	**Odour**	dtriangle	a=1, b=1, c=4	

Transfer coefficients

	Recovered	Air loss	Soil loss	Water loss	Comments	Reference
TP	0.96		0.01	0.03	* fresh manure	(Smith et al. 1998)
med.	0.96		0.01	0.03		
k	**25 [EJ]**					
TN	0.9	0.1	0	0	* 11- 60% of applied NH4-N lost by NH3 volatilization (depending on soil and rate of sludge addition), for TN see calculation 1	(Ryan and Keeney 1975)
	0.88	0.07	0.01	0.03		EJ based on (Smith et al. 1998)
med.	0.89	0.08	0.01	0.02		
k	**25 [EJ]**					
H2O	0.98		0.01	0.01		EJ
med.	0.98		0.01	0.01		
k	**100 [EJ]**					
TS	0.69		0.3	0.01	Organic Matter content in processed sludge is 40-70%; EJ: upper range used to account for inorganic beneficial compounds	(Torri et al. 2014)
med.	0.69		0.3			
k	**25 [EJ]**					

Calculations

1.

	Processed sludge				**med.s**	**TC_lost_min**	**TC_lost_max**
Total N	54 329	40 143	35 449	34 457	37 796	0.03	0.17
NH_{4-N}	31 879	11 735	9 394	8 069	10 565	0.11	0.6
% Ammonia of TN	0.59	0.29	0.27	0.23	0.28		
	Data from: (Ryan and Keeney 1975)						

D6. Surface solids disposal

Definition: Stockpiling of sludge, faeces or other materials that cannot be used elsewhere. Once the material has been taken to a surface disposal site, it is not used later (Tilley et al. 2014).

FG: use and/or disposal (D)

Products: dried faeces, transported dried faeces, compost, transported compost, processed sludge, transported processed sludge, pit humus, transported pit humus ->

Relations: Input: OR
Output: NA

Appropriateness

No.	Attribute name	Function	Value	Comment
5	**Frequency of O&M**	drange	lower=1, upper=2	
6	**Temperature range**	ptrapez	a=-5, b=5, c=30, d=40	
7	**Flooding**	ptrapez	a=0, b=0, c=12, d=50	
14	**Construction skills**	dtriangle	a=1, b=3, c=2	
15	**Design skills**	dtriangle	a=2, b=4, c=3	
16	**O&M skills**	dtriangle	a=2, b=4, c=3	
17	**Management**	pcat	household=1, shared=1, public=1	
21	**Spare parts supply**	dcat	low tech=1, technical parts=0 , specially manufactured=0	

Transfer coefficients

	Recovered	Air loss	Soil loss	Water loss	Comments	Reference
TP	0	0	0.97	0.03		EJ
med.	0.00	0.00	0.97	0.03		
k	**25 [EJ]**					
TN	0	0.01	0.96	0.03		EJ
med.	0.00	0.01	0.96	0.03		
k	**25 [EJ]**					
H2O	0	0.03	0.96	0.01		EJ
med.	0.00	0.03	0.96	0.01		
k	**100 [EJ]**					
TS	0	0.03	0.96	0.01		EJ
med.	0.00	0.03	0.96	0.01		
k	**100 [EJ]**					

D7. Biogas combustion

Definition: In principal, biogas can be used like other fuel gas. When produced in household-level biogas reactors, it is most suitable for cooking. Electricity generation is a valuable option when the biogas is produced in large anaerobic digesters (Tilley et al. 2014).

