Swiss TPH
Swiss Tropical and Public Health Institute
Schweizerisches Tropen- und Public Health-Institut
Institut Tropical et de Santé Publique Suisse

Associated Institute of the University of Basel

eawag
aquatic research

Sandec
Water and Sanitation in
Developing Countries

Resource Recovery and Reuse (RRR) Project

Output 7

Health and environmental risk and impact assessments of waste reuse business models proposed for Kampala

Authors:

Health assessments

Dr Mirko Winkler
MSc Samuel Fuhrimann
MSc Ali Halage
Prof Dr Guéladio Cissé

Environmental assessments

MSc Lars Schoebitz
Dr Charles Niwagaba
Dr Linda Stande

Final version, 20 February 2015

Basel and Dübendorf, Switzerland

eawag
aquatic research

Sandec
Water and Sanitation in
Developing Countries

Swiss TPH

Health assessments

Swiss TPH
Swiss Tropical and Public Health Institute
Schweizerisches Tropen- und Public Health-Institut
Institut Tropical et de Santé Publique Suisse

Associated Institute of the University of Basel

WE BUILD FOR THE FUTURE

Swiss Tropical and Public Health Institute
Socinstrasse 57
P.O. Box
4002 Basel
Switzerland

Dr Mirko Winkler
MSc Samuel Fuhrimann
Prof Dr Guéladio Cissé

Department of Epidemiology and Public Health
Ecosystem Health Sciences Unit

T: +41 61 284 8339

Correspondence to Mirko Winkler:
E-mail: mirko.winkler@unibas.ch

Website: www.swisstph.ch

School of Public Health
Makerere University
P.O. Box 7072
Kampala, Uganda

Mr. Abdullah Ali Halage

Department of Disease Control and
Environmental health

T: +256 772 663033

E-mail: ahalage@musph.ac.ug

Website: http://musph.mak.ac.ug/

Swiss TPH

eawag
aquatic research

Sandec
Water and Sanitation in
Developing Countries

Environmental assessments

eawag aquatic research **Sandec** Water and Sanitation in Developing Countries		
Eawag: Swiss Federal Institute of Aquatic Science and Technology Sandec: Department of Water and Sanitation in Developing Countries Ueberlandstrasse 133 P. O. Box 611 8600 Duebendorf Switzerland MSc Lars Schoebitz Dr. Linda Strande Department of Water and Sanitation in Developing Countries T: +41 58 765 5420 Correspondence to Lars Schoebitz E-mail: Lars.Schoebitz@eawag.ch Website: www.sandec.ch/rrr		College of Engineering, Design, Art and Technology (CEDAT) Makerere University Kampala Makerere University P.O. Box 7062 Kampala, Uganda Dr. Charles Niwagaba Department of Civil & Environmental Engineering T: +256 41 454 3152 E-mail: cniwagaba@cedat.mak.ac.ug cbniwagaba@yahoo.co.uk Website: www.mak.ac.ug

Executive summary health assessments

Introduction and methodology

For the 4 targeted feasibility cities of the RRR project, the health components around the selected business models (BM) employed two methodologies, with two different foci: Health Risk Assessment (HRA) and the Health Impact Assessment (HIA). The HRA aimed at identifying health risks associated with the input resources (e.g. faecal sludge, waste water) of proposed BMs and defining what control measures are needed for safeguarding occupational health and producing outputs (e.g. treated waste water, soil conditioner) that are compliant with national and international quality requirements. The HIA aimed at identifying potential health impacts (positive or negative) at community level under the scenario that the proposed BMs are implemented at scale in Kampala area. The magnitude of potential impacts was determined by means of a semi-quantitative impact assessment. The feasibility studies in Kampala were oriented towards eight BMs that were selected due to their potential in the given context. These BMs are:

- Model 1a: Dry fuel manufacturing: agro-waste to briquettes
- Model 2a: Energy service companies at scale: agro-waste to energy (electricity)
- Model 4: Onsite energy generation by sanitation service providers
- Model 9: On cost savings and recovery
- Model 10: Informal to formal trajectory in wastewater irrigation: incentivizing safe reuse of untreated wastewater
- Model 15: Large-scale composting for revenue generation
- Model 17: High value fertilizer production for profit
- Model 19: Compost production for sanitation service Delivery

Evidence-base of the HRIA

A broad evidence-base was assembled for the health risk and impact assessment (HRIA). At a large scale (i.e. city level) this entailed the collection of secondary data on the epidemiological profile, environmental exposures and the health system of Kampala. This included statistics of health facilities from urban, peri-urban and rural areas in and around Kampala city, as well as data from the peer-reviewed and grey literature. The literature review had a focus on (i) soil-, water- and waste-related diseases; (ii) respiratory tract diseases; and (iii) vector-borne diseases, since these disease groups are closely associated with unsafe disposal of waste and waste recovery. At a small scale, primary data was collected at the level of existing RRR activities by means of participatory data collection methods and direct observations. A total of 8 existing RRR cases were investigated in Kampala area:

- Case 1: Tiribogo gasification plant
- Case 2: Wastewater treatment at Bugolobi sewerage treatment and disposal works
- Case 3: Faecal sludge management by the Pit Emptier Association of Uganda (PEAU) and Kampala Capital City Authority (KCCA)

- Case 4: Kampala Jellistone briquette making factory
- Case 5: Katikolo compost plant
- Case 6: Municipal solid waste (MSW) to Kitezi sanitary landfill
- Case 7: Agali-Awamu organic banana peelings market
- Case 8: Eco-San latrines at St. James Biina primary school

The cases were studied considering the given context and by following a similar methodology in all 4 feasibility study cities. An additional important component of the case studies were an assessment of the use and acceptability of personal protective (PPE) among the workforce.

In addition to the standardised methodology of the health component around these 8 existing RRR cases, the city of Kampala benefited from particular complementary in-depth studies through one PhD study and one MSc study which focused on environmental and health risks related to the reuse of wastewater and faecal sludge for agriculture. The two in-depth studies were carried out in the context of the Nakivubo channel and wetland. With the aim to generate evidence on the exposure risk along the wastewater and faecal sludge chains in Kampala, a cross-sectional survey was implemented, targeting different exposure groups: wastewater treatment plant worker (n=114); faecal sludge worker (n=117); farmer (n=314); community members living in proximity to wastewater drainage channels (n=257); and community members as a control group without any direct contact to wastewater (n=354). In total, 1'156 individuals participated in the study, which comprised a questionnaire survey and the collection of stool samples to determine the prevalence and the intensity of parasitic infections. The second study had the goal to fill important data gaps in the knowledge on the environmental pollution of the Nakivubo channel and wetland. A total of 268 water, sediment, soil and plant samples were collected at strategic points and analysed for physiochemical parameters, bacteria, helminth eggs and heavy metals.

Summary of findings of the literature review and in-depth studies

According to health statistics from rural, peri-urban and urban areas of Kampala, malaria and acute respiratory infections were the leading causes of consultations in 2011 and 2012, independent of the environment. These were followed by skin diseases, intestinal worm infections, urogenital infections, gastrointestinal disorders, pneumonia, eye diseases, urogenital infections and sexually transmitted infections as major causes of morbidity

According to the 2011 Uganda Demographic and Health Survey (UDHS), two in three households use non-improved toilet facilities (73% in rural areas and 28% in urban areas), while one in ten households in Uganda, mainly in rural areas, does not have a toilet facility. Approximately 20% of all household are connected to the water supply grid, which is concentrated to high-income areas. However, there are an estimated 70% of the population using piped water for domestic needs in combination with the use of alternative sources. Against this background, it is not surprising that all major STH species are endemic and of public health importance in Uganda. In our own in-depth study at the Nakivubo channel and wetland, the most common STH infections were hookworm and *T. trichiura* with prevalences of 27.8% and 26.1% in local farmers, respectively. Prevalence of *Giardia lamblia* was found to be considerably lower (below 2% in all population groups sampled). *Entamoeba coli* was found to be the most common type of intestinal protozoa in farmers (prevalence: 38.4%) and the general community (prevalence: 36.2%). Eye problems and skin problems were reported by approximately 30% of all population groups investigated.

Acute respiratory diseases are a major public health concern in Kampala (second leading cause of consultations at health facilities). This clearly shows that a lot of transmission is taking place, with poor personal hygiene and poor sanitation system as two important determinants. Also the burden of chronic respiratory diseases and cardiovascular diseases is high, accounting for 2% and 9% of total mortality (all ages, both sexes), respectively, in Uganda.

Various vector-borne diseases are endemic and of major public health relevance (e.g. malaria, dengue, yellow fever, Rift Valley fever, lymphatic filariasis). Clearly, malaria is the most important vector-borne disease. It is the leading cause of morbidity and mortality, accounting for approximately 8–13 million episodes per year in Uganda. In urban areas, however, generally less than 5% of people are infected with malaria. Kampala district does not belong to the districts affected by lymphatic filariasis. Trachoma, another vector-borne disease (flies), is the leading infectious cause of blindness with an estimated eight million Ugandans being at risk of suffering from Trachoma.

For Kampala, little recent data is available on environmental determinants such as water and soil quality. In our own in-depth study, high levels of faecal coliform bacteria, *E. coli*, *Salmonella* spp., and hookworm eggs were found in water and soil samples within the Nakivubo wetland. Concentrations showed temporal variability and values were always above the national standards for the discharge of effluents into the environment and WHO guidelines for the safe use of wastewater in agriculture. In terms of industrial pollution, high levels of copper, iron, and cadmium were found in water, and high levels of zinc, iron, cadmium and lead were found in soil. Plants also showed heavy metal concentrations above existing safety levels.

Key findings of the HRA

All of the identified occupational health risk – such as exposure to pathogens, skin cuts or inhalation of toxic gases – can be managed by providing appropriate PPE, health and safety education to workers and appropriate design of the operation and technical elements.

Biological hazards mostly derive from human and/or animal wastes that serve as inputs *per se* for the proposed BM (e.g. animal manure or human faeces) or are a component thereof (e.g. human waste in wastewater). For meeting pathogen reduction rates as proposed by the World Health Organization’s ‘Guidelines for the Safe Use of Wastewater, Excreta and Greywater’ and other standards, a series of treatment options are at disposal. The HRA provides guidance on which treatment options are required for what reuse option. When it comes to the implementation of the BM, the challenge will be to respect indicated retention times and temperatures for achieving the required pathogen reduction rates. Since the proposed retention times may also have financial implications, it is important that these are taken up by the financial analysis. Also vector-related diseases are an important concern in Kampala area and therefore vector-control measures are indicated for many processes of the BMs.

Chemical hazards primarily concern wastewater fed BMs. The environmental sampling in the Nakivubo channel and wetland found high variation in heavy metal concentration, often exceeding national and international thresholds. Besides the soil and water samples, also Cd, Pb and Cr concentrations in yam and sugarcane exceeded WHO threshold values. This clearly indicates that irrigation with wastewater is of concern in Kampala from a health and environmental perspective, though high local variation might apply. This needs to be taken into account for the planning of any wastewater fed BM, i.e. environmental sampling is indicated for identifying suitable locations. Where threshold values of toxic chemicals exceed national and WHO guideline values, physiochemical treatment for removing toxic chemicals such as heavy metals are required. Also co-composting with wastewater sludge is only an option if the sludge is compliant with heavy metal thresholds. In addition, for both irrigation with treated wastewater and the use of sludge-based soil conditioner, chemical parameters of receiving soils need to be taken into account.

In terms of physical hazards, sharp objects deriving from contaminated inputs (e.g. faecal sludge or MSW) ending-up in soil conditioner are a risk that has been identified for a number of BM. This will require careful pre-processing of inputs and sieving of End-products. Moreover, users need to be sensitised about the potential presence of sharp objects in the soil conditioner and advised to wear boots and gloves when applying the product. Also emissions such as noise and volatile compounds are of concern at workplace and community level. While PPE allows for controlling these hazards at workplace level, a buffer zone between operation and community infrastructure needs to be respected so that ambient air quality and noise exposure standards are not exceeded. Of note, the actual distance of the buffer zone is depending on the level of emissions. Finally, for businesses involving burning processes and power plants, fire/explosion and electric shock are risks of high priority that need to be managed appropriately.

Overall, the health risks associated with most of the proposed BM can be mitigated with a reasonable set of control measures. Concerns about heavy metals and other chemical contaminants remain for all the wastewater-fed BM. Model 10 – untreated wastewater for irrigation and groundwater recharge – is not recommended in the setting of Kampala. Model 15 and 17, both of which use municipal solid waste (MSW) as an input, are only an option if no medical waste from health facilities is mixed with common MSW. Although, at the kick-off workshop in Kampala in March 2013 it was reported that there is a separate collection system for medical waste, this needs further investigation.

Key findings of the HIA

The objective of the HIA was to assess potential health impacts at community level of proposed BMs for Kampala under the assumption that the control measures proposed by the HRA are deployed. This included consideration of both potential health benefits (e.g. business is resulting in reduced exposure to pathogens as it entails treatment of wastewater) and adverse health impacts (e.g. exposure to toxic gases by using briquettes as cooking fuels). Since the HIA aimed at making a prediction of potential health impacts of a given BM under the assumption that it was implemented at scale, a scenario was defined for each BM as an initial step. The scenario was then translated into the impact level, the number of people affected and the likelihood/frequency of the impact to occur. By means of a semi-quantitative impact assessment, the magnitude of the potential impacts was calculated.

A summary of the nature and magnitude of anticipated health impacts for each of the proposed BM is presented in Table 1. Most of the proposed BMs have the potential for resulting in a minor to moderate positive health impacts. Under the given scenarios, Model 4 (onsite energy generation in enterprises providing sanitation services) and Model 9 (treated wastewater for irrigation/fertilizer/energy: cost recovery) have the greatest potential for having a positive impact since they will result in a reduction in exposure to pathogens at community level. Model 1a – Dry fuel manufacturing: agro-waste to briquettes – bears the risk to result in a moderate negative impact by replacing more clean cooking fuels such as gas and electricity with briquettes. As already highlighted under the HRA, from a health perspective it is not recommended to promote the reuse of untreated wastewater for irrigation purposes in Kampala (Model 10).

Table 1 – Summary table of anticipated health impacts and their respective magnitude

Business model	**Scale of the BM: applied scenario**	**Anticipated health impact**	**Magnitude** (score)
Model 1a – Dry fuel manufacturing: agro-waste to briquettes	One percent of the population in Kampala will use briquettes from the BM as cooking fuel	Impact 1: increase in chronic respiratory disease and cancer	**Moderate negative impact (-300)**
Model 2a – Energy service companies at scale: agro-waste to energy (electricity)	50 villages in rural and peri-urban areas of Kampala will implement the BM	Impact 1: changes in health status due to access to electricity	**Insignificant (0)**
		Impact 2: reduction in respiratory, diarrhoeal and intestinal diseases	**Moderate positive impact (75)**
Model 4 – Onsite energy generation by sanitation service providers	30 villages in rural and peri-urban areas of Kampala will implement the BM	Impact 1: reduction in respiratory, diarrhoeal and intestinal diseases	**Moderate positive impact (472.5)**
		Impact 2: access to electricity	**Insignificant (0)**
Model 9 – On cost savings and recovery	Wastewater treatment plant similar to BSTDW with 500 farmers and 10'000 community members being exposed to the treated wastewater	Impact 1: reduction in respiratory, diarrhoeal and intestinal diseases	**Major positive impact (3,625)**
		Impact 2: reduction in exposure to toxic chemicals (e.g. heavy metals)	**Moderate positive impact (190)**
		Impact 3: access to electricity	**Insignificant (0)**
Model 10 – Informal to formal trajectory in wastewater irrigation: incentivizing safe reuse of untreated wastewater	Unknown	Impact 1: increase in exposure to pathogens and chemicals such as heavy metals	**Not recommended**
Model 15 – Large-scale composting for revenue generation	Two centralised co-composting plants are installed in Kampala, serving 2'000 households each	Impact 1: reduction in respiratory, diarrhoeal and intestinal diseases	**Minor positive impact (2.5)**
		Impact 2: indirect health benefits due to reduced MSW loads on landfills	**Moderate positive impact (75)**
Model 17 – High value	Two centralised co-	Impact 1: reduction in	**Minor positive**

fertilizer production for profit	composting plants are installed in Kampala, serving 2’000 households each	respiratory, diarrhoeal and intestinal diseases	**impact (2.5)**
		Impact 2: indirect health benefits due to reduced MSW loads on landfills	**Moderate positive impact (75)**
Model 19 – Compost production for sanitation service Delivery	30 villages in rural and peri-urban areas of Kampala will implement the BM	Impact 1: reduction in respiratory, diarrhoeal and intestinal diseases	**Moderate positive impact (472.5)**

Executive summary environmental assessments

For the Environmental Impact Assessment (EIA), business model flow diagrams are used as a tool to visualize both impact assessments. The EIA takes into consideration the “Technology Assessment”, which comprises an extensive literature review on technologies for resource recovery also identifying potential environmental hazards and measures of mitigation.

Within the scope of this assessment, the environmental impact of the business models are not assessed in detail, as information on facility scale and specific location in the city was not available. Rather, with the level of technical detail currently available, the EIA shows potential environmental hazards, which should be recognized and mitigated during implementation.

More detailed analysis of specific environmental impacts can follow at a later stage if treatment infrastructure has been clearly defined based of an analysis of market demand for End-products and the respective determination of treatment goals. Such an evaluation would have to include detailed laboratory analyses of the waste streams to be utilized, so that treatment technologies can be selected and designed in detail.

Currently, and based on the EIA as a stand-alone component, the feasibility of business models cannot be ranked, which is the reason for all business models resulting in “medium feasibility”. Ultimately, the implementing business has to mitigate the identified potential environmental hazards, which will results in little, or no environmental impact.

Table 2 provides a summary for all business models, the respective waste streams, End-products technologies, processes and potential environmental hazards, including proposed mitigation measures.

