**Structured Approach for Comparison of Treatment Options for Nutrient-recovery from Fecal Sludge**

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**SUPPLEMENTRARY MATERIAL**

S1: Interview Questions

S2: Multi-criteria Assessment – process details & evaluation

**S1: Interview Questions**

Sample questions from semi-structured interviews. Note that questions were adapted to match the specific knowledge areas and responsibilities of each stakeholder. Semi-structured interviews were held with representatives from five different municipalities in Metropolitan Kampala, the water and sanitation utility, one ministry, two research institutions and one NGO.

*General information on sanitation, reuse & decision-making*

* What is the core mission of your organization with regards to sanitation?
* Does your organization work with reuse? In what way?
* What type of criteria you use in decision-making regarding on-site sanitation systems that are implemented?
* What criteria are most important in decision-making?

*Probing issues regarding Recycled product*

* What criteria do recycled waste products need to meet to be appropriate for agriculture application?

*Probing issues regarding Institutional & Health issues*

* Do standards/policy exist for regulating the quality of the reused products? How are these applied?
* Is there any control of the quality of the reused products?

*Probing issues regarding Socio-technical issues*

* Has there been any change in how resource recovery has been viewed in the last ten years, or as long as you have worked?
* Do you see a market for reused waste products?
* What challenges have you encountered with reuse? What is limiting the use of recycled waste products?

**S2: Multi-criteria Assessment – process details & evaluation**

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| **Table S1:** Details of how scores were assigned for the various criteria in the multi-criteria assessment. In general, ++ means considerable better, + mean better, 0 means the same quality, - means worse, -- means considerably worse. | | | |
| **Criteria** | **Current system** | **Scoring** | |
| **Pathogen exposure in end-product** | Significant coliform die-off. Ascaris likely remains | **++** | Log 6 or greater reduction of major pathogens  *(e.g. viruses, fecal coliforms, Ascaris*) |
| **+** | Reduction but less than Log 6 reduction of major pathogens *(e.g. viruses, fecal coliforms, Ascaris)* |
| **0** | Similar reduction of major pathogens |
| **Capital costs** | Annualized capital investment for FSTP approx.  USD $650 0001 | **0** | Same/minimal change |
| **-** | Low additional investment |
| **- -** | Moderate additional investment |
| **O&M costs** | Annual O&M costs for FSTP approx.  USD$200 0001 | **0** | Same/minimal change = 0 |
| **-** | Additional annual costs less than US$20000 (10% increase) |
| **- -** | Additional annual O&M cost greater than US$20000 |
| **Value of product** | Contains ~4,6 g P and 23 g N per kg sludge. Sold for ~UD$3.50 per ton. | **++** | Value of the end-product is greatly increased (*valued at more than UD$20 per ton)* |
| **+** | Value of the end-product is slightly increased (*valued at US$5-UD$20 per ton, or other improved qualities)* |
| **0** | Same/minimal change |
| **Organizational capacity** | Exists | **0** | Same/minimal change |
| **-** | Can be operated by existing personal, provided they are giving additional training *(e.g. health and safety training)* |
| **- -** | Requires specialized knowledge and training |
| **Odor** | Slightly septic smell | **-** | Smell is pungent, chemical or otherwise unpalatable |
| **0** | Smells the same |
| **+** | Odor-free or more acceptable/pleasant odor |
| **Robustness** | Roofs leak leading to irregular treatment | **+** | More resilient to changing environmental conditions than the existing system |
| **0** | Same as reference |
| **-** | Sensitive to changing environmental conditions |
| **--** | Highly sensitive to changing environmental conditions |
| **Volume reduction** | Total sludge volume reduced ca 85% from incoming sludge | **+** | Sludge volume reduced in the process |
| **0** | Same as reference |
| **-** | Sludge volume increase in the process |