FG: use and/or disposal (D)

Products: biogas, transported biogas ->

Relations: Input: XOR
Output: NA

Appropriateness

No.	Attribute name	Function	Value	Comment
5	**Frequency of O&M**	drange	lower=0, upper=1	
6	**Temperature range**	prange	lower=-20, upper=50	
14	**Construction skills**	dtriangle	a=2, b=4, c=3	
15	**Design skills**	dtriangle	a=2, b=4, c=3	
16	**O&M skills**	dtriangle	a=1, b=3, c=2	
17	**Management**	pcat	household=1, shared=1, public=1	
20*	**Concrete supply**	pcat	easy=1, medium=1, hard=0.5	
21	**Spare parts supply**	dcat	low tech=0.8, technical parts=0.2 , specially manufactured=0	
22*	**Surface area**	prange	lower=0.2, upper=10000	
25*	**User awareness requirements**	ptrapez	a=1, b=1, c=2, d=6	

Transfer coefficients

	Recovered	Air loss	Soil loss	Water loss	Comments	Reference
TP	0	1	0	0		EJ
med.	0.00	1	0	0		
k	**25 [EJ]**					
TN	0	1	0	0		EJ
med.	0	1	0	0		
k	**100 [EJ]**					
H2O	0	1				EJ
med.	0.00	1				
k	**100 [EJ]**					
TS	0.95		0.05			EJ
med.	0.95		0.05			
k	**25 [EJ]**					

D8. Briquettes as fuel

Definition: The briquettes can be used like charcoal in any cooking or heating application.
FG: use and/or disposal (D)
Products: transported briquettes ->
Relations: Input: NA
Output: NA

Appropriateness

No.	Attribute name	Function	Value	Comment
5	**Frequency of O&M**	drange	lower=0, upper=1	
6	**Temperature range**	prange	lower=-20, upper=50	
14	**Construction skills**	dtriangle	a=2, b=4, c=3	
15	**Design skills**	dtriangle	a=2, b=4, c=3	
16	**O&M skills**	dtriangle	a=1, b=3, c=2	
17	**Management**	pcat	household=1, shared=1, public=1	
21	**Spare parts supply**	dcat	low tech=0.8, technical parts=0.2 , specially manufactured=0	

Transfer coefficients

	Recovered	Air loss	Soil loss	Water loss	Comments	Reference
TP	0	0.05	0.95	0	some airloss is assumed, rest to ash	EJ
med.	0.00	0.05	0.95	0.00		
k	**25 [EJ]**					
TN	0	0.5	0.5	0	50% of airloss, rest goes to ash	EJ
med.	0.00	0.50	0.50	0.00		
k	**5 [EJ]**					
H2O	0	1				EJ
med.	0.00	1.00				
k	**100 [EJ]**					
TS	0.5		0.5		50% can be reused, all the rest is lost - based on the assumption that all the ash + some of the rest of TS contribute to the calorific value	EJ
med.	0.50		0.50			
k	**25 [EJ]**					

D9. Soak pit

Definition: A covered, porous-walled chamber that allows water to slowly soak into the ground (Tilley et al. 2014).
FG: use and/or disposal (D)
Products: effluent, greywater, secondary effluent, urine, stored urine, stabilized urine ->
Relations: Input: OR
Output: NA

Appropriateness

No.	Attribute name	Function	Value	Comment
5	**Frequency of O&M**	drange	lower=1, upper=4	
6	**Temperature range**	ptrapez	a=-10, b=0, c=50, d=50	
7	**Flooding**	Ptrapez	a=0, b=0, c=6, d=30	
9	**Slope**	ptrapez	a=0, b=0, c=70, d=100	
10	**Soil type/ hydraulic conductivity**	pcat	clay=0, silt=0.5, sand=1, gravel=1	
11	**Groundwater depth**	ptrapez	a=3.5, b=6, c=100, d=100	
12	**Excavtation**	pcat	easy=1, hard=0.5	
14	**Construction skills**	dtriangle	a=1, b=3, c=2	
15	**Design skills**	dtriangle	a=3, b=5, c=4	
16	**O&M skills**	dtriangle	a=2, b=4, c=3	
17	**Management**	pcat	household=1, shared=1, public=0	
20*	**Concrete supply**	Pcat	easy=1, medium=1, hard=0.5	
21	**Spare parts supply**	dcat	low tech=1, technical parts=0 , specially manufactured=0	
22*	**Surface**	prange	lower=0.5 ,upper=10000	
23*	**Potential to accommodate for changing water volume**	ptrapez	a=-100, b=-50, c=50, d=100	
24*	**Potential to accommodate for changing pollution load**	ptrapez	a=-100, b=-50, c=50, d=100	
27*	**Odour**	dtriangle	a=1, b=1, c=2	