Table 2 – Summary table of anticipated environmental impacts and proposed mitigation

BM	Waste stream	End-product	Technologies	Process	Pot. Env. Hazard	Mitigation measures
1a	• MSW • AIW	• Briquettes	• Carbonized - low pressure • Raw - mechanized high pressure • Carbonized - mechanized	• Briquetting	• Hazardous air emissions • Accumulated inorganic waste • Process water	• Air emission control technologies (e.g. activated carbon, scrubbers) • Proximate and ultimate analyses • Post-treatment of process water
2a	• MSW • AIW • AM	• Gasification -> Electricity • Biogas -> Electricity	• Gasification technologies • Single stage • Multi-stage • Batch • Biogas conversion technologies	• Gasifi-cation • Anaerobic digestion • Biogas to electricity conversion	• Hazardous air emissions • Residuals (tar, char, oil) • Solid residue (digestate) • Liquid effluent	• Air emission control technologies • Collection/Storage/ Disposal at appropriate location • Solid/liquid residue post-treatment

4	• Feces • Urine • FS	• Biogas -> Cooking fuel	• Single stage • Multi-stage • Batch	• Anaerobic digestion	• Air emissions • Solid residue (digestate) • Liquid effluent	• Maintenance of anaerobic digester • Solid/liquid residue post-treatment
9	• WW • WW sludge	• Electricity • Soil conditioner • Water (for reclamation)	• Conventional wastewater treatment technologies • Biogas conversion technologies	• Conven-tional WW treatment • Biogas to electricity conversion	• Heavy metals in effluent and/or WW sludge • Solid residue (sludge from WW treatment) • Air emissions	• Upstream monitoring of heavy metal concentration • Monitoring of effluent and solids • Solid residue (sludge from WW treatment) post-treament • Maintenance of anaerobic digester
10	• WW	• Water (for reclamation) • Water for groundwater recharge	• Slow rate infiltration • Rapid infiltration • Overland flow • Wetland application	• Land treatment	• Groundwater contamination (heavy metals/pathogens) • Contamination of irrigated crops with heavy metals and/or pathogens	• Upstream monitoring of heavy metal concentration • Monitoring of effluent and solids • Crop selection • 2006 WHO guidelines
15	• MSW • FS	• Soil Conditioner	• Solid/liquid separation • Drying beds • Co-composting	• Co-com-posting (MSW + FS)	• Accumulated inorganic waste • Leachate from composting • Insufficient pathogen inactivation • Liquid effluent (from FS treatment)	• Storage/transport/disposal (sanitary landfill) • Moisture control • Leachate treatment • Temperature control (compost heap) • Post-treatment of liquid effluent
17	• MSW • FS	• Fertilizer (NPK added)	• Solid/liquid separation • Drying beds • Co-composting	• Co-com-posting (MSW + FS)	• Accumulated inorganic waste • Leachate from composting • Insufficient pathogen inactivation • Liquid effluent (from FS treatment)	• Storage/transport/disposal (sanitary landfill) • Moisture control • Leachate treatment • Temperature control (compost heap) • Post-treatment of liquid effluent
19	• Urine • Feces	• Stored urine • Soil conditioner	• UDDTs • Co-composting	• Urine application • Co-com-posting	• Ammonia intoxication • Ammonia oxidization • Insufficient pathogen inactivation • Leachate from co- composting	• Urine dilution with water • Moisture control • Leachate treatment • Temperature control (compost heap)

Table of contents

List of figures

List of tables

Abbreviations

AIDS	Acquired Immune Deficiency Syndrome
ARI	Acute Respiratory Infections
BM	Business Model
BSTDW	Bugolobi Sewerage Treatment and Disposal Works
Cd	Cadmium
CO	Carbon Monoxide
COPD	Chronic Obstructive Pulmonary Disease
Cr	Chromium
Cu	Copper
dB	Decibel
EIA	Environmental Impact Assessment
Fe	Iron
FECT	Formalin-Ether Concentration Technique
FGD	Focus Group Discussion
HIA	Health Impact Assessment
HRA	Health Risk Assessment
HRIA	Health Risk and Impact Assessment
IL	Impact Level
KCCA	Kampala Capital City Authority
KII	Key Informant Interviews
LF	Lympahtic Filariasis
LoF	Likelihood or Frequency
MSW	Municipal Solid Waste
NO_x	Nitrogen Oxides
NPK	Nitrogen, Phosphorus and Potassium
NWSC	National Water and Sewerage Cooperation
PA	People Affected
Pb	Lead
PEAU	Pit Emptier Association of Uganda
PM	Particulate Matter
PPE	Personal Protective Equipment
RRR	Resource, Recovery and Reuse
RS	Risk Score
SO_x	Sulphur Oxides
SSP	Sanitation Safety Planning
STH	Soil-transmitted helminth
STI	Sexually Transmitted Infection
TTC	Thermo Tolerant Coliform
UDHS	Uganda Demographic and Health Survey
USEPA	United States Environmental Protection Agency
UTI	Urogenital Tract Infection
WHO	World Health Organization
WWTP	Wastewater Treatment Plant
Zn	Zinc

Annexes

1 Introduction

Outcome 7 of the resource, recovery and reuse (RRR) project entails the assessments of health and environmental risks for proposed waste reuse business models (BMs). For the strategic health planning components of Outcome 7, different forms of health assessments are available with different foci, i.e. from workplace health to community health, as illustrated in Figure 1. Since both workplace health and community health are of concern for the feasibility studies of proposed BMs, a health risk assessment (HRA) and health impact assessment (HIA) methodology were employed [1]. Health needs of communities in Kampala were also considered in the frame of baseline data collection activities such as the characterisation of the epidemiological profile and the assessment of environmental exposures. BM flow diagrams were developed to identify outputs posing health and environmental risks. The environmental impact assessment (EIA) and HRA take into consideration the "Technology Assessment" report [2], which comprises an extensive literature review on technologies for resource recovery also identifying potential environmental hazards and measures of mitigation.

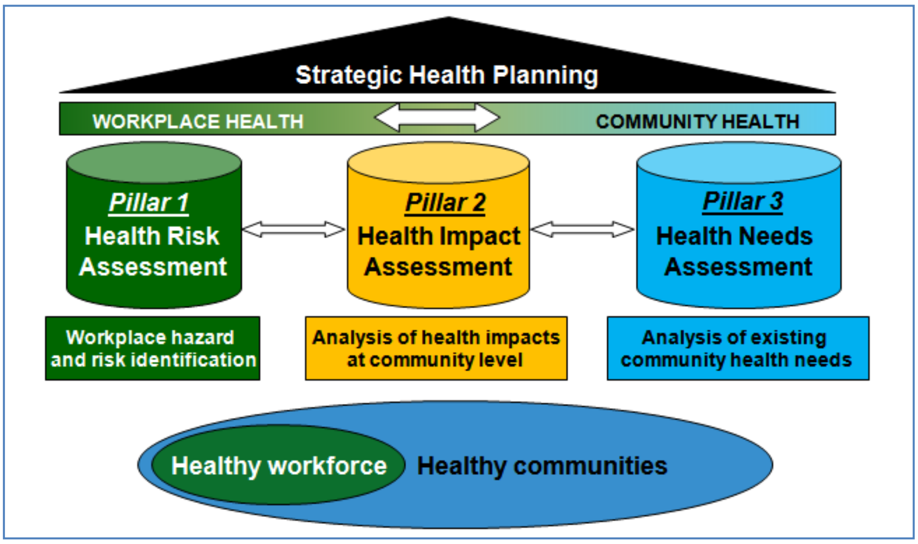


Figure 1 – Different types of health assessments and their inter-linkages

The specific objectives of the health assessments were:

- To characterise the common disease profile and exposures to environmental health hazards associated to waste streams in Kampala
- To identify common occupational and community health risks associated with existing RRR activities in Kampala
- To evaluate the acceptability of control measures to mitigate health risk in Kampala
- To define control measures required for safeguarding occupational health and ensuring safe products for each of the BMs proposed for Kampala
- To assess residual health risks with the proposed control measures in place

- To assess potential health impacts at community level (positive or negative) of proposed BMs for Kampala under the assumption that the proposed control measures (see previous objective) are deployed

The specific objectives of the EIA were:

- To create BM flow diagrams, identify BM outputs (e.g. emissions into air) that could form a potential environmental hazard
- To identify the specific potential environmental hazards of identified outputs (e.g. polycyclic aromatic hydrocarbons)
- To identify technical solutions for mitigation of potential environmental hazards to prevent a negative environmental impact (e.g. activated carbon, scrubbers)
- To provide guidance on technical solutions that have to be recognizes when implementing waste-based BMs

Within the scope of the EIA, the environmental impact of the business models are not assessed in detail, as information on facility scale and specific location in the city was not available. Rather, with the level of technical detail currently available, the EIA shows potential environmental hazards, which should be recognized and mitigated during implementation. More detailed analysis of specific environmental impacts can follow at a later stage if treatment infrastructure has been clearly defined based of an analysis of market demand for End-products and the respective determination of treatment goals. Such an evaluation would have to include detailed laboratory analyses of the waste streams to be utilized, so that treatment technologies can be selected and designed in detail.

Chapter 2 provides an overview of the tools and methods that were deployed for assembling the baseline data to inform the specific objectives above and introduces the HRA, HIA and EIA methodologies. In Chapter 3, the evidence-base for the HRA and HIA is summarized in five sub-chapters (i.e. epidemiological profile; environmental parameters; self-reported health issues by workers of reuse cases; and acceptability and use of personal protective equipment). At the core of the present report are the HRA, HIA and EIA in Chapter 4.

2 Methodology

In order to assemble the information needed for the HRA and HIA components, a methodological triangulation was carried out (see Figure 2). At a large scale (i.e. city level) this entailed the collection of secondary data on the epidemiological profile, environmental exposures and the health system of Kampala. At a small scale, primary data was collected at the level of existing RRR activities by means of participatory data collection methods and direct observations. In addition, in-depth studies on the concentration of heavy metals, protozoa and helminth eggs were carried out in the frame of the pre-testing of the Sanitation Safety Planning (SSP) manual in Kampala.

Section 2.1 provides an overview of the survey tools and methods that were employed for the different baseline data collection activities. The full description of survey tools and methods is available in Annex I ('Methodology and tools for feasibility studies: baseline data collection for the health risk and impact assessments'). A summary of the key findings of the different data collection activities is provided in Chapter 3. These data serve as evidence-base for the HRA and HIA in Chapters 4 and 5.

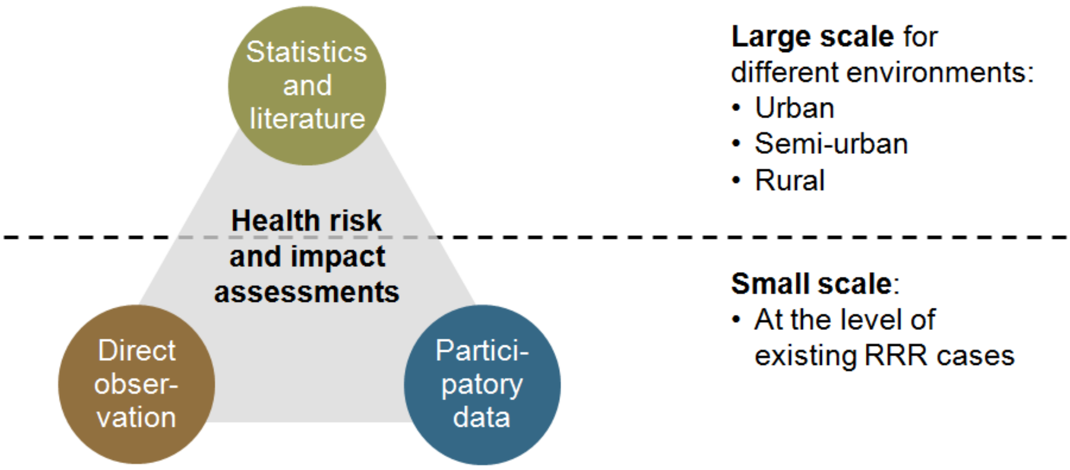


Figure 2 – Methodological triangulation for the health risk and impact assessments

2.1 Baseline data collection activities

The description of the epidemiological profile, environmental parameters and other contextual information of Kampala is a crucial element of the health assessments. The baseline data collection activities involved the assembling of secondary data, as well as primary data collection exercises. The data from various sources is presented in Chapter 3, entitled 'evidence-base of the HRA and HIA'. In order to remain focused on health issues that have a direct link to sanitation systems and resource reuse activities, the epidemiological profile is structured along three disease groups: (i) soil-, water- and waste-related diseases; (ii) respiratory tract diseases; and (iii) vector-borne diseases.

2.1.1 Data collection at the level of existing RRR cases

With the goal to determine the range and magnitude of potential occupational and community health risks associated with the proposed BMs for Kampala, a number of existing RRR cases were assessed. In addition, it was considered important to evaluate the cultural and financial acceptability of health risk mitigation measures in the given context. The selection of existing RRR cases aimed at covering cases that have as many as possible commonalities with the BMs proposed for the feasibility studies in Kampala. In total, eight existing RRR cases were analysed:

- Case 1: Tiribogo gasification plant
- Case 2: Wastewater treatment at Bugolobi sewerage treatment and disposal works
- Case 3: Faecal sludge management by the Pit Emptier Association of Uganda (PEAU) and Kampala Capital City Authority (KCCA)
- Case 4: Kampala Jellistone briquette making factory
- Case 5: Katikolo compost plant
- Case 6: Municipal solid waste (MSW) to Kitezi sanitary landfill
- Case 7: Agali-Awamu organic banana peelings market
- Case 8: Eco-San latrines at St. James Biina primary school

For the data collection at the level of existing RRR cases, a specific set of tools and methods was developed. A detailed description of the different working steps and associated survey tools is provided in Annex I. The main steps can be summarized as follows:

1. Case description: this includes a system flow diagram and a process description, as well as the identification and characterization of different exposure groups (i.e. farmers, workers, local community and consumers)
2. Identification of health hazards, exposure routes and validation of existing control measures: this step was carried out by means of the 'tool for hazard identification, control validation and risk assessment'
3. Risk assessment: the ranking of the risk associated with each health hazard aimed at identifying which of the health hazards are already well controlled or insignificant, while highlighting those that represent a major health risk. For this purpose a semi-quantitative risk assessment was performed
4. Key informant interviews (KII) and community focus group discussions (FGD): the KII were carried out (i) with the RRR case business owner/operator and (ii) health care providers in proximity to the RRR case. In the community living in proximity to the RRR business case, FGD were conducted. Both KII and FGD were guided by semi-structured questionnaire routes
5. Worker questionnaire: a questionnaire-based interview was conducted with the workers of existing RRR cases, covering the following topics: (i) worker health; (ii) worker risk perception; (iii) worker safety (e.g. use and acceptance of personal protective equipment (PPE)); (iv) reasons for potentially missing PPE; and (v) willingness to pay for potential controls/mitigation.

The data that were collected in the different case studies are presented in Annex II.

2.1.2 In-depth studies

In addition to the data collection activities at the level of existing RRR cases, two in-depth studies were implemented in Kampala both of which focused on the Nakivubo channel and wetland:

The first study was led by Samuel Fuhrimann; a PhD student of Swiss TPH. Samuel's study had the goal to generate evidence on the exposure risk along the wastewater and faecal sludge chains in the perspective of potential promotion of the safe recovery and reuse of wastewater and faecal sludge in the context of Kampala city. For this purpose, a cross-sectional survey was carried out to assess and map the existing exposure risks due to wastewater and faecal sludge. A total of 1'156 individuals were enrolled in the study, representing different exposure groups: wastewater treatment plant worker (n=114); faecal sludge worker (n=117); farmer (n=314); community members living in proximity to wastewater drainage channels (n=257); and community members as a control group without any direct contact to wastewater (n=354). The cross-sectional survey comprised two components: (i) a questionnaire study to obtain self-reported data on health risks and health outcomes (e.g. diarrhoeal episodes and skin and eye disease) related to the exposure to wastewater and faecal sludge; and (ii) the collection of stool samples to determine the prevalence and the intensity of parasitic infections. The stool samples were analysed for helminth infections by means of the Kato-Katz technique. As a quality control measure, one stool sample was subjected to duplicate Kato-Katz thick smear. Protozoa infections were assessed with the formalin-ether concentration technique (FECT).

The second study was led by Michelle Stalder; an MSc student of the Swiss Federal Institute of Technology. Michelle's master thesis project aimed at filling important data gaps in the knowledge on the environmental pollution of the Nakivubo channel and wetland. A sampling framework was developed in close collaboration with local partners. For the duration of eight weeks, water, soil, sediment and plant samples were collected in different areas along the Nakivubo channel and wetland. The samples were analyzed for bacteria, helminth eggs and heavy metals. Additionally, physiochemical parameters and meteorological and geographical information were obtained for each sample. The microbial analysis was conducted according to the recommended methods by the World Health Organization (WHO). Heavy metal analysis was done by subcontractors. For the spatial modelling of pathogens, universal kriging predictions were used.

The key findings of both in-depth studies are presented in Chapter 3. The full studies are presented elsewhere.

2.2 Health risk assessment

The objectives of the HRA were: (i) to identify potential biological, chemical and physical hazards and hazardous events associated with the proposed BMs in the given context; (ii) to define a set of mitigation measures that need to be incorporated in the final BM description for eliminating or controlling the identified risks; and (iii) to assess the residual health risk with the proposed control measures in place, taking into account the technical efficiency and cultural acceptability in the given context. For this purpose, the HRA combined the findings of the various data collection activities with the technology of the proposed BMs. The ultimate goal of the HRA was to assess whether potential health risks of proposed BMs can be managed appropriately. The approach described in the subsequent sub-chapters has been applied to each BM proposed for Kampala.

2.2.1 Input characterization and quality requirements for outputs

As an entry point for the HRA, input-resources of the BM (e.g. solid and liquid waste products) were characterized in terms of composition and potential associated health hazards. Source documents for this initial step were the ‘technology assessment’ and the ‘waste supply and availability’ reports for Kampala. For the outputs of the BM, quality requirements were determined. Since the institutional analysis for Kampala was not yet available during compilation of the present report, international standards are referenced. Wherever possible, WHO thresholds apply. If such do not exist, values from the United States Environmental Protection Agency (USEPA) or the European Union are cited.

2.2.2 Identification of potential health hazards linked to specific processes

In consideration of the epidemiological and environmental baseline data for Kampala, potential biological, chemical and physical health hazards were identified for each of the processes described for the BM:

- Biological hazards: constituents with the potential for impacts on occupational and public health such as viruses bacteria, pathogenic protozoa, helminth eggs and disease vectors
- Chemical hazards: chemicals with the potential for causing acute or chronic health effects, i.e. organic and inorganic substances and those with accumulative effects such as heavy metals and pharmaceuticals
- Physical hazards: dangers that could result in injury to the workers (e.g. open water bodies, working at height, noise pollution and radiation)

In a next step, hazardous events linked to each of the identified hazards (e.g. discharge of untreated waste or release of toxic gases) were described. Potential exposure groups were also taken into account in this process. Finally, general issues (e.g. operational matter), which cannot be assigned to a specific process of the BM but would rather affect the entire operation, were also added to the list of hazardous events in order to be considered in the subsequent steps of the risk assessment.

2.2.3 Identification and appraisal of control measures

For each of the health hazards and hazardous events identified under the previous step, options available to control the hazard were listed. The full range of control measures were considered such as physical barriers (e.g. screening or filtration), physical processes (e.g. sedimentation, decomposition), chemical treatment options (e.g. chlorination), disease prophylaxis (e.g. preventive chemotherapy), behavioural measures (e.g. health education), protective measures (e.g. PPE) and modifications/additions to the design of the technical components of the BM (e.g. covering open water bodies, access restriction, retention basins, protection shields and backup generators). Since in many cases multiple control options for a given hazard exist, a prioritization was made by rating the technical efficiency and acceptability (which includes cost considerations) of the proposed measure. This rating of the 'mitigation potential' of the control measure was based on the multiplication of a technical efficiency score (low: 1; medium: 2; and high: 3) with the acceptability score (low: 1; medium: 2; and high: 3). Resulting values were classified into three levels of mitigation potential:

- Low mitigation potential of the control measure: range 1-3;
- Medium mitigation potential of the control measure: range 4-6; and
- High mitigation potential of the control measure: range 7-9.

For the appraisal and mitigation of biological health hazards, the pathway of pathogens through the technical process of the BM was determined and log reduction rates were indicated as per the 2006 WHO Guidelines for the Safe Use of Wastewater, Excreta and Greywater (here after referred to as 'WHO 2006 Guidelines') [3] and other source documents. In consideration of the reuse scenario of the different products of the BM, it was evaluated whether the technical processes of the BM (e.g. retention time; processing temperature) allow for compliance with the pathogen thresholds defined by WHO, as well as national standards. Recommendations for improving pathogen reduction throughout the process were made where indicated. In case the targeted reduction rate could not be achieved along the technical process of the BM, a multi-barrier approach, as proposed by the WHO 2006 Guidelines, was considered, with additional control measures at the level of inputs, reuse activities or consumers. The acceptability and feasibility of such 'outside the system' control measures was taken into account in the subsequent risk assessment.