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| **Table S2:** Details of the information used to make the scoring in the multi-criteria assessment for improving safe, nutrient-recovery from Lubigi Fecal Sludge Treatment Plant, Kampala Uganda. | | | | | | | | |
|  | *Health* | | *Financial* | | *Institutional* | | *Socio-technical* | |
| **Pathogen exposure in end-product** | **Capital costs** | **O&M costs** | **Value of product** | **Organizational capacity** | **Odor** | **Robustness** | **Volume reduction** |
| **Current system** | Significant coliform die-off. Ascaris likely remains. | Annualized capital investment for FSTP USD $650000 | Annual O&M costs for FSTP USD$200000 | Contains ~4,6 g P and 23 g N per kg sludge. Sold for ~UD$3.50 per ton. | Exists | Slightly septic smell | Roofs leak leading to irregular treatment | Total sludge volume reduced ca 85% from incoming sludge. |
| **Optimized existing system** | Storage time > 1 year needed to achieve 6 log reduction in majority of pathogens.2 A 6 month storage time would improve sludge quality, but not reach 6 log reduction. | Investment required to fix leaking roofs and implement trash removal. Low investment. † | No change† | No change in quality of the sludge as a fertilizer.† | Same routines, same training needed † | No change\* | Repaired roofs lead to more regular treatment.3 | No change† |
| + | - | 0 | 0 | 0 | 0 | + | 0 |
| **Composting** | A well-operated thermophilic compost achieves complete *Ascaris* egg die-off within 7 weeks, as well as inactivation of excreted pathogens.4 | Possible to implement within existing covered storage areas, if roofs are repaired. Low investment.† | Additional labor needed for mixing compost (< full-time employee). Organic waste additives needed (unknown, but probably low cost).† | Composting process results in 10-50% N loss and 0.8-2.4 % P loss.5 Addition of organic waste increase organic content and nutrient value of the compost.† Compost price US$5 per ton6 | Well-trained maintenance staff are needed to properly operate the composting process.7 In addition, obtaining clean amendment material for the co-composting may be logistically challenging.† | “Earthy” smell is generally perceived as positive† | Composts are sensitive to changing temperatures and moisture contents and thus may be more sensitive to climate change.7 | Mass reduction by composting 11-31 %5, but additional material added so net resulting volume similar to current situation. |
| ++ | - | - | + | **- -** | + | - | 0 |
| **Vermicomposting** | Additional treatment needed for complete sanitization.8 | Investment in specialized compartments for worms needed. Can be done with locally available material. Moderate investment.\* | Additional labor needed for care of the worm beds, perhaps 1 full-time employee (~US$12000/year). No additional inputs needed. † | Worms can be sold as a protein feed, price assumed similar to BSF larvae, ~US$200 per ton.9 Organic residues could also be sold after additional treatment. | Well-trained maintenance staff are needed to properly operate a vermicomposting process.7 | Vermicomposting is odor free.8 | Vermicomposts are sensitive to changing temperatures and moisture contents.7 The worms are extremely sensitive and without proper management they will die.† | Similar to composting, vermicomposting reduces the total volume of sludge. Better then composting because additional organic matter not needed. |
| 0 | **- -** | - | ++ | **- -** | + | **- -** | + |
| **Black Soldier Fly composting** | BSF achieved 6 log reduction of Salmonella, but not for other fecal pathogens. Not sufficient pathogen reduction to produce class A Biosolids 10 | Investment in specialized compartments for larvae needed. Can be done with locally available material. Moderate investment.\* | Additional labor needed for care of the larvae beds, perhaps 1 full-time employee (~US$12000/year). Purchase of BSF eggs if a colony is not established (low cost). † | BSF larvae can be sold as a protein feed, ~US$200 per ton.9 Organic residues could also be sold after additional treatment. | Well-trained maintenance staff are needed to properly operate a BSF-composting process.\*† | There is a special pungent odor from BSF larvae that may not be appealing to some people. † | BSF larvae are robust and tolerate changes in feedstock, temperature and moisture well.† | 50% reduction wet-weight, 73% reduction in total TS10 |
| 0 | **- -** | - | ++ | **- -** | - | 0 | + |
| **Lactic acid fermentation** | Treated sludge may not be sufficiently treated and may still contain pathogens7 | Construction of sealed containers necessary to enable optimum treatment. Judged to be moderately expensive costly.† | Recirculation pump needed for inoculation of batches with bacteria, leading to an electrical cost or increased labor if done manually. 7 | As the fermentation is performed in sealed containers, there should be no change in nutrient content, nor added value of the sludge.† | New process unit. Staff will need training to properly operate it. † | The smell of fermentation is generally considered bad.† | Biological process that is susceptible to changing environmental conditions.7 | Water loss negligible in sealed containers. Some biological degradation occurs but may be offset by volumes of inoculant added at start of process. † |
| 0 | **- -** | - | 0 | **- -** | - | - | 0 |
| **Ammonia treatment** | Addition of 1% urea at 14-34C produced 6 log reduction within 2 months for Salmonella 11 | Investment needed for sealed containers for urea treatment. Judged to be moderately expensive.\*† | Addition of ~1.5% urea by weight. US$1.38 per kg of Urea in local stores. ~4500 tons sludge produced per year leads to cost of US$93 000 per year for urea. In addition to additional labor or pump for mixing/ loading containers.7\* | Addition of urea would increase the N content of the sludge. Urea worth US$20 per ton sludge has been added and some of this cost could be recovered in the sales price.\*† | System can be run with existing personal. Due to potential health risks when handling urea additional health and safety training is required.7 | Strong chemical smell reported by the students.\* | Sealed chemical treatment that is resilient to changing weather conditions.† | Chemical addition is minimal, water loss negligible in sealed containers and minimal biological activity so volume reduction would be minimal.† |
| ++ | **- -** | - - | + | - | - | + | 0 |
| **Alkaline stabilization** | Ca(OH)2 applied at 1g/L in soil gave 5 log E coli reduction after 7 days.12 Storage >6 months recommended after alkaline treatment to achieve 6 log reduction2 | Can be performed in existing covered storage areas with minor modifications. Low investment. \*† | Addition of ~10% lime by weight. Lime costs US$1.38 per kg in local stores. ~4500 tons sludge produced per year leads to cost of US$ 620 000 per year for lime. In addition to addition labor mixing.\* | N slight reduction from air-stripping13, but P same as input sludge. Limed sludge would be attractive for acidic soils which are common in Uganda.† | System can be run with existing personal. Due to potential health risks when handling lime additional health and safety training is required.7 | “Residual humus –like odor” after initial mixing. 13 Students reported septic smell similar to the reference sludge.\* | Chemical treatment that is resilient to changing weather conditions.† | TSS % ca doubled after lime addition14 |
| ++ | - | **- -** | + | - | 0 | + | - |
| **Solar drying** | Solar drying does not meet all requirements for a class A Biosolid, however levels of viruses and helminths were reduced.15 | Existing covered storage area could be modified to a greenhouse by enclosing the sides and changing the roof. Moderate investment † | Additional maintenance in greenhouse and mixing sludge would be marginally more than what is currently done today.† | No change in quality of the sludge as a fertilizer.† | Can be operated with existing staff training on routines and safety.† | Smell inside the greenhouse is similar to reference sludge† | Drying process will be affected by rain and temperature, but when performed in a greenhouse this process should be more resilient than existing covered beds.† | Volume reduction will depend when the sludge is placed in the solar drier, but through reducing water content it reduces the volume of the sludge.16 |
| + | - - | 0 | 0 | 0 | 0 | + | + |

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\* Data from student field trials during 2018

† Expert knowledge from the research team

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