Transfer coefficients

	Recovered	Air loss	Soil loss	Water loss	Comments	Reference
TP	0		1			EJ
med.	0		1			
k	**100 [EJ]**					
TN	0		1			EJ
med.	0		1			
k	**100 [EJ]**					
H2O	0		1			EJ
med.	0		1			
k	**100 [EJ]**					
TS	0		1			EJ
med.	0		1			
k	**100 [EJ]**					

D10. Irrigation

Definition: Wastewater can be used for irrigation to reduce dependence on freshwater and have a constant supply. To lower the risk of crop contamination, only wastewater that has had secondary treatment should be used via drip irrigation or surface water irrigation (Tilley et al. 2014).
FG: use and/or disposal (D)
Products: effluent, transported effluent, secondary effluent, transported secondary effluent, stormwater, transported stormwater ->
Relations: Input: OR
Output: NA

Appropriateness

No.	Attribute name	Function	Value	Comment
5	**Frequency of O&M**	drange	lower=1, upper=2	
6	**Temperature range**	ptrapez	a=0, b=5, c=50, d=50	
7	**Flooding**	Ptrapez	a=0, b=0, c=6, d=60	
9	**Slope**	ptrapez	a=0, b=0, c=70, d=100	
15	**Design skills**	dtriangle	a=4, b=6, c=5	
16	**O&M skills**	dtriangle	a=2, b=4, c=3	
17	**Management**	pcat	household=0.5, shared=1, public=1	
21	**Spare parts supply**	dcat	low tech=1, technical parts=0 , specially manufactured=0	
22*	**Surface area**	prange	lower=5, upper=10000	
27*	**Odour**	dtriangle	a=1, b=1, c=2	

Transfer coefficients

	Recovered	Air loss	Soil loss	Water loss	Comments	Reference
TP	0.9		0.1		* retainment depends on soil type	(Odindo et al. 2016)
med.	0.9		0.1			
k	**25 [EJ]**					
TN	0.87	0.03	0.1		* retainment depends on soil type	(Odindo et al. 2016)
med.	0.87	0.03	0.1			
k	**25 [EJ]**					
H2O	0.9		0.1		* retainment depends on soil type	(Odindo et al. 2016)
med.	0.9		0.1			
k	**25 [EJ]**					
TS	0.9		0.1		* retainment depends on soil type	(Odindo et al. 2016)
med.	0.9		0.1			
k	**25 [EJ]**					

D11. Surface Water Disposal

Definition: Treated effluent and/or stormwater can be directly discharged into receiving water bodies (Tilley et al. 2014).

FG: use and/or disposal (D)

Products: secondary effluent, transported secondary effluent, stormwater, transported stormwater ->

Relations: Input: OR
Output: NA

Appropriateness

No.	Attribute name	Function	Value	Comment
5	**Frequency of O&M**	dtriangle	a=1, b=3, c=2	
6	**Temperature range**	ptrapez	a=0, b=5, c=50, d=50	
7	**Flooding**	Ptrapez	a=0, b=0, c=4, d=40	
9	**Slope**	ptrapez	a=0, b=0, c=50, d=100	
15	**Design skills**	dtriangle	a=4, b=6, c=5	
16	**O&M skills**	drange	lower=3, upper=5	
17	**Management**	pcat	household=0.1, shared=0.5, public=1	

Transfer coefficients

	Recovered	Air loss	Soil loss	Water loss	Comments	Reference
TP	0			1		EJ
med.	0			1		
k	**100 [EJ]**					
TN	0			1		EJ
med.	0			1		
k	**100 [EJ]**					
H2O	0			1		EJ
med.	0			1		
k	**100 [EJ]**					
TS	0			1		EJ
med.	0			1		
k	**100 [EJ]**					

6 Literature

Al Seadi, T., Drosg, B., Fuchs, W., Rutz, D. and Janssen, R. (2013) The biogas handbook. Wellinger, A., Baxter, D. and Murphy, J. (eds), pp. 267–301, Woodhead Publishing Limited, Oxford.