The appraisal and mitigation of chemical health hazards followed the same process as for biological hazards, though, no log reduction rates apply and considerable data gaps exist. For chemical hazards with unknown transformation and elimination processes, the worst case scenario (i.e. no reduction by simple physical processes) applied.

In most instances, physical health hazards can be mitigated by means of PPE, which has a high technical efficiency if applied appropriately. Since workers will often operate multiple processes, the choice of PPE needed has to be made on an individual basis. Therefore, the summary term PPE was used for the control measure indication. Guidance on which type of PPE is required to prevent specific physical hazards is provided in Annex II.

2.2.4 Semi-quantitative risk assessment

By means of a semi-quantitative risk assessment, the theoretical residual risks of the proposed BM were assessed, i.e. under the assumption that the identified control measures are in place. For this purpose the **impact level** (IL) (ranging from insignificant to catastrophic) and the **likelihood or frequency** (LoF) of the hazardous event to occur were determined for each of the identified health hazards, according to the definitions provided in Table 3. Of note, for determining the likelihood or frequency of occurrence, the mitigation potential (i.e. the combination of technical effectiveness and acceptability of the proposed control measure) was taken into account. The combination of the likelihood or frequency with the level of impact resulted in a **risk score** (RS) (RS = IL x LoF; low risk: <6; moderate risk: 7–12; high risk: 13–32; and very high risk: ≥32) as illustrated by the risk matrix in Figure 3.

The entire rating was based on a modified Delphi approach [4]; a technique intended for use in judgement and forecasting situations in which pure model-based statistical methods are not practicable. In practice this means that the risk assessment was performed by multiple assessors who found an agreement on the final rating.

Table 3 – Definition of impact level, and likelihood for the HRA (adapted from [5])

IMPACT LEVEL (I)		
Category	**Score**	**Description**
Insignificant	**1**	No health consequences anticipated and no impact on normal operations
Minor impact	**2**	Impact not resulting in any perceivable or measurable health effect; easily manageable disruptions to operation; no rise in complaints anticipated
Moderate impact	**4**	Impact resulting in minor disability (e.g. fever, headache, diarrhoea, small injuries) or unease (e.g. noise, malodours); may lead to complaints or minor community annoyance; operations may be disrupted for short duration
Major impact	**8**	Impact resulting in moderate disability (e.g. acute intoxication, malaria, injury) or minor disability of long duration; may lead to legal complaints and major community concerns; operations could be significantly affected by the impact
Catastrophic impact	**16**	Impact resulting in severe disability, chronic disease or even loss of life; major investigation by regulator with prosecution are likely; can lead to complete failure of system
LIKELIHOOD or FREQUENCY (LoF)		
Category	**Score**	**Description**
Very unlikely	**1**	In consideration of the technical effectiveness and local acceptability of proposed control measures, it is very unlikely that exposure to the health hazard will occur (odds: <5%). Frequency: once every 5 years
Unlikely	**2**	In consideration of the technical effectiveness and local acceptability of proposed control measures, it is unlikely that exposure to the health hazard will occur (odds: 5–40%). Frequency: once a year
Possible	**3**	In consideration of the technical effectiveness and local acceptability of proposed control measures, it is possible that exposure to the health hazard will occur (odds: 41-60%). Frequency: once a month
Likely	**4**	In consideration of the technical effectiveness and local acceptability of proposed control measures, it is likely that exposure to the health hazard will occur (odds: 61-95%). Frequency: once a week
Almost certain	**5**	In consideration of the technical effectiveness and local acceptability of proposed control measures, it is almost certain that exposure to the health hazard will occur (odds: >95%). Frequency: once a day

Risk score: (RS) = (IL) x (LoF) Very high risk >32 High risk 13–32 Moderate risk 7–12 Low risk <6		IMPACT LEVEL (IL)				
		Insignificant (1)	Minor impact (2)	Moderate impact (4)	Major impact (8)	Catastrophic impact (16)
LIKELIHOOD or FREQUNCY (LoF)	Very unlikely (1)	1	2	4	8	**16**
	Unlikely (2)	2	4	8	**16**	**32**
	Possible (3)	3	6	12	**24**	**48**
	Likely (4)	4	8	**16**	**32**	**64**
	Almost certain (5)	5	10	**20**	**40**	**80**

Figure 3 – Semi-quantitative assessment matrix (adapted from [5])

2.3 Health impact assessment

The objective of the HIA was to assess potential health impacts at community level of proposed BMs for Kampala under the assumption that the control measures proposed by the HRA are deployed. This included consideration of both potential health benefits (e.g. operation resulting in reduced exposure to pathogens since it entails treatment of wastewater) and adverse health impacts (e.g. toxic emissions of an operation, which cannot be avoided). The findings of the various data collection activities served as evidence-base for the HIA. The approach described in the subsequent sub-chapters has been applied to each BM proposed for Kampala.

2.3.1 Definition of impact pathways

The impact definition is a description of the pathway(s) the BM may impact on the health status of affected communities (e.g. decrease in the incidence of diarrhoeal diseases due to reduced pathogen loads in irrigation water). Once the potential impact pathways of a BM were identified, literature that provides evidence for the direction and magnitude of the potential health impacts was reviewed and reference added.

2.3.2 Semi-quantitative impact assessment

By means of a semi-quantitative risk assessment, the potential health impacts of the proposed BM were characterized in terms of nature (positive or negative) and magnitude (minor to major). For this purpose the **IL** (ranging from major negative impact to major positive impact), the **LoF** of the impact to occur and the estimated number of **people affected** (PA) were determined for each of the identified potential health impact (see definitions provided in Table 3). Of note, in order to be able to make an estimation of people affected, an assumption was made about the scale a BM could reach in Kampala area. The assumption was clearly stated at the end of the introduction of the HIA of each BM.

The combination of the IL with the LoF and the estimated number of people affected resulted in the magnitude of the health impact (Magnitude = IL x LoF x PA; low positive impact: 0–4; moderate positive impact: 10–4,499; high positive impact: ≥4,500; low negative impact: 0– -4; moderate negative impact: -10– -4,499; and high negative impact: ≤-4,500) (see risk matrix in Figure 4). As for the HRA, the rating for the HIA was based on a modified Delphi approach (Rowe and Wright, 1999).

Table 4 – Definition of impact level and likelihood for the HIA (adapted from [6])

IMPACT LEVEL (IL)		
Category	**Score**	**Description**
Major positive impact	**1**	Impact reduces incidence of diseases or injury, resulting in severe disability, chronic disease or even loss of life
Moderate positive impact	**0.5**	Impact reduces incidence of diseases or injury, resulting in moderate disability that may require hospitalisation (e.g. acute intoxication, malaria, injury) or minor disability of long duration
Minor positive impact	**0.1**	Impact reduces incidence of disease or injury, resulting in minor disability of short duration (e.g. acute diarrhoea, acute respiratory infection) that does not require hospitalization
Insignificant	**0**	Impact not resulting in any perceivable or measurable health effect
Minor negative impact	**-0.1**	Impact increases incidence of diseases or injury, resulting in minor disability of short duration (e.g. acute diarrhoea, acute respiratory infection) that does not require hospitalization
Moderate negative impact	**-0.5**	Impact increases incidence of diseases or injury, resulting in moderate disability that may require hospitalisation (e.g. acute intoxication, malaria, injury) or minor disability of long duration
Major negative impact	**-1**	Impact increases incidence of diseases or injury, resulting in severe disability, chronic disease or even loss of life
PEOPLE AFFECTED (PA)		
Category	**Score**	**Description**
Individual cases	**1**	A few individuals are concerned by the impact (e.g. road traffic accidents)
Specific population	**100**	A relatively small specific population group is concerned by the impact (e.g. people living in proximity to an operation)
Medium population group	**1,000**	A medium size population group is concerned by the impact (e.g. people living downstream a river that may be contaminated by an operation)
Large population group	**10,000**	A large population group is concerned by the impact (e.g. consumers of a widely used product of an operation)
Major population group	**100,000**	A major population group is concerned by the impact (e.g. a small city that will gain access to safe drinking water)
LIKELIHOOD or FREQUENCY (LoF)		
Category	**Score**	**Description**
Very unlikely	**0.05**	It is very unlikely that the impact will occur (odds: <5%). Frequency: once every 5 years
Unlikely	**0.3**	It is unlikely that the impact will occur (odds: 5–40%). Frequency: once a year
Possible	**0.5**	It is possible that the impact will occur (odds: 41-60%). Frequency: once a month
Likely	**0.7**	It is likely that the impact will occur (odds: 61-95%). Frequency: once a week
Almost certain	**0.95**	It is almost certain that the impact will occur (odds: >95%). Frequency: once a day

			PEOPLE AFFECTED (PA)				
			Individual cases	Specific population	Medium popu-lation group	Large popu-lation group	Major population
			1	100	1,000	10,000	100,000
IMPACT LEVEL (IL)	Major positive impact	1	0.05	30	500	7,000	95,000
	Moderate positive impact	0.5	0.03	15	250	3,500	47,500
	Minor positive impact	0.1	0.01	3	50	700	9,500
	Insignificant	0	0.00	0.00	0.00	0.00	0.00
	Minor negative impact	-0.1	-0.01	-3	-50	-700	-9,500
	Moderate negative impact	-0.5	-0.03	-15	-250	-3,500	-47,500
	Major negative impact	-1	-0.05	-30	-500	-7,000	-95,000
			0.05	0.3	0.5	0.7	0.95
			Very unlikely	Unlikely	Possible	Likely	Almost certain
			LIKELIHOOD or FREQUENCY (LoF)				

Figure 4 – Impact assessment matrix (adapted from [6])

2.4 Environmental Impact Assessment

The EIA is based on the same input characterization and quality requirements for outputs as the HRA. Each business model consists of a process for the conversion of waste into a resource. Along the process of conversion, several potential environmental hazards were identified and mitigation measures considered. These hazards and mitigation measures are presented in this report in the last section of each business model chapter. The technology assessment report describes technologies for mitigation in more detail [2]. A more thorough impact assessment, based on environmental pollution, can be performed once business models are selected, that must include specific information such as scale, location and market demand for End-products.

3 Evidence-base for the HRA and HIA

3.1 Epidemiological profile

Health outcomes of reported cases in the year 2010, 2011 and 2012 are presented in Table 5, Table 6 and Table 7 for urban, peri-urban and rural Kampala, respectively. The data present summary statistics of a number of peripheral health facilities and hospitals:

- Rural Kampala: health centres in Nakaseke district (approximately 70km from Kampala city); population covered: 260’00 people;
- Peri-urban areas around Kampala: health centres in Mukono district (approximately 20km from Kampala city); population covered: 551’000 people; and
- Urban Kampala: 6 major public health centres (of Kampala city, which serve the majority of the population (i.e. low socio-economic status) of the capital city (approximately 1.8 million people).

Independent of the environment, malaria and acute respiratory infections were the leading causes of morbidity at the health facilities in 2011 and 2012. These were followed by skin diseases, intestinal worm infections, urogenital infections, gastrointestinal disorders, pneumonia, eye diseases, urogenital infections and sexually transmitted infections as major causes of morbidity. The most striking difference between the different environments is the high number of AIDS cases reported at the rural health facilities when compared to the urban and peri-urban health facilities. However, there might be a diagnostic and/or reporting error since the high numbers of confirmed AIDS cases is very unlikely. Also differences in the availability of HIV care options for urban residents may play a role in this. This may also apply to other indicators such as malaria cases, which may be mostly be identified based on a symptomatic diagnosis due to limited availability of rapid test and microscopy. Thus, it is important to note that due to limited diagnostics at health facilities, and the fact that the entire population does not have adequate access to health care services, these statistics have distinct limitations. Nevertheless, such data provide a comprehensive overview of potential disease patterns in Kampala area and are an important information source for the description of the baseline health status and risk assessment.

Table 5 – Disease profiles for urban Kampala, 2010-2012

DISEASE PROFILES FOR URBAN KAMPALA, 2010-2012														
CASES REPORTED 2010					CASES REPORTED 2011					CASES REPORTED 2012				
Disease Diagonised		Total Pop.	1,804,000		Disease Diagonised		Total Pop.	1,804,000		Disease Diagonised		Total Pop.	1,804,000	
	0-4	5+	TOTAL	Inc.		0-4	5+	TOTAL	Inc.		<5	>5	TOTAL	Inc.
Malaria	40,353	72,705	113,058	6.27	Malaria	34,530	72,565	107,095	5.94	Malaria	26,288	61,143	87,431	4.85
Eye conditions	10,846	82,728	93,574	5.19	Cough and colds	28,988	48,630	77,618	4.30	Cough and colds	25,398	44,882	70,280	3.90
Cough and colds	26,892	35,207	62,099	3.44	Skin diseases	7,193	11,400	18,593	1.03	Skin diseases	6,580	13,593	20,173	1.12
AIDS	186	25,156	25,342	1.40	Intestinal worms	5,674	9,987	15,661	0.87	Intestinal worms	5,507	12,624	18,131	1.01
Skin diseases	11,574	13,529	25,103	1.39	UTIs	550	11,563	12,113	0.67	UTIs	1,110	11,752	12,862	0.71
UTIs	5,444	19,107	24,551	1.36	STIs	182	11,731	11,913	0.66	Pelvic inflammatory disease	-	8,320	8,320	0.46
Intestinal worms	7,608	16,773	24,381	1.35	Pelvic inflammatory disease	-	9,059	9,059	0.50	STIs	90	5,731	5,821	0.32
STIs	191	20,244	20,435	1.13	Oral diseases	444	6,205	6,649	0.37	Persistent diarrhoea	2,902	1,862	4,764	0.26
Pelvic inflammatory disease	54	11,433	11,487	0.64	Acute diarrhoea	3,071	3,206	6,277	0.35	Eye conditions	1,479	3,108	4,587	0.25
Oral diseases	1,213	8,201	9,414	0.52	AIDS	124	5,857	5,981	0.33	ENT conditions	1,179	2,790	3,969	0.22
Pneumonia	2,047	5,850	7,897	0.44	Eye conditions	2,244	2,554	4,798	0.27	Pneumonia	2,322	1,334	3,656	0.20
ENT conditions	2,463	3,721	6,184	0.34	ENT conditions	1,447	2,817	4,264	0.24	Acute diarrhoea	2,078	1,433	3,511	0.19
Gastrointestinal disorders	1,450	4,052	5,502	0.30	Pneumonia	2,143	1,199	3,342	0.19	Hypertension	-	3,391	3,391	0.19
Acute diarrhoea	2,492	2,499	4,991	0.28	Trauma	949	2,298	3,247	0.18	Gastrointestinal disorders	360	2,649	3,009	0.17
Hypertension	7	3,997	4,004	0.22	Hypertension	-	2,785	2,785	0.15	Trauma	414	1,760	2,174	0.12
Persistent diarrhoea	1,148	1,164	2,312	0.13	Persistent diarrhoea	1,326	1,115	2,441	0.14	Oral diseases	38	1,338	1,376	0.08
Typhoid	62	1,973	2,035	0.11	Gastrointestinal disorders	610	1,536	2,146	0.12	Epilepsy	11	892	903	0.05
Depression	38	1,786	1,824	0.10	Typhoid	113	1,612	1,725	0.10	Tuberclosis	5	880	885	0.05
Trauma	428	1,315	1,743	0.10	Tuberclosis	8	1,340	1,348	0.07	Typhoid	6	807	813	0.05
Aneamia	470	949	1,419	0.08	Aneamia	315	795	1,110	0.06	Asthma	108	586	694	0.04
Epilepsy	72	985	1,057	0.06	Asthma	195	808	1,003	0.06	AIDS	3	582	585	0.03
Asthma	161	886	1,047	0.06	Epilepsy	91	849	940	0.05	Severe Malnutrition	498	63	561	0.03
Tuberclosis	34	971	1,005	0.06	Severe Malnutrition	568	79	647	0.04	Aneamia	172	342	514	0.03
Diabetes Mellitus	-	409	409	0.02	Measles	464	145	609	0.03	Dysentery	82	219	301	0.02
Injuries due to road accidents	43	362	405	0.02	Depression	290	225	515	0.03	Diabetes Mellitus	-	262	262	0.01
Severe Malnutrition	303	14	317	0.02	Injuries due to road accidents	36	394	430	0.02	Injuries due to road accidents	10	233	243	0.01
Dysentery	97	211	308	0.02	Dysentery	277	148	425	0.02	Measles	125	95	220	0.01
Measles	41	19	60	0.00	Diabetes Mellitus	1	250	251	0.01	Depression	10	140	150	0.01
Schizophrenia	-	44	44	0.00	Schizophrenia	-	-	-	-	Schizophrenia	-	25	25	0.00

Table 6 – Disease profiles for semi-urban Kampala, 2010-2012

DISEASE PROFILES FOR SEMI-URBAN KAMPALA, 2010-2012														
CASES REPORTED 2010					CASES REPORTED 2011					CASES REPORTED 2012				
Disease Diagonised		**Total Pop.**	**582,100**		**Disease Diagonised**		**Total Pop.**	**536,400**		**Disease Diagonised**		**Total Pop.**	**551,000**	
	0-4	**5+**	**TOTAL**	**Inc.**		**0-4**	**5+**	**TOTAL**	**Inc.**		**0-4**	**5+**	**TOTAL**	**Inc.**
Malaria	127,361	255,814	383,175	65.83	Malaria	51,310	133,810	185,120	34.51	Malaria	45,172	116,238	161,410	29.29
Cough and colds	50,507	95,794	146,301	25.13	Cough and colds	27,685	60,310	87,995	16.40	Cough and colds	28,980	65,422	94,402	17.13
Pneumonia	25,698	43,313	69,011	11.86	Pneumonia	12,092	22,236	34,328	6.40	Pneumonia	8,817	16,674	25,491	4.63
Intestinal worms	14,854	29,140	43,994	7.56	Intestinal worms	7,332	21,226	28,558	5.32	Intestinal worms	6,230	17,492	23,722	4.31
Skin diseases	12,006	20,720	32,726	5.62	Skin diseases	5,715	11,780	17,495	3.26	Skin diseases	4,452	9,562	14,014	2.54
Oral diseases	3,183	22,128	25,311	4.35	Acute diarrhoea	6,077	8,445	14,522	2.71	Acute diarrhoea	5,023	6,266	11,289	2.05
Acute diarrhoea	11,206	11,964	23,170	3.98	Gastrointestinal disorders	1,796	10,902	12,698	2.37	ENT conditions	2,064	6,372	8,436	1.53
Gastrointestinal disorders	2,821	19,731	22,552	3.87	Oral diseases	1,487	9,926	11,413	2.13	Gastrointestinal disorders	656	7,674	8330	1.51
STIs	369	19,672	20041	3.44	STIs	220	10,379	10599	1.98	STIs	100	7,850	7950	1.44
Eye conditions	4,657	12,816	17,473	3.00	Eye conditions	2,584	7,772	10,356	1.93	UTIs	327	7,268	7595	1.38
Trauma	2,611	13,308	15,919	2.73	ENT conditions	2,464	7,772	10,236	1.91	Eye conditions	1,984	5,524	7,508	1.36
UTIs	1,142	13,778	14,920	2.56	AIDS	386	9,435	9821	1.83	Trauma	906	6,162	7068	1.28
ENT conditions	4,126	9,434	13,560	2.33	UTIs	627	8,055	8682	1.62	Oral diseases	750	5,858	6608	1.20
AIDS	791	12,658	13449	2.31	Trauma	1,079	7,129	8,208	1.53	Pelvic inflammatory disease	0	4,058	4058	0.74
Pelvic inflammatory disease	33	10,935	10968	1.88	Pelvic inflammatory disease	5	5,477	5482	1.02	AIDS	169	3,158	3327	0.60
Aneamia	5,335	4,041	9,376	1.61	Aneamia	1,375	1,956	3,331	0.62	Aneamia	868	1,250	2118	0.38
Hypertension	0	5,706	5706	0.98	Hypertension	11	2,742	2753	0.51	Hypertension	2	1,784	1786	0.32
Asthma	519	2,631	3150	0.54	Asthma	255	1,495	1750	0.33	Injuries due to road accidents	120	1,317	1437	0.26
Injuries due to road accidents	398	2,666	3064	0.53	Injuries due to road accidents	182	1,521	1703	0.32	Asthma	100	1,041	1141	0.21
Typhoid	319	2,713	3032	0.52	Epilepsy	62	1,518	1580	0.29	Epilepsy	53	865	918	0.17
Persistent diarrhoea	1,170	1,293	2,463	0.42	Persistent diarrhoea	520	963	1483	0.28	Persistent diarrhoea	359	500	859	0.16
Epilepsy	67	1,954	2021	0.35	Typhoid	153	1,118	1271	0.24	Diabetes Mellitus	2	536	538	0.10
Diabetes Mellitus	0	1,460	1460	0.25	Diabetes Mellitus	5	709	714	0.13	Tuberclosis	4	235	239	0.04
Tuberclosis	40	783	823	0.14	Tuberclosis	51	467	518	0.10	Depression	0	189	189	0.03
Severe Malnutrition	363	59	422	0.07	Severe Malnutrition	141	17	158	0.03	Severe Malnutrition	157	24	181	0.03
Depression	0	101	101	0.02	Depression	1	91	92	0.02	Schizophrenia	0	9	9	0.00
Schizophrenia	0	17	17	0.00	Schizophrenia	0	10	10	0.00	Typhoid	0	0	0	-
Measles	0	0	0	-	Measles	0	0	0	-	Measles	0	0	0	-
Dysentery	0	0	0	-	Dysentery	0	0	0	-	Dysentery	0	0	0	-

Table 7 – Disease profiles for rural Kampala, 2010-2012

DISEASE PROFILES FOR RURAL KAMPALA, 2010-2012														
CASES REPORTED 2010					CASES REPORTED 2011					CASES REPORTED 2012				
Disease Diagonised	**Total Pop.**		**260,000**		**Disease Diagonised**	**Total Pop.**		**260,000**		**Disease Diagonised**	**Total Pop.**		**260,000**	
	0-4	**5+**	**TOTAL**	**Inc.**		**0-4**	**5+**	**TOTAL**	**Inc.**		**0-4**	**5+**	**TOTAL**	**Inc.**
Malaria	26,645	39,301	65,946	25.36	Malaria	27,447	54,074	81,521	31.35423	Malaria	1,466	4,421	5,887	2.26
Cough and colds	13,412	24,674	38,086	14.65	Cough and colds	13,517	28,311	41,828	16.08769	Cough and colds	899	2,497	3,396	1.31
AIDS	252	11,477	11729	4.51	AIDS	259	14,094	14353	5.520385	AIDS	26	1,141	1167	0.45
Intestinal worms	2,271	4,267	6,538	2.51	Skin diseases	1,947	7,349	9,296	3.575385	Eye conditions	163	474	637	0.25
Pneumonia	2,191	3,061	5,252	2.02	Intestinal worms	2,883	5,577	8,460	3.253846	Intestinal worms	210	372	582	0.22
Gastrointestinal disorders	543	4,550	5,093	1.96	Pneumonia	2,620	5,463	8,083	3.108846	Skin diseases	201	380	581	0.22
Trauma	634	4,045	4,679	1.80	Gastrointestinal disorders	1123	5,463	6586	2.533077	Gastrointestinal disorders	80	496	576	0.22
Skin diseases	1,562	3,109	4,671	1.80	Trauma	570	3,788	4358	1.676154	Pneumonia	208	324	532	0.20
Acute diarrhoea	2,060	1,717	3,777	1.45	Acute diarrhoea	2,119	2,108	4,227	1.625769	Acute diarrhoea	198	230	428	0.16
Eye conditions	893	2,108	3,001	1.15	Eye conditions	1,057	2,861	3,918	1.506923	Trauma	65	313	378	0.15
ENT conditions	703	2,012	2,715	1.04	ENT conditions	1,114	2,710	3,824	1.470769	ENT conditions	87	231	318	0.12
STIs	42	2,657	2699	1.04	STIs	0	2,897	2897	1.114231	STIs	0	306	306	0.12
Epilepsy	101	2,543	2644	1.02	UTIs	231	2,596	2827	1.087308	UTIs	21	278	299	0.12
UTIs	156	2,360	2,516	0.97	Oral diseases	402	2,335	2737	1.052692	Persistent diarrhoea	134	134	268	0.10
Oral diseases	392	1,945	2,337	0.90	Epilepsy	57	2307	2364	0.909231	Oral diseases	48	212	260	0.10
Aneamia	828	466	1,294	0.50	Pelvic inflammatory disease	6	1,693	1699	0.653462	Epilepsy	3	222	225	0.09
Hypertension	5	1,283	1288	0.50	Diabetes Mellitus	0	1584	1584	0.609231	Pelvic inflammatory disease	0	168	168	0.06
Persistent diarrhoea	553	618	1,171	0.45	Aneamia	877	577	1454	0.559231	Hypertension	0	160	160	0.06
Injuries due to road accidents	66	733	799	0.31	Persistent diarrhoea	659	767	1426	0.548462	Diabetes Mellitus	0	111	111	0.04
Diabetes Mellitus	0	689	689	0.27	Hypertension	0	1,348	1348	0.518462	Injuries due to road accidents	8	82	90	0.03
Asthma	57	388	445	0.17	Injuries due to road accidents	73	934	1007	0.387308	Aneamia	35	41	76	0.03
Typhoid	22	418	440	0.17	Typhoid	31	539	570	0.219231	Typhoid	0	56	56	0.02
Tuberclosis	32	261	293	0.11	Asthma	64	393	457	0.175769	Asthma	2	44	46	0.02
Depression	0	55	55	0.02	Tuberclosis	14	217	231	0.088846	Dysentery	13	26	39	0.02
Pelvic inflammatory disease	0	0	42	0.02	Severe Malnutrition	191	15	206	0.079231	Severe Malnutrition	11	0	11	0.00
Schizophrenia	0	0	0	0	Depression	0	33	33	0.012692	Tuberclosis	0	8	8	0.00
Severe Malnutrition	0	0	0	-	Schizophrenia	0	12	12	0.004615	Depression	0	4	4	0.00
Measles	0	0	0	-	Measles	0	0	0	0	Measles	2	2	4	0.00
Dysentery	0	0	0	-	Dysentery	0	0	0	0	Schizophrenia	0	0	0	0.00

3.1.1 Soil-, water- and waste-related diseases

The prevalence of soil-, water- and waste-related diseases depends highly on sanitation facilities and access to safe drinking water, factors which often show high local variations. With regard to access to sanitation facilities, the 2011 Uganda Demographic and Health Survey (UDHS) found that two in three households use non-improved toilet facilities (73% in rural areas versus 28% in urban areas), while 10% of the households in Uganda, mainly in rural areas, have no toilet facilities at all [7].

In Kampala City, water supply and quality control is provided by the National Water and Sewerage Cooperation (NWSC). Raw-water is drawn from the Inner Murchison Bay on Lake Victoria and passed through one of three treatment plants (Gaba 1-3). Approximately 20% of all households are connected to the water supply grid which is concentrated to high income areas. However, there are an estimated 70% of the population using piped water for domestic needs in combination with the use of alternative sources [7]. Alternative water sources are primarily protected springs, which are found all over the city in low- and high-density areas. Several studies indicate that these springs are often contaminated with pathogens and associated with disease outbreaks [8, 9]. It is estimated that the disease burden from protected springs is more than one order of magnitude higher than the risk posed by the piped water supply and for cases of diarrhoea it exceeds the risk from piped water by about 1.5 orders of magnitude.

3.1.1.1 Diarrhoeal diseases

Diarrhoeal disease is the second leading cause of death in children under 5 years old, though it is both preventable and treatable. It is estimated that, diarrhoea kills around 760’000 children under five each year in developing countries. Additionally, diarrhoea is a leading cause of malnutrition in the same age group. A significant proportion of diarrhoeal disease can be prevented through safe drinking-water and adequate sanitation and hygiene. Globally, there are nearly 1.7 billion cases of diarrhoeal disease every year [10].

In Uganda an estimated 28’000 deaths occurred due to diarrhoea in 2004 [11]. Also in recent years acute diarrhoea ranked as a leading cause of morbidity at the health facilities in urban, peri-urban and rural Kampala. Due to limited diagnostics at peripheral health facilities, the cause of diarrhoeal disease is generally not determined. In addition, many people may not consult a health facility in the event of acute diarrhoeal.

Outbreaks of Typhoid fever (*Salmonella Typhi*) and cholera (*Vibrio cholera*) have been reported in Uganda [12, 13].

3.1.1.2 Helminthiasis

Soil-transmitted helminth (STH) infections are the most common helminth infections worldwide. Sub-Saharan Africa is among the regions with the highest prevalence of soil-transmitted helminth infection and progress to reduce the burden of soil-transmitted helminthiasis has been slower than in any other region of the world [14]. In Uganda all major STH species are endemic and of public health importance [15]. The median predicted risk estimates for *Ascaris lumbricoides*, *Trichuris trichiura* and hookworm in Uganda from 2000 onwards are shown in [16]. The predictions match with the findings of our own in-depth study carried out in selected population groups along the Nakivubo Channel: the most common STH infection were hookworm and *T. trichiura* with prevalences of 27.8% 27.8% (68/245) and 26.1% (64/245) in local farmers, respectively [17]. More detailed findings on STH infections along the Nakivubo Channel are available in Table 8.

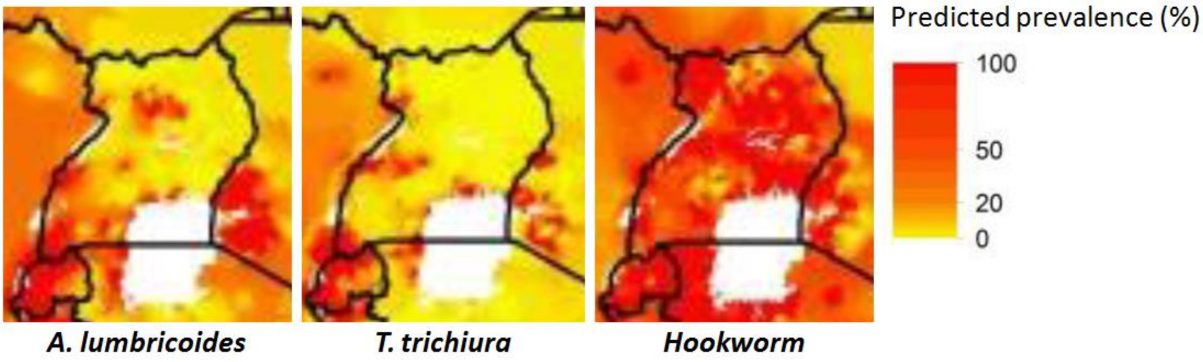


Figure 5 – median predicted risk estimates for STH infection in Uganda [16]

Table 8 – Helminth infections along the Nakivubo Channel (2013) [18]

Soil transmitted helminth n=915	Percentage in wastewater treatment plant workers n=43	Percentage in faecal sludge worker n=67	Percentage in farmer n=245	Percentage in community 1 n=229	Percentage in community 2 n=331
Hookworm prevalence	**16.3**	**4.5**	**27.8**	**3.9**	**8.5**
Light infection	16.3	3.0	26.1	3.5	7.3
Moderate infection	0	1.5	1.6	0.4	0
***Trichuris trichiura* prevalence**	**2.3**	**0**	**26.1**	**3.5**	**1.8**
Light infection	2.3	0	24.9	3.5	1.8
Moderate infection	0	0	1.2	0	0
***Ascaris lumbricoides* prevalence**	**2.3**	**0**	**18.4**	**3.1**	**0**
Light infection	2.3	0	14.3	2.2	0
Moderate infection	0	0	4.1	0.9	0

Schistosomiasis, also known as Bilharzia, is a disease caused by parasitic trematode schistosome worms. In sub-Saharan Africa, 57 million school-aged children and 160 million people from the entire population were predicted to be infected with either *Schistosoma* species in 2012 [19]. The same study estimated the overall prevalence of Schistosomiasis in the entire population at 8.9% (*Schistosoma mansoni*: 5.3%; and *Schistosoma haematobium*: 3.9%), though considerable spatial variation can be observed throughout the country, with the zone around Lake Victoria as one of the high risk areas for *Schistosoma mansoni* transmission (see Figure 6). This was confirmed by our own data as shown in Table 9, with farmers (prevalence: 22.9%; 56/245) and the general community (prevalence: 12.2%; 30/245) being most affected by *S. mansoni* infection.

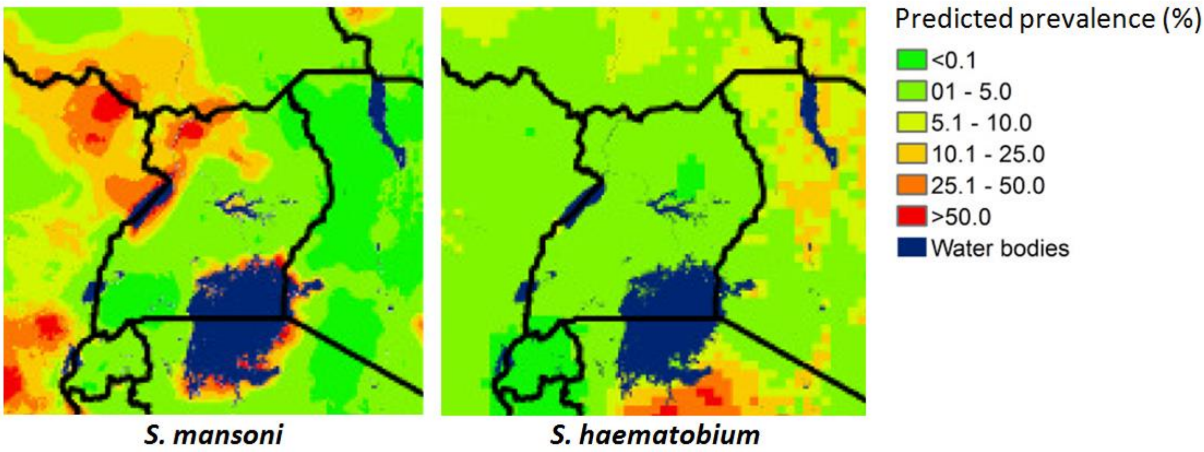


Figure 6 – Predicted prevalence of schistosomiasis in Uganda (2012) [19]

Table 9 – Schistosomiasis infections along the Nakivubo Channel (2013) [18]

Schistosoma mansoni	Percentage in wastewater treatment plant workers	Percentage in faecal sludge worker	Percentage in farmer	Percentage in community 1	Percentage in community 2
n=915	n=43	n=67	n=245	n=229	n=331
Prevalence	**4.7**	**6.0**	**22.9**	**12.2**	**6.0**
Light infection	2.3	3.0	14.3	8.7	3.0
Moderate infection	2.3	1.5	6.1	1.3	2.1
Heavy infection	0	1.5	1.6	1.8	0.6

3.1.1.3 Intestinal protozoa

Intestinal protozoa show a worldwide distribution with infection being highest in infants and children. Little information is available on intestinal protozoa infection for Uganda. In a recent study, prevalences of *Giardia lamblia* and *Entamoeba histolytica* in communities bordering Lake Victoria were found at 12% and 10%, respectively [20]. In our own in-depth study carried out in selected population groups along the Nakivubo Channel, prevalence rates of *G. lamblia* were found to be considerably lower (below 2% in all population groups sampled). *Entamoeba coli* was found to be the most common type of intestinal protozoa in farmers (prevalence: 38.4%; 94/245) and the general community (prevalence: 36.2%; 87/245) (see Table 10).

Table 10 – Intestinal protozoa infections along the Nakivubo Channel (2013) [18]

Intestinal protozoa n=915	Percentage in wastewater treatment plant workers n=43	Percentage in faecal sludge worker n=67	Percentage in farmer n=245	Percentage in community 1 n=229	Percentage in community 2 n=331
Entamoeba histolytica	11.6	7.5	15.1	3.9	6.0
Entamoeba coli	18.6	19.4	38.4	36.2	27.8
Giardia lamblia	0	1.5	0.8	0.4	1.5
Balantidium coli	0	0	0.4	0	0.3
Chilomastix mesnili	2.3	0	0.4	0.4	0.3
Entamoeba hartmanni	0	0	0.4	7.0	3.6
Iodamoeba buetschlii	0	1.5	4.5	4.4	3.9

3.1.1.4 Skin and eye infections

Reliable data on skin and eye infection are scarce in Uganda. Case reports from hospital and health centres from Kampala area show that skin diseases rank among the leading morbidities in the urban, peri-urban and rural environments in 2011 and 2012 (see Table 5, Table 6 and Table 7). Also eye conditions are an important cause for consultation. Also in our cross-section survey in the Nakivubo Channel, eye problems and skin problems were frequently reported among all population groups investigated as shown in Table 11.

Table 11 – Frequency of reported eye and skin problems, Nakivubo Channel (2013) [18]

Eye and skin problems n=915	Percentage in wastewater treatment plant workers n=43	Percentage in faecal sludge worker n=67	Percentage in farmer n=245	Percentage in community 1 n=229	Percentage in community 2 n=331
Eye problems	32.6	32.8	38.0	27.5	20.2
Skin problems	30.2	38.8	33.1	28.0	28.7

3.1.2 Respiratory tract diseases

Respiratory tract diseases are diseases that affect the air passages, including the nasal passages, the bronchi and the lungs. They range from acute infections, such as pneumonia and bronchitis, to chronic conditions such as asthma and chronic obstructive pulmonary disease.

3.1.2.1 Acute respiratory tract infections

Acute respiratory infections (ARI) (e.g. pneumonia) are an abnormal inflammation of the lung and have a variety of causes including bacteria, viruses, fungi or parasites. ARI are the most common cause of death in children and kills about 3 million children every year in the developing world. Children under the age of 5 years, and especially those under 2 years, constitute the greatest risk group. ARI can be spread in a number of ways. The most important transmission pathway is air-borne droplets from a cough or sneeze of an infected individual. But also transmission via wastewater and food products that are contaminated with human waste is an important transmission pathway, and thus indirectly associated with sanitation and drinking water systems, as well as resource recovery and reuse activities.

According to the health statistic obtained for the urban, peri-urban and rural environments in Kampala area, cough and cold was the second leading cause of consultation at the health facilities in all three environments in 2011 and 2012. This clearly makes ARI a major public health concern and also shows that a lot of transmission is taking place.