Alcocer, J., Lugo, A., López, A. and Rosario Sánchez, M. (1993) Efficiency of a waste stabilization pond system in a subtropical area of Mexico. Revista Internacional de Contaminación Ambiental 9(1), 29–36.

Álvarez, J.A., Ruíz, I. and Soto, M. (2008) Anaerobic digesters as a pretreatment for constructed wetlands. Ecological Engineering 33(1), 54–67.

Amoah, P., Gbenatey Nartey, E. and Schrecongost, A. (2016) Performance evaluation of biofil toilet waste digester technologies in Ghana: The efficacy of effluent treatment options. Environmental Technology 37(23), 3002–3013.

Andriessen, N., Ward, B.J. and Strande, L. (2019) To char or not to char? Review of technologies to produce solid fuels for resource recovery from faecal sludge. Journal of Water, Sanitation and Hygiene For Development 10.2166/washdev.2019.184.

Bachmann, N., La Jansen, J.C., Baxter, D., Bochmann, G. and Montpart, N. (2015) Sustainable biogas production in municipal wastewater treatment plants, IEA Bioenergy, [Great Britain].

Belevi, H. (2002) Material flow analysis as a strategic planning tool for regional waste water and solid waste management, pp. 13-15.

Benitez, E., Nogales, R., Elvira, C., Masciandaro, G. and Ceccanti, B. (1999) Enzyme activities as indicators of the stabilization of sewage sludges composting with Eisenia foetida. Bioresource Technology 67(3), 297–303.

Bernal-Martínez, A., González-Barceló, Ó. and González-Martínez, S. (2000) Nutrient removal and sludge age in a sequencing batch reactor. Bioprocess Engineering 23(1), 41–45.

Bezanson, J., Edelman, A., Karpinski, S. and Shah, V.B. (2017) Julia: A Fresh Approach to Numerical Computing. SIAM Review 59(1), 65-98.

Cofie, O.O., Agbottah, S., Strauss, M., Esseku, H., Montangero, A., Awuah, E. and Kone, D. (2006) Solid-liquid separation of faecal sludge using drying beds in Ghana: implications for nutrient recycling in urban agriculture. Water Res 40(1), 75-82.

Conradin, K., Kropac, M. and Spuhler, D. (2010) The SSWM Toolbox, seecon international gmbh, Basel.

Consoli, S., Milani, M., Cirelli, G., Barbagallo, S., Marzo, A., Vanella, D. and Toscano, A. (2018) Energy and water balance of a treatment wetland under mediterranean climatic conditions. Ecological Engineering 116, 52–60.

Dunigan, E.P. and Dick, R.P. (1980) Nutrient and Coliform Losses in Runoff from Fertilized and Sewage Sludge-Treated Soil. Journal of Environment Quality 9(2), 243.

Eawag (2014) eCompendium – The Online Compendium of Sanitation Systems and Technologies, Dübendorf.

Esrey, S.A., Gough, J., Rapaport, D., Sawyer, R., Simpson-Hébert, M. and Vargas, J. (1998) Ecological sanitation, p. 92 s, Department for Natural Resources and the Environment, Stockholm.

Etter, B., Tilley, E., Khadka, R. and Udert, K.M. (2011) Low-cost struvite production using source-separated urine in Nepal. Water Research 45(2), 852-862.

Etter, B., Udert, K.M. and Gounden, T. (2015) VUNA Final Report, Eawag: Tghe Swiss Federal Institute of Aquatic Science & Technology, Duebendorf, Switzerland.

Gupta, R. and Garg, V.K. (2008) Stabilization of primary sewage sludge during vermicomposting. Journal of hazardous materials 153(3), 1023–1030.

Hafford, L.M., Ward, B.J., Weimer, A.W. and Linden, K. (2017) Fecal Sludge as a Fuel: Characterization, cofire limits, and two methods to improve its quality.

Hait, S. and Tare, V. (2011) Vermistabilization of primary sewage sludge. Bioresource Technology 102(3), 2812–2820.