3.1.2.2 Chronic respiratory diseases

The most common non-infectious respiratory diseases are asthma, chronic obstructive pulmonary disease (COPD), respiratory allergies and pulmonary hypertension. In 2005, COPD caused more than 3 million deaths, with 90% of those occurring in low- and middle-income countries [21]. COPD is predicted to be the third most common cause of death in 2030. Risk factors include tobacco smoking, indoor air pollution (e.g. indoor cooking with wood or coal), outdoor air pollution (e.g. burning domestic waste or traffic related dust), allergens and occupational exposure (e.g. asbestos, silica, certain gasses). In addition to causing chronic respiratory diseases, indoor and outdoor air pollution is also directly associated with cardiovascular disease such as hyper tension, shock and cardiac infarction.

In Uganda, chronic respiratory diseases and cardiovascular diseases account for 2% and 9% of total mortality (all ages, both sexes), according to estimates of the WHO [22]. Taken together, those two health conditions account for one in 10 deaths in Uganda, which makes exposure to indoor and outdoor air pollution an important public health concern.

3.1.3 Vector-borne diseases

In the terminology of epidemiology, vectors are organisms that transmit infections from one host to another. The most commonly known biological vectors are arthropods but many domestic animals are also important vectors or asymptomatic carriers of parasites and pathogens that can affect or infect humans or other animals. In the present chapter we will focus on diseases associated with mosquito and fly vectors.

Depending on the season a broad range of mosquitos vectors such as *Anopheles spp.*, *Aedes spp*. and *Culex spp*. are present in Uganda. Therefore, various vector-borne diseases are endemic in the country and are of major public health relevance (e.g. malaria, dengue, yellow fever, Rift Valley fever, lymphatic filariasis).

3.1.3.1 Malaria

Malaria, a protozoan infection transmitted by anopheline mosquitoes, is the most important parasitic disease in humans. Malaria is one of the most serious public-health issues in many parts of the developing world, but especially so in sub-Saharan Africa. Malaria endemic countries are not only poorer than countries free of the disease, but the highly malaria-endemic countries also have significantly lower rates of economic growth [23].

The climate in Uganda allows stable, year round malaria transmission with relatively little seasonal variability in most areas and therefore highly endemic in most parts of the country putting over 90% of the population at risk. In Uganda, *Plasmodium falciparum*, the most dangerous type of malaria parasites, is responsible for the vast majority of the cases (approximately 99% of all infections) [15, 24].

Malaria is the leading cause of morbidity and mortality in Uganda, accounting for approximately 8–13 million episodes per year. Prevalences are particularly high in rural and peri-urban areas, often ranging from 40 to 60% [24]. In urban areas such as Kampala city, generally less than 5% of people are infected with malaria. Interestingly, according to the health statistic obtained for the urban, peri-urban and rural environments in Kampala area, malaria was the leading cause of consultation at the health facilities in all three environments. This discrepancy is most likely due to the limited availability of diagnostic testing equipment at peripheral health facilities. However, malaria is clearly a major public health issue in Uganda, claiming an enormous toll in lives, medical costs and days of schooling or labour lost.

3.1.3.2 Arboviral diseases

Yellow fever, Dengue fever, West Nile virus and Rift Valley fever are viral diseases that involve several species of mosquitoes within the genus *Aedes* and *Culex* in their transmission cycle. These mosquitoes live in close association with man since they breed in any small water collection, including open containers, old tires and tree holes. Both species are endemic in Uganda and also cases of different arboviral diseases are reported, though at relatively low and intermittent frequency. However, many cases of arboviral infections might go undetected as diagnostics for those diseases are cost and equipment intensive.

3.1.3.3 Lymphatic filariasis

Lympahtic fliariasis (LF) caused be *Wuchereria bancrofti* is a major public health concern. In Uganda the disease affects more than 13 million people in 54 districts [15]. Kampala district does not belong to the districts affected by LF.

3.1.3.4 Trachoma

Globally, Trachoma is responsible for visual impairment of about 2.2 million people, with 1.2 million of them permanently blind, according to the World Health Organisation [25]. In Uganda, Trachoma is the leading infectious cause of blindness with an estimated eight million Ugandans being at risk of suffering from Trachoma. The disease is caused by the bacterium *Chlamydia trachomatis*. Transmission occurs through contact with eye and nose discharge of infected people, particularly young children who form the reservoir of infection. It is also spread by flies which have been in contact with the eyes and nose of infected people. Hence, poor sanitation, crowded living conditions, and not enough clean water and toilets also increase spread.

3.2 Environmental parameters

3.2.1 Liquid waste system

In Kampala, 94% of the population is served by on-site sanitation (OSS) systems. In this report, OSS refers to all sanitation technologies that are not connected to the sewer system. In general, in Kampala these technologies are VIP latrines, unlined pit latrines, septic tanks, Ecosan toilets and Urine Diverting Dry Toilets (UDDT). Ecosan toilets, VIP and unlined pit latrines are typically dry systems without a flush, whereas septic tanks systems typically do have a flush toilet. The management of FS from OSS systems is a major challenge in Kampala, as they are typically built without consideration of how they will be emptied once they get full. They are also frequently difficult to access for collection and transport vacuum trucks due to narrow alleys and pathways in informal settlements.

The PEAU is a professional organization of FS collection and transport companies in Kampala. In total, there are 110 members of the PEAU with 45 trucks, and 75% of all collection and transport FSM businesses in Kampala belong to the association. In addition to the PEAU, KCCA also has seven trucks, of which six are currently operating. There are also two schools in Kampala that own and operate their own trucks. Other trucks that do not belong to the PEAU include a hotel, the army, the police and two private companies each with one truck. The collected faecal sludge is discharged into settling tanks at the Bugolobi Sewerage Treatment and Disposal Works (BSTDW) which is operated by NWSC. The liquid effluent gets collected and is pumped to the influent of BSTDW. There is no further treatment for the settled faecal sludge, which gets collected several times per year and is disposed of at the Kiteezi Landfill.

Due to the increasing volume of the faecal sludge disposed and the lack of improvement of the infrastructure of the treatment plant, the current design to handle the faecal sludge and sewerage is questioned and inadequate treatment became a common reality [26-28]. Due to such practises there are concerns that root crops (e.g. coco yams) and leaf crops (e.g. salads and vegetables) which are grown, for example in the Nakivubo swamp, contain harmful pathogens and chemicals. To underline these concerns, a study undertaken by Kayima et al. (2008) showed a high degree of pollution in Nakivubo channel which is caused by discharge of waste from various sources such as slums, markets and industries [29]. The operational quality control of the wastewater undertaken by NWSC within the treatment plant and in the Nakivubo Channel and swamp showed a significant level of pollution which is far above WHO standards for wastewater reuse in unrestricted irrigation ($<10^3$-10^4 *Escherichia coli*/100ml) [3].

To improve the current situation, the Kampala sanitation master plan recommends to improve conventional wastewater treatment and anaerobic digestion for the production of biogas from the wastewater treatment plant sludge in the Nakivubo area and to build three new semi-decentralised treatment plants in Lubigi, Nalukolongo and Kinawataka. Moreover, the city authorities plan to improve the sewage coverage from 6% to 30% by 2033. This means, that on-site sanitation using pit latrines and septic tanks will continue to be relevant until 2033 and beyond. In addition, more appropriate treatment solutions need to be developed [26, 30]. In May 2014, the first large scale faecal sludge treatment plant (i.e. Lubigi Faecal Sludge and Wastewater Treatment Plant) was commissioned in Kampala with a design capacity of 400 m^3/d [2].

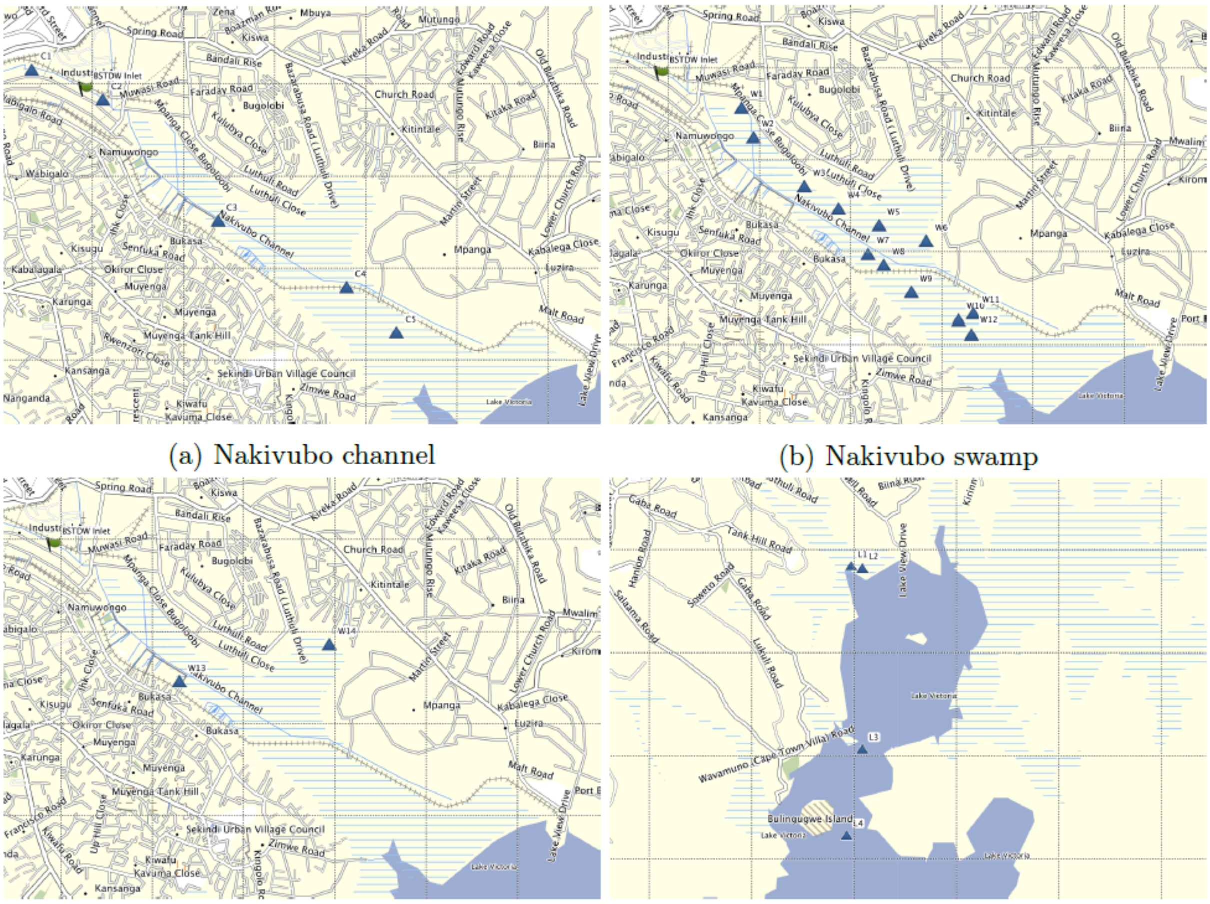
3.2.2 Solid waste collection system

KCCA collects municipal solid waste in and around Kampala city and transports it to Kitezi sanitary landfill, located in Kitezi village, Mpererwe in Wakiso district which is located about 25km from Kampala city. There are 380 people from the neighbouring communities who scavenge and sort wastes at the landfill. The case study of the Kitezi sanitary landfill, which was undertaken as part of the baseline data collection of the HRIA, identified a range of serious health risk for people working on the landfill. For example, skin cuts caused by broken bottles, needles and other sharp objects are a major concern since most waste pickers are not equipped with appropriate PPE. Moreover, the effluent of the landfill serves as breeding sites for mosquito vectors and it was also reported that contamination of ground and surface water is an issue of great concern.

3.2.3 Environmental sampling along the Nakivubo wetland

The Nakivubo Channel, which is at the outlet of BSTDW plant, has become an open sewer and is steadily extended almost right through the entire Nakivubo swamp. Hence, the wastewater ends either informally on the fields of the farmers being active in the Nakivubo swamp or it is discharged into the inner Murchison Bay of Lake Victoria; one of the major sources of raw water for Kampala city. Consequently, the current situation does not only pose considerable health risks to local farmers and community members but also the drinking water quality is negatively impacted [28].

Against this background, and due to a lack of recent environmental data for Kampala City, soil and water samples were collected as part of the baseline studies of the HRIA from mid-October to early December 2013 (see Annex IV) [31]. The sampling locations are shown in Figure 7 (blue triangles; green flag: inlet of BSTDW effluent into the channel). Key data are presented in Table 12 to Table 17. The findings can be summarized as follows:



(a) Nakivubo channel (b) Nakivubo swamp

(c) Community area (d) Inner Murchison Bay, Lake Victoria

Figure 7 – Environmental sampling framework Nakivubo wetland (2013) [31]

Within the Nakivubo wetland, high levels of faecal coliform bacteria, *E. coli*, *Salmonella* spp., and hookworm eggs were found. Concentrations showed temporal variability, but values were always above the national standards for the discharge of effluents into the environment and WHO guidelines for the safe use of wastewater in agriculture. In terms of industrial pollution high levels of copper (Cu), iron (Fe), and cadmium (Cd) were found in water, and high levels of zinc (Zn), Fe, Cd and lead (Pb) were found in soil. Plants also showed heavy metal (Cd, Pb, Chromium (Cr)) concentrations above existing safety levels. Concentrations of bacteria were correlated with different physiochemical, meteorological and geographical parameters, which could be used to improve predicted pathogen concentrations. Regarding spatial variations within the wetland, a decrease in bacteria concentrations was observed along the channel with increasing distance from the city. However, the decrease was most marked where the original wetland is still intact. Looking at spatial variation in bacterial concentrations within the swamp area by applying universal kriging, 'hot spots' of contamination could be identified at the beginning of the swamp as well as shortly before its transition into Lake Victoria. Furthermore, a trend towards higher bacterial contamination was evident in the wet season as compared to the dry season. More information on the study is available in Annex III – MSc Thesis Michelle Stalder.

Table 12 – Physiochemical parameters for different areas, Nakivubo wetland (2013) [31]

Physiochemical parameter	Min	Max	Mean	Lower 95% CI	Upper 95% CI
Temp (°C)	18.1	34.3	26.4	26.1	26.8
pH	5.9	9.3	7.2	7.1	7.3
EC (μS/cm)	104.7	1320.0	574.6	538.1	611.2
Total Alkalinity (mg l^{-1})	28.0	556.0	240.5	225.1	255.8
TSS (mg l^{-1})	6.0	5100.0	198.7	140.8	256.7
BOD_5 (mg l^{-1})	2.0	425.7	91.4	82.7	100.0
COD (mg l^{-1})	5.0	3231.0	257.4	211.3	303.5
Total Phosphate (mg l^{-1})	0.01	84.1	11.5	9.7	13.3
Orthophosphate (mg l^{-1})	0.0	26.2	5.2	4.5	5.9
Ammonia-N (mg l^{-1})	0.0	52.8	21.2	19.6	22.8
Nitrate-N (mg l^{-1})	0.0	2.5	0.20	0.15	0.25

Table 13 – Bacterial concentrations in water samples, Nakivubo wetland (2013)[31]

Area	Counts in CFU 100 ml^{-1}				
Microorganism	min	max	mean	Lower 95% CI	Upper 95% CI
Channel (n=112)					
Faecal coliforms	$1.2x10^3$	$1.8x10^8$	$4.3x10^6$	$2.7x10^6$	$6.9x10^6$
E.coli	$8.4x10^2$	$9.0x10^7$	$3.8x10^5$	$2.3x10^5$	$6.4x10^5$
Salmonella spp.	0.0	$2.0x10^5$	$3.8x10^2$	$2.5x10^2$	$5.7x10^2$
Swamp (n=48)					
Faecal coliforms	$4.0x10^2$	$2.2x10^8$	$2.9x10^5$	$1.0x10^5$	$8.0x10^5$
E.coli	$1.0x10^2$	$7.9x10^7$	$9.9x10^4$	$3.6x10^4$	$2.7x10^5$
Salmonella spp.	0.0	$1.2x10^5$	$1.4x10^2$	63	$3.2x10^2$
Communities (n=8)					
Faecal coliforms	$4.2x10^3$	$3.1x10^9$	$1.5x10^7$	$8.4x10^4$	$2.9x10^9$
E.coli	$1.9x10^3$	$6.0x10^7$	$7.3x10^5$	$1.8x10^4$	$2.9x10^7$
Salmonella spp.	36	$6.0x10^2$	99	35	$2.8x10^2$
Lake (n=32)					
Faecal coliforms	0.0	40	3.7	2.3	6.0
E.coli	0.0	11	1.3	1.1	1.7
Salmonella spp.	0.0	8.0	1.3	1.0	1.6

Red: concentrations exceeding maximum acceptable concentrations for faecal coliform bacteria (NEMA, 1999) and *E. coli* (WHO, 2006). No maximum acceptable concentrations for Salmonella spp.

Table 14 – Helminth eggs in water samples, Nakivubo wetland (2013) [31]

Area / Nematodes	Counts l^{-1} Min	Max	Mean	Lower 95% CI	Upper 95% CI	No. positive	Prevalence rates % positive	Lower 95% CI	Upper 95% CI
Channel (n=112)									
Hookworms	0	160	2.0	1.5	2.6	23	20.5	13.0	28.0
T. trichiura	0	0	–	–	–	0	0	–	–
A. lumbricoides	0	10	1.1	1.0	1.1	3	2.7	–	–
Swamp (n=48)									
Hookworms	0	933	1.3	0.9	1.8	3	6.3	–	–
T. trichiura	0	0	–	–	–	0	0	–	–
A. lumbricoides	0	0	–	–	–	0	0	–	–
Communities (n=8)									
Hookworms	0	0	–	–	–	0	0	–	–
T. trichiura	0	0	–	–	–	0	0	–	–
A. lumbricoides	0	40	1.6	0.5	4.7	1	12.5	–	–
Lake (n=32)									
Hookworms	0	40	1.3	0.8	2.2	1	3.1	–	–
T. trichiura	0	0	–	–	–	0	0	–	–
A. lumbricoides	0	0	–	–	–	0	0	–	–
Total (n=200)									
Hookworms						27	13.5	8.8	18.2
T. trichiura						0	0	–	–
A. lumbricoides						4	2.0	0.1	3.9
Overall total						31	15.5	10.5	20.5

Table 15 – Helminth eggs in soil and sediment samples, Nakivubo wetland (2013) [31]

Sample / Parasites	No. positive	Prevalence rate % positive	Lower 95% CI	Upper 95% CI
Channel sediments (n=8)				
Hookworms	1	12.5	–	–
T. trichiura	0	0	–	–
A. lumbricoides	1	12.5	–	–
Swamp soil (n=28)				
Hookworms	4	14.3	1.3	27.3
T. trichiura	0	0	–	–
A. lumbricoides	0	0	–	–
Lake sediments (n=16)				
Hookworms	0	0	–	–
T. trichiura	0	0	–	–
A. lumbricoides	0	0	–	–
Total (n=52)				
Hookworms	5	9.6	1.6	17.6
T. trichiura	0	0	–	–
A. lumbricoides	1	1.9	–	–
Overall total	6	11.5	2.8	20.2

Table 16 – Concentration of heavy metals in water samples, Nakivubo wetland (2013) [31]

Area	Concentration in ppm				
Metal	Min	Max	Mean	Lower 95% CI	Upper 95% CI
Channel (n=9)					
Cu	0.9	6.3	3.3	1.6	5.0
Zn	0.2	3.0	1.4	0.7	2.0
Fe	8.1	38.1	21.5	13.9	29.0
Cd	0.05	0.31	0.14	0.07	0.22
Pb	0.09	3.00	1.60	0.94	2.26
Cr	0.01	0.10	0.06	0.03	0.08
Swamp (n=12)					
Cu	0.9	4.0	2.3	1.7	3.0
Zn	0.01	1.1	0.3	0.1	0.6
Fe	10.9	33.5	18.6	14.1	23.1
Cd	0.01	0.31	0.13	0.07	0.19
Pb	0.10	2.60	1.02	0.56	1.49
Cr	0.003	0.21	0.06	0.01	0.10
Communities (n=2)					
Cu	1.7	4.2	3.0	–	–
Zn	0.17	0.20	0.19	–	–
Fe	18.2	27.6	22.9	–	–
Cd	0.14	0.26	0.20	–	–
Pb	1.3	3.8	2.5	–	–
Cr	0.01	0.02	0.02	–	–
Lake (n=4)					
Cu	1.0	2.1	1.4	0.6	2.2
Zn	0.2	0.5	0.3	0.1	0.5
Fe	15.0	21.1	17.7	12.7	22.7
Cd	0.09	0.11	0.10	0.09	0.11
Pb	0.91	1.64	1.25	0.76	1.73
Cr	0.01	0.02	0.014	0.004	0.023

Red: concentrations exceeding maximum acceptable concentrations (NEMA, 1999). Cu: Copper, Zn: Zinc, Fe: Iron, Cd: Cadmium, Pb: Lead, Cr: Chromium.

Table 17 – Heavy metal concentration in solid samples, Nakivubo wetland (2013) [31]

Sample	Concentration in ppm				
Metal	Min	Max	Mean	Lower 95% CI	Upper 95% CI
Soil (n=28)					
Cu	18.3	98.3	53.1	44.3	61.8
Zn	32.8	742.5	293.0	218.0	368.0
Fe	15000	80000	47000	40000	54000
Cd	0.3	3.5	1.8	1.5	2.1
Pb	20.0	427.5	132.7	98.4	167.0
Cr	24.5	105.3	49.4	41.2	57.5
Sediment (n=8)					
Cu	12.8	78.3	35.8	16.9	54.8
Zn	37.0	351.3	134.9	35.4	234.4
Fe	15000	28000	25000	20000	30000
Cd	0.5	5.3	2.1	0.9	3.3
Pb	2.5	90.0	25.6	2.2	49.0
Cr	29.0	103.0	49.8	30.7	68.9
Yam (n=15)					
Cu	0.0	11.9	2.6	0.7	4.5
Zn	0.0	387.5	62.8	5.1	120.5
Fe	0.0	87.5	42.1	23.7	60.5
Cd	0.0	0.5	0.2	0.1	0.3
Pb	0.0	8.8	4.0	2.1	6.0
Cr	0.0	13.9	4.4	1.7	7.1
Sugarcane (n=13)					
Cu	0.0	9.0	2.4	0.8	4.0
Zn	0.0	553.8	67.1	–	–
Fe	26.3	92.5	59.0	47.2	70.7
Cd	0.0	0.5	0.2	0.1	0.3
Pb	0.0	17.5	4.3	1.2	7.5
Cr	1.0	14.3	8.4	5.4	11.5

Red: concentrations exceeding maximum acceptable concentrations (NEMA, 1999).
Cu: Copper, Zn: Zinc, Fe: Iron, Cd: Cadmium, Pb: Lead, Cr: Chromium.

3.3 Self-reported health issues by workers of reuse cases

In the frame of the questionnaire survey that was carried out at the level of existing RRR cases in Kampala, 176 workers were asked what kind of health complaints they have experiences within the past two weeks. Results are presented in Figure 8 and can be summarized as follows:

More than 1 in 3 workers (35%) reported to have experienced some form of musculoskeletal pain (back, joint, and/or muscle pain) in the two weeks preceding the survey. Musculoskeletal conditions were followed by headache (29%), acute coughing (25.7%) and fever (25%). Also chest pain, eye irritations and abdominal pain was reported by more than 15% of all workers. Diarrhoea, which is often declared as one of the major health outcomes when handling waste, was only reported by 5.6% of the respondents (Figure1).

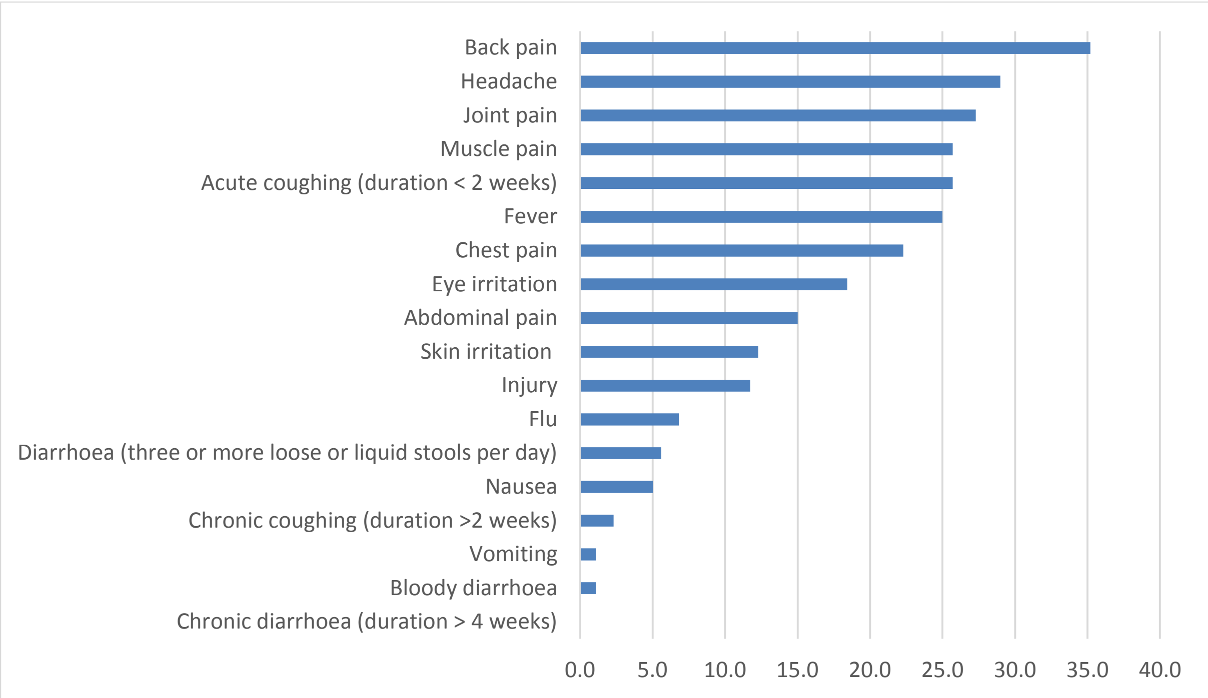


Figure 8 – Health issues reported by workers of RRR cases in Kampala area (n=176)

When asked about medication for treating and preventing adverse health conditions, 28.5% of the workers reported to take pain killers, 11.2% said they swallow de-worming pills, 6.7% use antibiotics and 5.1% take anti-malarial drugs.

3.4 Acceptability and use of personal protective equipment

The acceptability and use of a total of 18 different types of PPE to protect head, eyes, ears, airways, whole body, hand, legs and feet were assessed at the level of existing RRR businesses in Kampala area. A total of 176 workers participated in the study.

First, the health risk assessors from the Makerere University School of Public Health pre-selected different type of PPE consider as necessary for preventing occupational health hazards at the level of each RRR case according to their expert opinion after a site visit and the key informant interview with the business operators. Overall, uniforms/overalls and rubber boots were considered as appropriate for all the workers (100%). This was followed by hard hat (65.0%), simple face masks (60.0%), long safety gloves (60.2%) and rubber gloves (39.0%). Noise reduction head set, water proof trousers and face shield were only seen as appropriate for 0.5%, 3.4% and 3.9% of all workers, respectively.

Second, whenever a PPE option was considered relevant for the given tasks of a worker, he was asked whether the worker actually uses the PPE. If this was not the case, it was assessed, which of three options is the primary reason for not wearing the PPE: (i) no need, (ii) not available; or (iii) do not like it. 'Not available' was by far the most common reason for not wearing a specific PPE, followed by 'do not like it'. Only few workers reported not to see a need for wearing a PPE would clearly be appropriate for his tasks. Overall, the vast majority of the workers clearly stated that they are willing to wear the indicated PPE if it is available. Details of the study on the use, acceptability and willingness to pay of PPE at the level of RRR cases in Kampala area are available in Table 18 and Figure 9.

Third, workers were asked whether, besides PPE, they see additional measures/controls that could improve their safety during work. While the majority of workers did not have any suggestion, the following proposals were made: medical check-ups & provide free medical service (n=12); improve road network to avoid accidents, increase salary and provide a better quality of PPEs (n=8 each); proper segregation of medical waste, cover open manholes, provide milk for workers and reduce exposure to dust and gases at working place (n=5 each); provide a tap for washing hands, maintain clean toilet facilities, medical insurance and toilet facilities (n=4 each); and clean up the work place (n=3).

Table 18 – Use, acceptability and willingness to pay for PPE at RRR cases in Kampala

Personal protective equipment (PPE) Total worker (n:176)	Head protection		Eyes protection		Ear protection		Airway protection			Whole body protection			Hand protection			Leg and foot protection		
	Soft hat	Hard hat	Safety glasses	Face shield	Ear plugs	Noise reduction head set	Simple face mask (quarter mask)	Half mask respirator	Respirator with oxygen supply	Uniform /overall	High-visibility clothing	Rain jacket	Rubber gloves	Safety rubber gloves	Long safety gloves	Rubber boots	Safety boots	Water proof trousers
	%	*No*	*No*	*No*	*No*	*No*	*No*	*No*	*No*	*No*	*No*	*No*	*No*	*No*	*No*	*No*	*No*	*No*
Relevant for RRR case : n	49	114	44	7	14	1	105	46	9	176	24	7	68	10	106	171	21	6
%	*27.8*	*64.7*	*25*	*3.9*	*7.9*	*0.6*	*60.3*	*26.1*	*5.1*	*100*	*13.6*	*4*	*38.6*	*10*	*60.2*	*97.2*	*11.9*	*3.4*
Worker wear PPE (n/%) n	**65**	**52**	**12**	**3**	**0**	**0**	**38**	**29**	**6**	**137**	**7**	**5**	**35**	**8**	**87**	**136**	**17**	**4**
%			***27.2***	***42,8***	***0***	***0***	***36.1***	***63.0***	***66.7***	***77.8***	***29.2***	***71.4***	***51.5***	***80.0***	***82.1***	***79.5***	***81.0***	***66.7***
PPE appropriate for the task: %	100	100	100.0	100			105.6	100.0	100	98.5	100	100	102.9	100	100	98.5	100	100
Worker bought PPE: %	100	30.5	16.7	0.0			66.7	0.0	100	51.9	0	0	14.7	12.5	60.9	47.8	50.0	0
Cost UGX: mean							9'333			23'401			5'200	6'000	9'435	19'371	32'428	
Cost UGX: min							1'000			3'500			1'000		2'500	10'000	5'000	
Cost UGX: max							25'000			100'000			10'000		50'000	50'000	70'000	
Worker not wear PPE: n	**17**	**55**	**32**	**4**	**14**	**1**	**68**	**17**	**3**	**39**	**17**	**2**	**33**	**2**	**19**	**34**	**4**	**2**
%	***34.6***	***48.2***	***72.7***	***57.1***	***100.0***	***100.0***	***64.8***	***36.9***	***33.3***	***22.2***	***70.8***	***28.6***	***48.5***	***20.0***	***17.9***	***19.9***	***19.0***	***33.3***
Do not like: %	29.4	3.6	0	25.0	0	0	11.8	11.8	0	12.8	5.9	0	6.1	0	10.5	0.0	0	0
No need fo: %	11.8	1.8	0	0	0	0	0	0	0	2.6	5.9	0	6.1	0	5.3	5.9	0	0
Not available: %	58.8	92.7	100	75.0	100	100	88.2	88.2	100	84.6	88.2	100	87.9	100	100	94.1	100	100
Worker wears PPE if available: %	100	96.1	100	100	100	100	86.7	100	100	97.0	100	100	93.1	100	84.2	100.0	100	100
Worker would buy PPE: %	90.0	75.5	46.9	66.7	57.1	100	100	33.3	33.3	71.9	93.3	100	74.1	100	75.0	87.5	75.0	0
Expenditure for PPE UGX: mean	3'222	17'702	10'200	6'000	5'937	5'000	6'655	12'400	10'000	14'913	8'428	12'500	5'125	3'500	13'625	18'125	10'000	
Expenditure for PPE UGX: min	1'500	2'000	1'000	5'000	2'000		100	1'000		5'000	2'000	12'500	1'000	2'000	12'903	5'000	8'000	
Expenditure for PPE UGX: max	5'000	30'000	50'000	7'000	12'500		20'000	40'000		30'000	30'000	12'500	20'000	5'000	2'500	50'000	12'000	

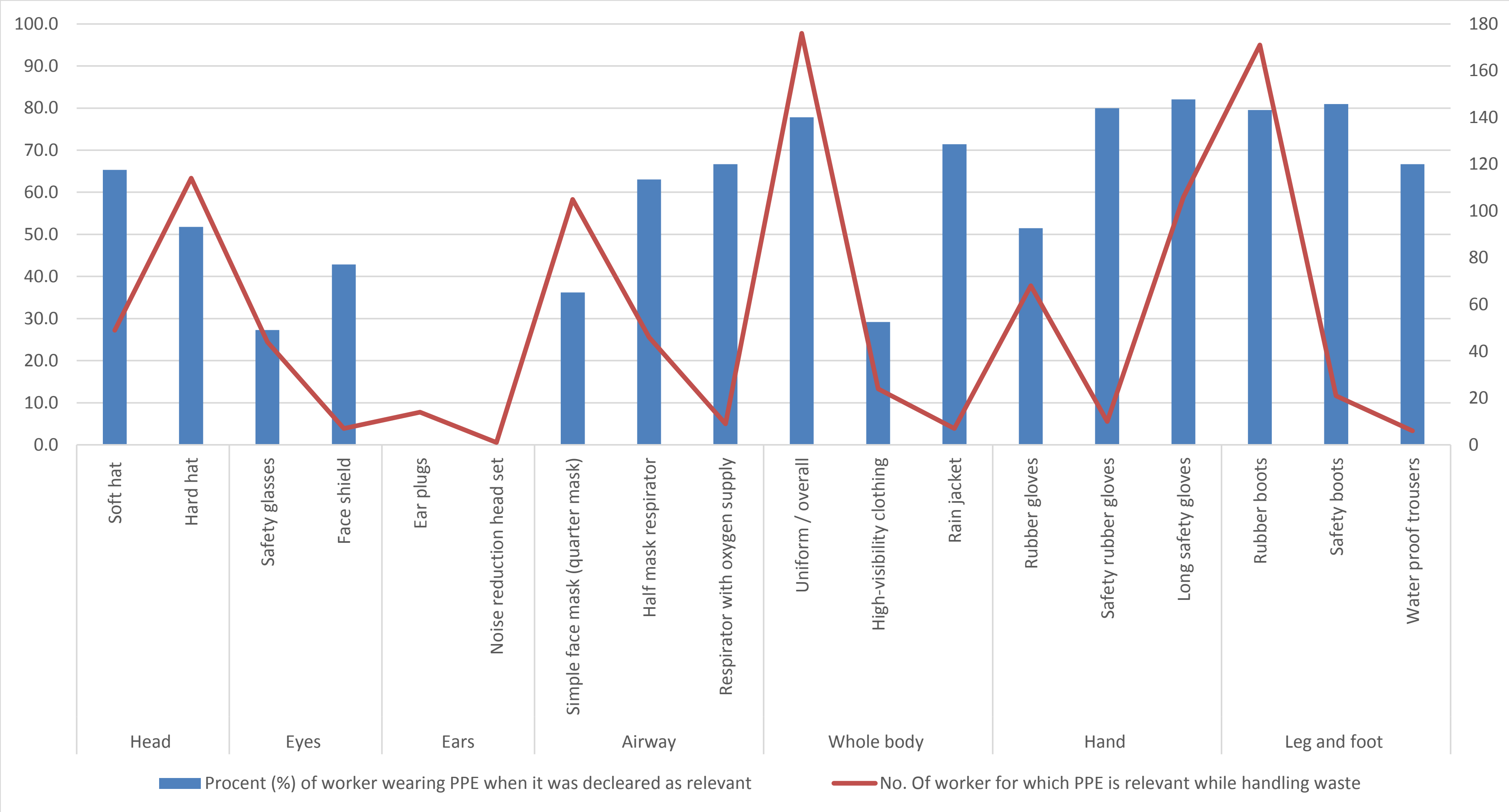


Figure 9 – Percentage of workers wearing PPE considered relevant for the given task

4 Health risk and impact assessment

In this chapter, potential health risks and impacts are outlined after a brief introduction of the BM and respective inputs and outputs. For each of the outputs, quality/safety requirements are listed, which can then also be used as operational and verification monitoring indicators during operation. Of note, if not referenced otherwise, quality standards, pathogen reduction rates and threshold values are as described in the WHO 2006 Guidelines on the safe use of wastewater, excreta and greywater [3].

For the HRA, the data collected at the level of existing RRR cases in Kampala served as important information source in combination with the epidemiological and environmental indicators summarized in the previous chapter. For each case a comprehensive risk assessment matrix was completed, which are available in Appendix I. These tables include a risk assessment of each process and list potential hazards, hazardous events, exposure routes, indicated control measures and a risk assessment. A summary of indicated control measures is provided for each BM under the respective chapters. The risk assessment of each BM concludes with an analysis of residual risks. This covers all the risks classified as moderate to very high by the risk assessment (with the proposed control measure in place). For this purpose, the concerned processes (as per flow diagram) are listed and the issues of concern are discussed. In case the control measures at hand for mitigating the risk at the level of the BM are not sufficient, down-stream control measures (e.g. at consumer level) are proposed.

The HIA provides an analysis on how the proposed BM might impact on community health if implemented at scale. The anticipated scale of the business is indicated for each BM. Based on the assumption that the control measures recommended under the risk assessment are implemented, potential impact pathways are described. Finally, the magnitude of each impact is determined by means of a semi-quantitative risk assessment.