Hamader, K. and Javorszky, M. (2014) Analysis of Mass Flows for Water Supply and Wastewater Treatment Technologies, p. 37.

Hauser, B.A. (1996) Practical manual of wastewater chemistry, Ann Arbor Press, Chelsea, Mich.

He, Z.L., Calvert, D.V., Alva, A.K., Li, Y.C., Stoffella, P.J. and Banks, D.J. (2003) Nitrogen Transformation and Ammonia Volatilization From Biosolids and Compost Applied to Calcareous Soil. Compost Science & Utilization 11(1), 81-88.

Headley, T.R., Davison, L., Huett, D.O. and Müller, R. (2012) Evapotranspiration from subsurface horizontal flow wetlands planted with Phragmites australis in sub-tropical Australia. Water Research 46(2), 345–354.

Heinonen-Tanski, H. and van Wijk-Sijbesma, C. (2005) Human excreta for plant production. Bioresource Technology 96(4), 403–411.

Ho, L.T., van Echelpoel, W. and Goethals, P.L.M. (2017) Design of waste stabilization pond systems: A review. Water Research 123, 236–248.

Howard, K.W.F. (ed) (2007) Urban groundwater - meeting the challenge: Selected papers from the 32nd International Geological Congress (IGC), Florence, Italy, August 2004 ; Matthias Eiswirth Memorial Volume, Taylor & Francis, London.

Jacks, G., Sefe, F., Carling, M., Hammar, M. and Letsamao, P. (1999) Tentative nitrogen budget for pit latrines - eastern Botswana. Environmental Geology 38(3), 199–203.

Jones, J. (2017) Closing the Poop Loop. The Chemical Engineer doi:10.2134/jeq1980.00472425000900020016x(913/14).

Jönsson, H.k., Richert, A., Vinnerås, B.r. and Salomon, E. (2004) Guidelines on the Use of Urine and Faeces in Crop Production, EcoSanRes Programme,
Stockholm Environment Institute (SEI).

Kampschreur, M.J., Temmink, H., Kleerebezem, R., Jetten, M.S.M. and van Loosdrecht, M.C.M. (2009) Nitrous oxide emission during wastewater treatment. Water Research 43(17), 4093–4103.

Keller, J., Watts, S., Battye-Smith, W. and Chong, R. (2001) Full-scale demonstration of biological nutrient removal in a single tank SBR process. Water Sci Technol 43(3), 355–362.

Kirchmann, H. and Pettersson, S. (1995) Human urine - Chemical composition and fertilizer use efficiency. Fertilizer Research 40(2), 149–154.

Koottatep, T., Wanasen, S.-a. and Morel, A. (2018) Potential of the Anaerobic Baffled Reactor as decentralized wastewater treatment system in the tropics.

Kuffour, R.A. (2015) Improving Faecal Sludge Dewatering Efficiency of Unplanted Drying Bed.

Lalander, C.H., Hill, G.B. and Vinnerås, B. (2013) Hygienic quality of faeces treated in urine diverting vermicomposting toilets. Waste Manag 33(11), 2204-2210.

Lalander, C.H., Komakech, A.J. and Vinnerås, B. (2015) Vermicomposting as manure management strategy for urban small-holder animal farms - Kampala case study. Waste management (New York, N.Y.) 39, 96–103.

Leitzinger, C. (2001) Waste Composting for Urban and Peri-urban Agriculture: Closing the Rural-Urban Nutrient Cycle in Sub-Saharan Africa // Waste composting for urban and peri-urban agriculture. Bradford, A.M. (ed), p. 150, International Water Management Institute (IWMI) Food and Agriculture Organization of the United Nations (FAO) CABI Publishing, Oxon; UK.

Lima, D.L.D., Santos, S.M., Scherer, H.W., Schneider, R.J., Duarte, A.C., Santos, E.B.H. and Esteves, V.I. (2009) Effects of organic and inorganic amendments on soil organic matter properties. Geoderma 150(1-2), 38–45.

Lochmatter, S., Maillard, J. and Holliger, C. (2014) Nitrogen removal over nitrite by aeration control in aerobic granular sludge sequencing batch reactors. International Journal of Environmental Research and Public Health 11(7), 6955–6978.

Lüthi, C., Morel, A., Tilley, E. and Ulrich, L. (2011) Community-Led Urban Environmental Sanitation Planning (CLUES), Swiss Federal Institute of Aquatic Science and Technology (Eawag), Dubendorf.

Maurer, M., Bufardi, A., Tilley, E., Zurbrügg, C. and Truffer, B. (2012) A compatibility-based procedure designed to generate potential sanitation system alternatives. Journal of Environmental Management 104(15 August, 2012), 51-61.

Maurer, M., Pronk, W. and Larsen, T.A. (2006) Treatment processes for source-separated urine. Water Research 40(17), 3151-3166.

Meinzinger, F. (2010) Resource efficiency of urban sanitation systems: a comparative assessment using material and energy flow analysis, Technischen Universität Hamburg-Harburg.

Minale, M. and Worku, T. (2014) Anaerobic co-digestion of sanitary wastewater and kitchen solid waste for biogas and fertilizer production under ambient temperature: Waste generated from condominium house. International Journal of Environmental Science and Technology 11(2), 509–516.

Montangero, A. and Belevi, H. (2007) Assessing nutrient flows in septic tanks by eliciting expert judgement: a promising method in the context of developing countries. Water Res 41(5), 1052-1064.

Montangero, A. and Strauss, M. (2002) Faecal Sludge Treatment, Duebendorf, Switzerland.

Mudrack, K. and Kunst, S. (2003) Biologie der Abwasserreinigung: 18 Tabellen, Spektrum Akad. Verl., Heidelberg.

Nasr, F.A., Doma, H.S. and Nassar, H.F. (2009) Treatment of domestic wastewater using an anaerobic baffled reactor followed by a duckweed pond for agricultural purposes. The Environmentalist 29(3), 270–279.

Nasr, F.A. and Mikhaeil, B. (2013) Treatment of domestic wastewater using conventional and baffled septic tanks. Environmental Technology 34(13-16), 2337–2343.

Nasr, F.A. and Mikhaeil, B. (2014) Treatment of domestic wastewater using modified septic tank. Desalination and Water Treatment 56(8), 2073–2081.

Nikiema, J., Cofie, O. and Impraim, R. (2014) Technological options for safe resource recovery from fecal sludge, International Water Management Institute (IWMI). CGIAR Research Program on Water, Land and Ecosystems (WLE).

Nyenje, P.M., Foppen, J.W., Kulabako, R., Muwanga, A. and Uhlenbrook, S. (2013) Nutrient pollution in shallow aquifers underlying pit latrines and domestic solid waste dumps in urban slums. Journal of Environmental Management 122, 15–24.

O'Shaughnessy, S.A., Song, I., Artiola, J.F. and Choi, C.Y. (2008) Nitrogen loss during solar drying of biosolids. Environ Technol 29(1), 55-65.

Odindo, A.O., Bame, I.B., Musazura, W., Hughes, J.C. and Buckley, C.A. (2016) Integrating Agriculture in Designing On-site, Low Cost Sanition Technonologies in Social Housing Schemes, South Africa.

Poach, M.E., Hunt, P.G., Sadler, E.J., Matheny, T.A., Johnson, M.H., Stone, K.C., Humenik, F.J. and Rice, J.M. (2002) Ammonia volatilization from constructed wetlands that treat swine wastewater. Transactions of the ASAE 45(3), 619-627.

Polprasert, C. and Rajput, V.S. (1982) Septic Tank and Septic Systems, Bangkok, Thailand.

R Development Core Team (2018) R: A language and environment for statistical computing, R Foundation for Statistical Computing, Vienna, Austria.

Rahman, M.M., Shahidullah, A.H.M. and Ali, M.A. (1999) An evaluation of septic tank performance: Proceedings from 25th Water Engineering Development Center Conference on Integrated Development for Water Supply and Sanitation, Addis Ababa, Ethiopia.