For Kampala, a total of eight BMs were selected to be assessed in the frame of the feasibility studies:

- Model 1a: Dry fuel manufacturing: agro-waste to briquettes
- Model 2a: Energy service companies at scale: agro-waste to energy (electricity)
- Model 4: Onsite energy generation by sanitation service providers
- Model 9: On cost savings and recovery
- Model 10: Informal to formal trajectory in wastewater irrigation: incentivizing safe reuse of untreated wastewater
- Model 15: Large-scale composting for revenue generation
- Model 17: High value fertilizer production for profit
- Model 19: Compost production for sanitation service Delivery

4.1 Model 1a – Dry fuel manufacturing: agro-waste to briquettes

Model 1a aims at processing crop residues like wheat stalk, rice husk, maize stalk, groundnut shells, coffee husks, saw dust etc. for converting them into briquettes as fuel. The process of briquetting involves reducing moisture content in the crop residues and compress the biomass at high temperature or/and using a binding agent. To produce charcoal from crop residues by burning them in low-oxygen atmosphere is also an option. The resulting charred material is compressed into briquettes

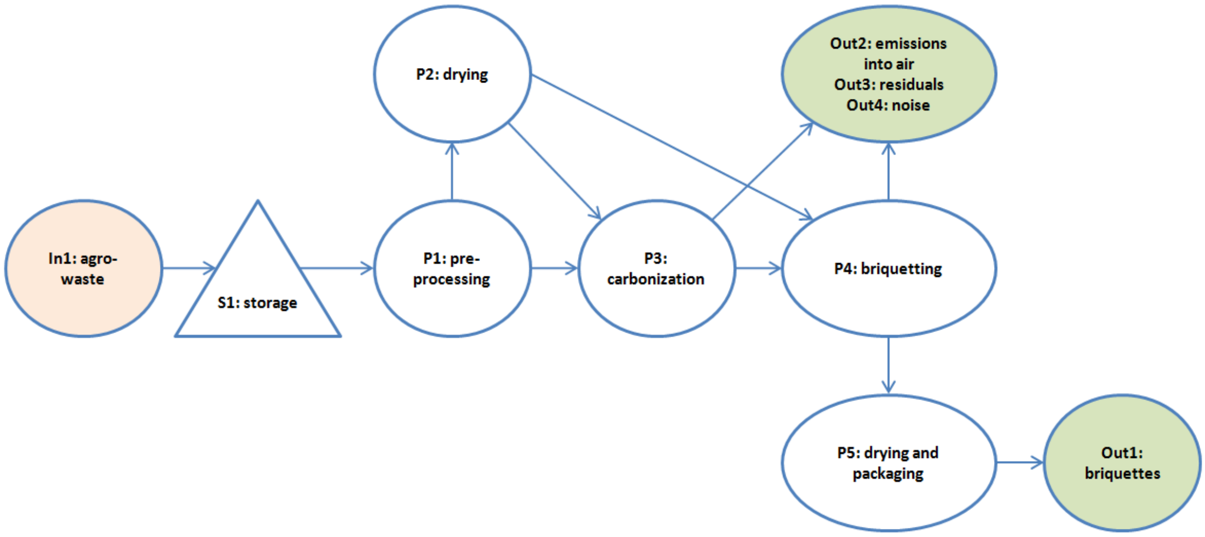


Figure 10 – Model 1: system flow diagram

4.1.1 Health risk assessment

From an occupational health perspective, heat and toxic gas emissions related to the carbonization process are of primary concern. In addition, there is a set of quality requirements linked to the briquettes for warranting safe use at household level. First, it is crucial that the briquettes are free of inorganic components in order to avoid toxic fumes when burning the briquettes. Second, the agro-waste used for briquetting needs to be free of sharp objects for preventing cuts when handling the waste and briquettes. Third, as people are likely to handle the briquettes with their bare hands, hand-to-mouth transmission of pathogens needs to be avoided by reducing pathogen load of the briquettes to a minimum. Finally, it is recommended that moisture content of the briquettes is at low levels to reduce smoke nuisances at household level.

Table 19 – Model 1a: Inputs and associated potential health hazards

Inputs of health relevance	Potential hazards
In1: agro-waste	Faecal contamination (pathogens)
	Contamination with MSW (inorganic; sharp objects)

Table 20 – Model 1a: Quality/safety requirements for outputs

Outputs of health relevance	Quality/safety requirements
Out1: briquettes	Free of inorganic components; free of sharp objects; free of pathogens; moisture content: <10%

Out2: emissions into air	<u>Ambient air quality standards[a]:</u>
	• $PM_{2.5}$: 10 μ/m^3 24-hour mean; 25 μ/m^3 annual mean
	• PM_{10}: 20 μ/m^3 24-hour mean; 50 μ/m^3 annual mean
	• Ozone: 100 μ/m^3 8-hour mean
	• NO_2: 200 μ/m^3 1-hour mean; 40 μ/m^3 annual mean
	• SO_2: 500 μ/m^3 10-minutes mean; 20 μ/m^3 24-hour mean
	<u>Indoor air quality standards[b]:</u>
	• Carbon monoxide (CO):
	  • 15 minutes – 100 mg/m3
	  • 1 hour – 35 mg/m3
	  • 8 hours – 10 mg/m3
	  • 24 hours – 7 mg/m3
	• Nitrogen dioxide
	  • 200 μg/m3 – 1 hour average
	  • 40 μg/m3 – annual average

Out3: residuals	None since considered as waste
Out4: noise	<u>Occupational noise exposure limits[c]:</u> • Equivalent level (8h):85 decibel (dB)(A) • Maximum level (short duration): 140 dB(A) <u>Community noise exposure limits[d]:</u> • Day time equivalent level: 55 dB(A) • Night time equivalent level: 45 dB(A)

[a] WHO (2005). Air quality guidelines - global update 2005. Geneva: World Health Organization
[b] WHO (2010). Guidelines for indoor air quality: selected pollutants. Geneva: World Health Organization
[c] WHO (1995). Occupational exposure to noise: evaluation, prevention and control. Geneva: World Health Organization
[d] WHO (1999). Guideline values for community noise in specific environments. Geneva: World Health Organization

4.1.1.1 Indicated control measures

The full risk assessment matrix is available in Appendix I. Indicated control measures are as follows:

- Protective equipment
  - Workers handling any raw material (e.g. agro-waste) need to wear appropriate PPE and use tools (e.g. shovels)
  - Workers that are directly exposed to fumes from the carbonization need to be equipped with gas mask respirators
  - Workers that are exposed to heat need to wear appropriate PPE
  - Workers that are exposed to high levels of noise (e.g. briquetting process; 85 decibel (dB) permanent or 140 dB short duration) need to wear hearing protection
- Processes
  - The pre-processing of the agro-waste needs to include: (i) separation and discharge of any faecally contaminated components/fractions; and (ii) separation and discharge of any inorganic contaminants, including sharp objects

- Infrastructure
    - Respect a buffer zone between operation and community infrastructure so that ambient air quality and noise exposure standards are not exceeded (see Table 20). The actual distance is depending on the level of emissions
    - In case the carbonization is done in a closed environment, carbon monoxide (CO) monitors need to be installed
- Behavioural aspects and prevention
    - Insect vector- and rodent-control (e.g. screening or use of larvicides, insecticides) at storage sites
    - Educate workers on ergonomic hazards and how to avoid musculoskeletal damage or injury due to inappropriate working practices
    - Protect workers from long term exposure to sunlight
    - Restrict access to the operations

4.1.1.2 Residual risks

By implementing all the proposed control measures, all the identified health risks of Model 2a can be reduced to **low and moderate levels**. The residual moderate risks are linked to the following processes:

- P3: carbonization: inhalation of toxic gases emitted by the carbonization process at workplace and community level was identified as a moderate risk. To enforce the use of gas mask respirators when being exposed to smoke of the process will be important. When selecting the location of the operation, a buffer zone to communities needs to be considered, taking into account pre-dominant wind directions.

Finally, it is recommended to implement a worker well-being programme that includes regular sessions (e.g. weekly) where general health concerns are reported and health protection measures are promoted (e.g. regular hand washing, purpose of PPE and sun protection, ergonomic hazards, etc.).

4.1.2 Health impact assessment

Under the assumption that the above mitigation measures are implemented, the briquettes should be free of inorganic contaminants, sharp objects and pathogens. Hence, it is a safe product. However, an important health concern that remains is the fugitive emissions from burning the briquettes at household level. Prolonged exposure to CO, sulphur oxides (SO_x), Nitrogen oxides (NO_x), hydrocarbons and particulate matter may cause human health complications [32, 33].

- **Scale of the BM:** the impact assessment of Model 1a is based on the assumption that 1% of the population in Kampala will use briquettes from the BM as cooking fuel

4.1.2.1 Impact 1: increase in chronic respiratory disease and cancer

For assessing the potential health impact of increased use of briquettes, one has to take into consideration which cooking fuel types are currently used at household level in Kampala.

According to the Uganda Demographic and Health Survey 2011, 67.8% of households in urban areas and 12.4% in rural areas use charcoal as cooking fuel [7]. Wood is the primary cooking fuel source in rural areas at 85.3% (see Table 21).

Literature on emission factors of different cooking fuel types is diverse [33-36]. Charcoal, wood, crop residuals and dung are similar in terms of emissions; they all emit high levels of toxic gases and particulate matter, and thus are important causes of chronic respiratory disease and lung cancer in low- and middle-income countries where non improved biomass stoves are used [32]. In terms of potential adverse effects on health, natural gas, kerosene or electricity are clearly better than biomass fuels.

Table 21 – Cooking fuels used in rural and urban areas in Uganda (2011 UDHS)

	Residence		
Housing characteristic	Urban	Rural	Total
Cooking fuel			
Electricity	1.3	0.1	0.3
LPG/natural gas/biogas	3.3	0.0	0.6
Kerosene	4.3	0.3	1.1
Charcoal	67.8	12.4	22.8
Wood	16.9	85.3	72.5
Straw/shrubs/grass	0.0	0.2	0.2
No food cooked in household	6.4	1.5	2.4

In conclusion, biomass fuels pose many health hazards unless they are used with an improved biomass stove. The replacement of charcoal or wood with briquettes is, however, unlikely to result in a considerable increased or reduction in exposure to toxic gases and particulate matter. If the briquettes are replacing other cooking fuels such as natural gas, kerosene or electricity, an increase in hazardous emissions would result. Hence, in urban areas, where almost 10% of the population is using other cooking fuel types than biomass, the wide marketing of briquettes could result in a minor negative health impact.

Of note, to promote or even market improved biomass stoves together with the briquettes might be an interesting addition to the BM that should be further explored.

Since the replacement of wood or charcoal does not make a considerable difference in terms of emissions, the health impact assessment for Model 1a only considers the potential negative impact of people replacing more safe cooking fuels (i.e. kerosene, gas or electricity) with briquettes.

Model 1a, impact 1, assumptions:

- **Impact level:** long term exposure to indoor air pollution may increase the incidence of ARI and result chronic diseases such as COPD and cancer
- **People affected:** the briquetting business would be of interest to 1% of the population in Kampala; 10% of the urban population is using kerosene, gas or electricity; and only 10% of those would actually switch to briquettes (1.0 million living in urban environment in Kampala x 0.01 x 0.1 = 1’000 people)
- **Likelihood:** 1 in 10 people being exposed to biomass fuel fumes would develop some form of chronic respiratory diseases or cancer

Table 22 – Model 1a, impact 1: increase in chronic respiratory disease and cancer

	Impact level (IL)	**People affected** (PA)	**Likelihood or frequency** (LoF)	**Magnitude** (ILxPAxL)
Category	Major negative impact	Medium population group	Unlikely	**Moderate negative impact**
Score	-1	1'000	0.3	**-300**

Proposed mitigation measures for reducing the potential negative impact are:

- to market briquettes only in rural areas that are predominantly using charcoal and wood as cooking fuel;
- to educate consumers of biomass briquettes about the health risks associated with indoor smoke (e.g. hazard labels on briquette packaging); and
- to actively promote improved biomass stoves among buyers of biomass briquettes.

4.1.3 Environmental Impact Assessment

Potential negative environmental impacts include: (1) hazardous air emissions, such as volatile organic compounds, carbon monoxide, polycyclic aromatic hydrocarbons, methane and nitrous oxide, which are created during the carbonization process and/or during use of briquettes, (2) accumulated waste resulting from separation of inorganic fractions from MSW prior to briquetting are disposed of or used improperly, and (3) process water, which accumulates during the carbonization process and during the compaction of uncarbonised input material, and when leaching into the environment can have a negative impact. Mitigation measures to avoid negative impacts include: (1.a) air emission control technologies, such as activated carbon and scrubbers, (1.b) proximate and ultimate analyses, prior to business model implementation for the characterization of the feedstock and the final briquettes, (2) storage, transport and disposal at a designated recycling facility or solid waste discharge site (sanitary landfill), and (3) post treatment of process water, which should be monitored for its physical and chemical properties to comply with local regulations prior to discharge into the environment. Further details on technology options are outlined in the "Technology Assessment Report" [1].

Table 23 – Model 1a: potential environmental hazards and proposed mitigation measures

Waste stream	**End-product**	**Technologies**	**Process**	**Pot. Env. Hazard**	**Mitigation measures**
• MSW • AIW	• Briquettes	• Carbonized - low pressure • Raw - mechanized high pressure • Carbonized - mechanized	• Briquetting	• Hazardous air emissions • Accumulated inorganic waste • Process water	• Air emission control technologies (e.g. activated carbon, scrubbers) • Proximate and ultimate analyses • Post-treatment of process water

4.2 Model 2a – Energy service companies at scale: agro-waste to energy (electricity)

This business model aims at transforming animal manure and agro-waste into electricity. An additional output option is treated effluent and soil conditioner, which is depending on the setup of the post-treatment of the sludge (digestate) and effluent of the anaerobic digestion. Since the post-treatment is not clearly defined as per the business model, the risk assessment is limited to the description of the efficiency of different post-treatment options but does not define which combination has to be selected. For the impact assessment it is assumed that the sludge and effluent of the anaerobic digestion are disposed of safely, i.e. appropriate disposal in case of no onsite post-treatment or treated effluent and soil conditioner that are compliant with quality/safety requirements as per the given scenario and context.

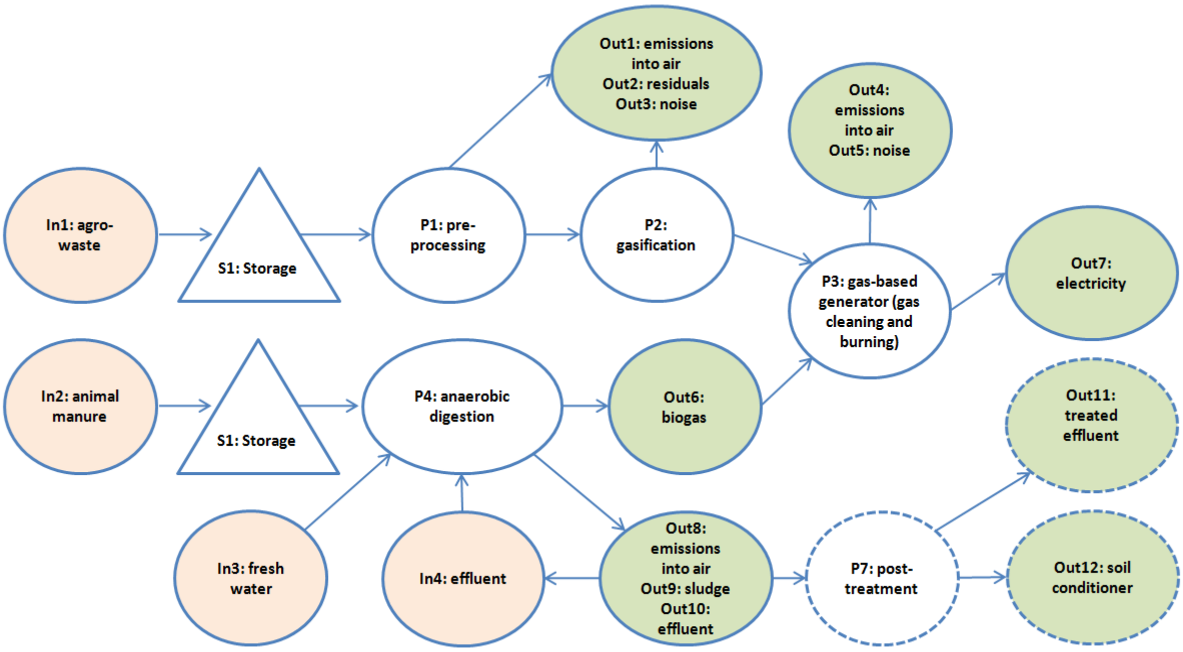


Figure 11 – Model 2a: system flow diagram

Table 24 – Model 2a: Inputs and associated potential health hazards

Inputs of health relevance	Potential hazards
In1: agro-waste	Faecal contamination (pathogens)
	Contamination with MSW (inorganic; sharp objects)
In2: animal manure	Pathogens
	Contamination with MSW (inorganic; sharp objects)
In3: fresh water	None
In4: liquid effluent	N.a. (within system)

Table 25 – Model 2a: Quality/safety requirements for outputs

Outputs of health relevance	Quality/safety requirements
Out1, Out4 and Out8: emissions into air	Ambient air quality standards[a]: • $PM_{2.5}$: 10 µ/m^3 24-hour mean; 25 µ/m^3 annual mean • PM_{10}: 20 µ/m^3 24-hour mean; 50 µ/m^3 annual mean • Ozone: 100 µ/m^3 8-hour mean • NO_2: 200 µ/m^3 1-hour mean; 40 µ/m^3 annual mean • SO_2: 500 µ/m^3 10-minutes mean; 20 µ/m^3 24-hour mean
Out2: residuals	None since considered as waste
Out3 and Out5: noise	Occupational noise exposure limits[b]: • Equivalent level (8h):85 dB(A) • Maximum level (short duration): 140 dB(A) Community noise exposure limits[c]: • Day time equivalent level: 55 dB(A) • Night time equivalent level: 45 dB(A)
Out6: biogas	N.a. (within system)
Out7: electricity	Intrinsically safe electrical installations and proper grounding
Out9: sludge	N.a. (within the system)
Out10: effluent	N.a. (within the system)
Out11: treated effluent	**Unrestricted irrigation** Root crops: • <10^3 *E. coli* per litre and <1 helminth egg per litre Leave crops: • <10^4 *E. coli* per litre and <1 helminth egg per litre Drip irrigation of high-growing crops: • <10^5 *E. coli* per litre and <1 helminth egg per litre Drip irrigation of low-growing crops: • <10^3 *E. coli* per litre and <1 helminth egg per litre **Restricted irrigation** Labour intensive agriculture: • <10^4 *E. coli* per litre and <1 helminth egg per litre Highly mechanized agriculture: • <10^5 *E. coli* per litre and <1 helminth egg per litre ➔ Chemical indicators in treated wastewater and receiving soils must not exceed thresholds as per WHO Guidelines (see Annex V)
Out12: soil conditioner	For agricultural use: • <1 helminth egg per 1 gram total solids; and <10^3 *E. coli* per gram total solids

[a] WHO (2005). Air quality guidelines - global update 2005. Geneva: World Health Organization
[b] WHO (1995). Occupational exposure to noise: evaluation, prevention and control. Geneva: World Health Organization
[c] WHO (1999). Guideline values for community noise in specific environments. Geneva: World Health Organization

4.2.1 Health risk assessment

Important health hazards linked to this BM relate to the pathogens bound in the animal manure, which will not be fully eliminated during anaerobic digestion (mesophilic digestion at >35°C for >9 days only results in 1 log reduction in *E. coli* and 0 log reduction in helminth eggs). Therefore, appropriate discharge or post-treatment of the sludge (digestate) and effluent from anaerobic digestion is required. Gasification and the operation of a gas-based generator are associated with heat, emissions into the air, noise and toxic burning-residuals.

These need to be managed at the level of the plant and an appropriate buffer zone to community houses needs to be established. In order to avoid electric shock of workers or users, intrinsically safe electrical installations, non-sparking tools and proper grounding need to be assured. Potential vector breeding at waste-storage sites and along the cooling water circuit of the gasification plant has to be controlled. There is considerable risk for injury to the body when operating the gasification plant or the gas-based generator. Hence, safety infrastructure, PPE and education of workers are crucial. Finally, a fire fire/explosion response plan needs to be developed and implemented.