Regmi, M.R. (2005) A sustainable approach towards rural development: Dry toilets in Nepal. Water Science and Technology 52(12), 19.

Reynolds, J.H. and Barrett, M.H. (2003) A review of the effects of sewer leakage on groundwater quality. Water and Environment Journal 17(1), 34–39.

Rieck, C., Münch, E. and Hoffmann, H. (2011) Technology Review of Urine-diverting dry toilets (UDDTs): Overview of design, operation, management and costs, p. 60, Eschborn.

Rose, C., Parker, A., Jefferson, B. and Cartmell, E. (2015) The Characterization of Feces and Urine: A Review of the Literature to Inform Advanced Treatment Technology. Crit Rev Environ Sci Technol 45(17), 1827-1879.

Ryan, J.A. and Keeney, D.R. (1975) Ammonia Volatilization from Surface-Applied Wastewater Sludge. Journal (Water Pollution Control Federation) 47(2), 386-393.

Sahito, A.R., Mahar, R.B., Siddiqui, Z. and Brohi, K.M. (2013) Estimating calorific values of lignocellulosic biomass from volatile and fixed solids. International Journal ofbiomass & renewables 2(1).

Sasse, L. (1998) DEWATS: Decentralised Wastewater Treatment in Developing Countries, Bremen.

Scholz, M. (2006) Wetland systems to control urban runoff, Elsevier, Amsterdam; Boston.

Schouw, N.L., Danteravanich, S., Mosbaek, H. and Tjell, J.C. (2002) Composition of human excreta — a case study from Southern Thailand. Science of the total environment 286(1-3), 155–166.

Seabloom, R.W., Bounds, T.R. and Loudon, T.L. (2004) Septik Tanks: University Curriculum Development for Decentralized Wastewater Management: National Decentralized Water Resources Capacity Development Project, p. 68.

Septien, S., Singh, A., Mirara, S.W., Teba, L., Velkushanova, K. and Buckley, C.A. (2018) 'LaDePa' process for the drying and pasteurization of faecal sludge from VIP latrines using infrared radiation. South African Journal of Chemical Engineering 25, 147–158.

Sheng, C. and Azevedo, J.L.T. (2005) Estimating the higher heating value of biomass fuels from basic analysis data. Biomass and Bioenergy 28(5), 499–507.

Shizas, I. and Bagley, D.M. (2004) Experimental Determination of Energy Content of Unknown Organics in Municipal Wastewater Streams. Journal of Energy Engineering 130(2), 45–53.

Siegrist, R.L. (2017) Decentralized Water Reclamation Engineering, Springer International Publishing, Cham.

Smith, K.A., Chalmers, A.G., Chambers, B.J. and Christie, P. (1998) Organic manure phosphorus accumulation, mobility and management. Soil Use and Management 14(s4), 154-159.

Soares, J., Silva, S.A., Oliveira, R.d., Araujo, A.L.C., Mara, D.D. and Pearson, H.W. (1996) Ammonia removal in a pilot-scale WSP complex in Northeast Brazil. Water Science and Technology 33(7), 165–171.

Sperling, M.v. (2007) Wastewater Characteristics, Treatment and Disposal, IWA Publishing, London.

Spuhler, D., Scheidegger, A. and Maurer, M. (2018) Generation of sanitation system options for urban planning considering novel technologies. Water Research 145, 259-278.

Spuhler, D., Scheidegger, A. and Maurer, M. (2020) Ex-ante quantification of nutrient, total solids, and water flows in sanitation systems. Submitted to Water Research.

Strande, L., Ronteltap, M. and Brdjanovic, D. (2014) Faecal Sludge Management: Systems Approach for Implementation and Operation, IWA Publishing.

SuSanA (2008) Towards more sustainable sanitation solutions - SuSanA Vision document, Sustainable Sanitation alliance (SuSanA).

Tchobanoglous, G., Burton, F.L. and Stensel, H.D. (2009) Wastewater engineering: Treatment and reuse, McGraw-Hill, Boston, Mass.

Tilley, E., Ulrich, L., Lüthi, C., Reymond, P. and Zurbrügg, C. (2014) Compendium of Sanitation Systems and Technologies - 2nd revised edition, Swiss Federal Institute of Aquatic Science and Technology (EAWAG), Duebendorf, Switzerland.

Torri, S.I., Corrêa, R.S. and Renella, G. (2014) Soil Carbon Sequestration Resulting from Biosolids Application. Applied and Environmental Soil Science 2014(3), 1–9.

Udert, K.M., Buckley, C.A., Wächter, M., McArdell, C.S., Kohn, T., Strande, L., Zöllig, H., Fumasoli, A., Oberson, A. and Etter, B. (2015) Technologies for the treatment of source-separated urine in the eThekwini Municipality. Water SA 41(2), 212.

Udert, K.M., Larsen, T.A. and Gujer, W. (2006) Fate of major compounds in source-separated urine. Water Science and Technology 54(11-12), 413–420.

Vertregt, N. and Rutgers, B. (1987) Animal Manure on Grassland and Fodder Crops. Fertilizer or Waste? Van Der Meer, H.G., Unwin, R.J., Dijk, T.A. and Ennik, G.C. (eds), pp. 361–363, Springer Netherlands, Dordrecht.

Villeneuve, J., Michel, P., Ménard, Y., Fehringer, R., Brandt, B., Brunner, P.H., Daxbeck, H., Neumayer, S. and Smutny, R. (2004) MFA-MANUAL. Guidelines for the Use of Material Flow Analysis (MFA) for Municipal Solid Waste (MSW) Management (Project AWAST), Ressourcen Management Agentur (RMA). Technische Universität Wien. BRGM. University of Stuttgart.

Vinnerås, B., Palmquist, H., Balmér, P. and Jönsson, H. (2006) The characteristics of household wastewater and biodegradable solid waste—A proposal for new Swedish design values. Urban Water Journal 3(1), 3-11.

Vymazal, J. (2007) Removal of nutrients in various types of constructed wetlands. Sci Total Environ 380(1-3), 48–65.

Vymazal, J. (2010) Constructed Wetlands for Wastewater Treatment. Water 2(3), 530–549.

Wanasen, S.-A. (2003) Upgrading conventional septic tanks by integrating in-tank baffles, p. 81.

Werther, J. and Ogada, T. (1999) Sewage sludge combustion. Progress in Energy and Combustion Science 25(1), 55–116.

Wilderer, P.A., Goronszy, M.C. and Irvine, R.L. (2000) Sequencing batch reactor technology, IWA, London.

Xian-Hua, W. (1994) Graphical presentation of the transformation of some nutrients in a wastewater stabilization pond system. Water Research 28(7), 1659–1665.

Xylem (2015) Case study: Increasing Denitrification in Sequencing Batch Reactors with Continuous Influent Feed, Sweden.

Yadav, K.D., Tare, V. and Ahammed, M.M. (2010) Vermicomposting of source-separated human faeces for nutrient recycling. Waste Manag 30(1), 50–56.

Yadav, K.D., Tare, V. and Ahammed, M.M. (2012) Integrated composting–vermicomposting process for stabilization of human faecal slurry. Ecological Engineering 47, 24–29.

Yin, C.-Y. (2011) Prediction of higher heating values of biomass from proximate and ultimate analyses. Fuel 90(3), 1128–1132.

Zavala, M.A.L. and Funamizu, N. (2005) Effect of Moisture Content on the Composting Process In a Biotoilet System. Compost Science & Utilization 13(3), 208–216.

Zhang, Y. and Li, H. (2017) Energy recovery from wastewater treatment plants through sludge anaerobic digestion: Effect of low-organic-content sludge. Environmental science and pollution research international 10.1007/s11356-017-0184-y.

Zhu, J., Zhang, Z. and Miller, C. (2006) A Laboratory Scale Sequencing Batch Reactor with the Addition of Acetate to remove Nutrient and Organic Matter in Pig Slurry. Biosystems Engineering 93(4), 437–446.