4.2.1.1 Indicated control measures

The full risk assessment matrix is available in Appendix I. Indicated control measures are as follows:

- Protective equipment
    - Workers handling any raw material (e.g. agro-waste or animal manure) need to wear appropriate PPE and use tools (e.g. shovels)
    - Workers that are directly exposed to fumes of the gasification or exhausts of the gas-based generator need to be equipped with gas mask respirators
    - Workers that are exposed to heat need to wear appropriate PPE
    - Workers that are exposed to high levels of noise (e.g. briquetting process; 85 dB permanent or 140 dB short duration) need to wear hearing protection
- Processes
    - Mesophilic anaerobic digestion is recommended at >35°C for >9 days (1 log reduction *E. coli* and 0 log reduction in helminth eggs)
- Infrastructure
    - Assure good ventilation of working areas where animal-manure is stored/processed
    - Install heat shields on hot parts that may be touched by individuals
    - Install handrails and fences at dangerous areas for preventing injuries
    - In case the gasification plant and/or gas-based generator are located in a closed environment: install CO monitors; ensure that exhausts are released to the outside
    - Respect a buffer zone between operation and community infrastructure so that ambient air quality and noise exposure standards are not exceeded (see Table 25). The actual distance is depending on the level of emissions
    - For removing the residuals in the gasification plant, installation of a bin/tank to collect and treat the toxic scrubbing water
    - At the electricity outlet of the gas-based generator, use intrinsically safe electrical installations, non-sparking tools and proper grounding
    - Prevent gas-leakage at the anaerobic digestion plant and install CO monitors in case the anaerobic digestion takes place in a closed environment
    - Depending on the further use of the outputs of the post-treatment, the following post-treatment options are proposed:

      Off-site (i.e. discharge):

        - Drain/transfer effluent to the influent of existing and existing wastewater treatment plant if within load capacity, co-manage sludge/solids handling with existing wastewater of faecal sludge treatment plant

On-site (in case of agricultural reuse of the outputs, a combination of the following options will be required for achieving the required quality standard (see table with quality/safety requirements for outputs)):

- Septic tank (≥1 log reduction of *E. coli* and ≥2 log reduction in helminth eggs)
- Anaerobic baffled reactor (≥1 log reduction of *E. coli* and ≥2 log reduction in helminth eggs)
- Anaerobic filter(≥1 log reduction of *E. coli* and ≥2 log reduction in helminth eggs)
- Constructed/vertical flow wetland (≥0.5-3 log reduction of *E. coli* and ≥1-3 log reduction in helminth eggs)
- Planted gravel Filter
- Unplanted gravel Filter
- Planted/unplanted drying beds (1-3 log reduction in helminth eggs)

- Behavioural aspects and prevention
  - Develop a fire/explosion response plan (e.g. installation of fire detection/suppression equipment; anti-back firing systems; separate fuel storage; escape routes; and purging system with nitrogen)
  - Educate workers on ergonomic hazards and how to avoid musculoskeletal damage or injury due to inappropriate working practices
  - Rodent and vector-control (e.g. screening or use of larvicides, insecticides) at waste-storage sites, drying beds and cooling water cycle.
  - Protect workers from long term exposure to sunlight
  - Restrict access to the operations
  - Implement a worker well-being programme that includes regular sessions (e.g. weekly) where general health concerns are reported and health protection measures are promoted (e.g. regular hand washing, purpose of PPE and sun protection, ergonomic hazards, etc.)

For more details on the mitigation of environmental and health risks associated with gasification of biomass, guidelines for safe and eco-friendly biomass gasification that have been developed for the European Commission are available: www.gasification-guide.eu/

4.2.1.2 Residual risks

By implementing all the proposed control measures, all the identified health risks of Model 2a can be reduced to **low, moderate and high levels**. The residual moderate risks are linked to the following processes:

- S1: storage: exposure of the workforce and community members to malodours is of concern related to the storage of animal manure. PPE, good ventilation of the storage area and to respect a buffer zone between operations and community infrastructure are essential

- P2: gasification and P3: gas-based generator: exposure to toxic gas and noise emissions are of concern for both workers and the community. However, these risks can be controlled with appropriate equipment, a good design of the operation and by respecting a buffer zone between the plant and community infrastructure. Also fire and explosion are major risks related to the gasification plant and the generator. This issue must primarily be taken into account when engineering of the plant. At the operational level a fire/explosion response plan needs to be developed and implemented. Finally, toxic residuals of the gasification plant need to be handled and disposed of with care
- Electric shock and fire/explosion are high risks that need to be managed accordingly

4.2.2 Health impact assessment

The production of power by using animal and/or crop waste may impact on community health in two ways. First, it has the potential to reduce exposure of community members to pathogens deriving from animal manure, and thus lower the incidence of respiratory, diarrhoeal and intestinal diseases. Second, the provision of electricity can impact socio-economic status and wellbeing, both of which have a strong link to community health.

- **Scale of the BM:** the impact assessment of Model 2a is based on the assumption that 50 villages in rural and peri-urban areas of Kampala will implement the BM

4.2.2.1 Impact 1: reduction in respiratory, diarrhoeal and intestinal diseases

In rural communities, where the BM would most likely be operating due to the availability of agro-waste, animal manure is currently used for agricultural purposes or disposed of into the environment. Indeed, according to the waste supply and availability report, approximately 60% of animal manure is currently unused and discarded in Kampala [37]. Consequently, there is a risk that pathogens from animal manure end-up in surface waters, particularly at the start of the rainy season. As a result, unsafe disposal of animal manure into the environment is likely to contribute to the incidence of respiratory and diarrhoeal diseases, as well as helminth infections. Hence, the recycling of animal manure has the potential to reduce the incidence of those diseases.

Impact 1, assumptions:

- **Impact level:** pathogens in animal manure generally cause disease of short duration and/or minor disability
- **People affected:** the operations would be based in 50 villages (average size ~300 people) where 1 in 10 individuals is exposed to pathogens from unused animal manure
- **Likelihood:** of those exposed, 1 in 2 would develop some form of clinical infection

Table 26 – Model 2a, impact 1: reduction in respiratory, diarrhoeal and intestinal diseases

	Impact level (IL)	**People affected** (PA)	**Likelihood or frequency** (LoF)	**Magnitude** (ILxPAxL)
Category	Minor positive impact	Medium population group	Possible	**Moderate positive impact**
Score	0.1	1’500	0.5	**75**

4.2.2.2 *Impact 2: changes in health status due to access to electricity*

The impact of electricity on the health status of receiving populations is marginal and the direction of health impact (i.e. positive or negative) is not obvious. For example, an improved socio-economic status often impacts positively on access to health care but is also negatively associated with life style related diseases such as obesity and diabetes. Where access to electricity can make a real difference, is at the level of rural health facilities, particularly during the night. However, this would require the provision of batteries that can store the electricity for the night when it is needed. Since this is not part of the BM, the potential health impact of supplying electricity to local health facilities is not taken into account. In addition, many of the rural health facilities in Uganda do have power supply.

Impact 1, assumptions:

- **Impact level:** minor positive and negative health impacts anticipated. Therefore, the impact level is insignificant
- **People affected:** 50 villages with an average of 300 individuals profits from the BM
- **Likelihood:** It is possible that access to electricity impacts on the health of people

Table 27 – Model 2a, impact 2: changes in health status due to access to electricity

	Impact level (IL)	**People affected** (PA)	**Likelihood or frequency** (LoF)	**Magnitude** (ILxPAxL)
Category	Insignificant	Large population	Definite	**Insignificant**
Score	0.0	15’000	1	**0**

4.2.3 Environmental Impact Assessment

Potential negative environmental impacts include: (1) hazardous air emissions, such as volatile organic compounds, carbon monoxide, polycyclic aromatic hydrocarbons, methane and nitrous oxide, which are created during the gasification process and/or the conversion of biogas into electricity, (2) residuals from the gasification process (i.e. tar, char, oil) that are disposed of or used improperly, (3) solid residue from the anaerobic digestion process (digestate), which when disposed of or used improperly can have a negative impact due to high nutrient and organic matter concentrations and (4) liquid effluent from the anaerobic digestion process disposed of or used improperly, which when disposed of or used improperly can have a negative impact due to high nutrient and organic matter concentrations. Mitigation measures to avoid negative impacts include: (1) air emission control technologies, such as activated carbon or scrubbers, (2) collection/storage/disposal of residuals at an appropriate location, (3) solid residue (digestate) post-treatment, and (4) liquid effluent post-treatment. The goal of RRR based businesses should be full resource recovery of all End-products, which implies end-use of dewatered and appropriately treated sludge (digestate) and liquid effluent from post-treatment. If for some reason this is not feasible, only then should disposal of solids at sanitary landfills be considered. Further details on technology options are outlined in the “Technology Assessment Report” [1].

Table 28 – Model 2a: potential environmental hazards and proposed mitigation measures

Waste stream	End-product	Technologies	Process	Pot. Env. Hazard	Mitigation measures
• MSW • AIW • AM	• Gasification -> Electricity • Biogas -> Electricity	• Gasification technologies • Single stage • Multi-stage • Batch • Biogas conversion technologies	• Gasifi-cation • Anaerobic digestion • Biogas to electricity conversion	• Hazardous air emissions • Residuals (tar, char, oil) • Solid residue (digestate) • Liquid effluent	• Air emission control technologies • Collection/Storage/ Disposal at appropriate location • Solid/liquid residue post-treatment

4.3 Model 4 – Onsite energy generation by sanitation service providers

The primary goal of BM 4 is to provide sanitation service to underserved communities who lack access to toilets. In addition, the business transforms black and brown water into electricity and soil conditioner to be sold to communities. The quality of the soil conditioner, and resulting end-use options, depend on the setup of the post-treatment of the sludge (digestate) and liquid effluent of the anaerobic digestion process. Since the post-treatment is not clearly defined as per the business model, the risk assessment is limited to the description of the efficiency of different post-treatment options but does not define which combination has to be selected. For the impact assessment it is assumed that the sludge and effluent of the anaerobic digestion are disposed of safely, i.e. appropriate disposal in case of no onsite post-treatment or treated effluent and soil conditioner that are compliant with quality/safety requirements as per the given scenario.

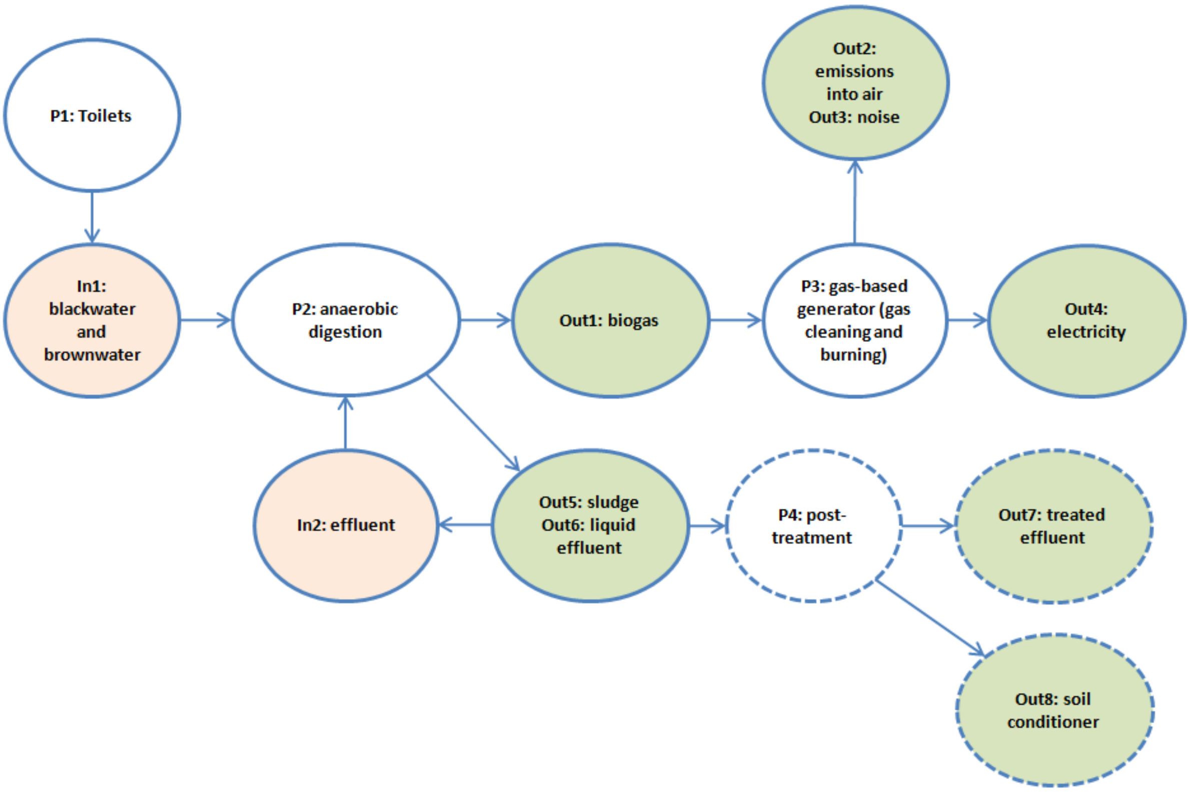


Figure 12 – Model 4: system flow diagram

Table 29 – Model 4: Inputs and associated potential health hazards

Inputs of health relevance	Potential hazards
In1: blackwater and brownwater	Pathogens
	Contamination with sharp objects and inorganic waste
In2: effluent	Pathogens

Table 30 – Model 4: Quality/safety requirements for outputs

Outputs of health relevance	Quality/safety requirements
Out1: biogas	N.a. (within the system)
Out2: emissions into air	Ambient air quality standards[a]: • $PM_{2.5}$: 10 µ/m^3 24-hour mean; 25 µ/m^3 annual mean • PM_{10}: 20 µ/m^3 24-hour mean; 50 µ/m^3 annual mean • Ozone: 100 µ/m^3 8-hour mean • NO_2: 200 µ/m^3 1-hour mean; 40 µ/m^3 annual mean • SO_2: 500 µ/m^3 10-minutes mean; 20 µ/m^3 24-hour mean
Out3: noise	Occupational noise exposure limits[b]: • Equivalent level (8h):85 dB(A) • Maximum level (short duration): 140 dB(A) Community noise exposure limits[c]: • Day time equivalent level: 55 dB(A) • Night time equivalent level: 45 dB(A)
Out4: electricity	Intrinsically safe electrical installations and proper grounding
Out5: sludge	Considered as waste or within the system (in the case of post-

	treatment)
Out6: effluent	Considered as waste or within the system (in the case of post-treatment)
Out7: treated effluent (optional)	**Unrestricted irrigation** Root crops: • <10^3 *E. coli* per litre and <1 helminth egg per litre Leave crops: • <10^4 *E. coli* per litre and <1 helminth egg per litre Drip irrigation of high-growing crops: • <10^5 *E. coli* per litre and <1 helminth egg per litre Drip irrigation of low-growing crops: • <10^3 *E. coli* per litre and <1 helminth egg per litre **Restricted irrigation** Labour intensive agriculture: • <10^4 *E. coli* per litre and <1 helminth egg per litre Highly mechanized agriculture: • <10^5 *E. coli* per litre and <1 helminth egg per litre ➔ Chemical indicators in treated wastewater and receiving soils must not exceed thresholds as per WHO Guidelines (see Annex V)
Out8: soil conditioner (optional)	For agricultural use: • <1 helminth egg per 1 gram total solids; and <10^3 *E. coli* per gram total solids

[a] WHO (2005). Air quality guidelines - global update 2005. Geneva: World Health Organization
[b] WHO (1995). Occupational exposure to noise: evaluation, prevention and control. Geneva: World Health Organization
[c] WHO (1999). Guideline values for community noise in specific environments. Geneva: World Health Organization

4.3.1 Health risk assessment

Black and brownwater pose two main health hazards: pathogens and sharp objects such as razor blades. The faecal pathogens will not be fully eliminated during anaerobic digestion (mesophilic digestion at >35°C for >9 days only results in 1 log reduction in *E. coli* and 0 log reduction in helminth eggs). Therefore, appropriate discharge or post-treatment of the sludge (digestate) and effluent from anaerobic digestion is required. Sharp objects that will be placed in the brownwater may end up in the soil conditioner and are thus a health hazard that needs to be controlled. The operation of a gas-based generator is associated with heat, emissions into the air, noise and toxic burning-residuals. These need to be managed at the level of the plant and an appropriate buffer zone to community houses needs to be established. In order to avoid electric shock of workers or users, intrinsically safe electrical installations, non-sparking tools and proper grounding need to be assured. There is risk for injury to the body when operating the gas-based generator. Hence, safety infrastructure, PPE and education of workers are crucial. Finally, a fire fire/explosion response plan needs to be developed and implemented

4.3.1.1 Indicated control measures

The full risk assessment matrix is available in Appendix I. Indicated control measures are as follows:

- Protective equipment
  - Workers handling any raw material (i.e. black and brown water) need to wear PPE and use tools (e.g. shovels)
  - Workers that are directly exposed to exhausts of the gas-based generator need to be equipped with gas mask respirators
  - Workers that are exposed to heat need to wear appropriate PPE
  - Workers that are exposed to high levels of noise (e.g. operating the generator; 85 dB permanent or 140 dB short duration) need to wear hearing protection
- Processes
  - Mesophilic anaerobic digestion is recommended at >35°C for >9 days (1 log reduction *E. coli* and 0 log reduction in helminth eggs)
- Infrastructure
  - Place clearly visible signs on toilets that prohibit disposal of any sharp object and inorganic waste into the toilet
  - Provide trash bins for disposal of sharp objects and inorganic waste components in each toilet
  - Install facilities where the dried anaerobic sludge or soil conditioner can be sieved carefully for removing any sharp objects
  - Install heat shields on hot parts that may be touched by individuals
  - In case the gas-based generator is located in a closed environment: install CO monitors and ensure that exhausts are released to the outside
  - Respect a buffer zone between operation and community infrastructure so that ambient air quality and noise exposure standards are not exceeded (see Table 25). The actual distance is depending on the level of emissions
  - At the electricity outlet of the gas-based generator, use intrinsically safe electrical installations, non-sparking tools and proper grounding
  - Prevent gas-leakage at the anaerobic digestion plant and install CO monitors in case the anaerobic digestion takes place in a closed environment
  - Depending on the further use of the outputs of the post-treatment, off-site and on-site post-treatment options are available (see section 4.2.1.1)
- Behavioural aspects and prevention
  - Develop and implement a fire/explosion response plan (e.g. installation of fire detection/suppression equipment; anti-back firing systems; separate fuel storage; escape routes; and purging system with nitrogen)
  - Place clearly visible danger signs on the packaging, indicating the risk of sharp objects and that users need to wear gloves and boots when applying the product
  - Insect vector- and rodent-control (e.g. screening or use of larvicides, insecticides) at storage sites
  - Educate workers on ergonomic hazards and how to avoid musculoskeletal damage or injury due to inappropriate working practices
  - Restrict access to the anaerobic digestion plant and the generator

- Implement a worker well-being programme that includes regular sessions (e.g. weekly) where general health concerns are reported and health protection measures are promoted (e.g. regular hand washing, purpose of PPE, ergonomic hazards, etc.)

4.3.1.2 Residual risks

By implementing all the proposed control measures, all the identified health risks of Model 4 can be reduced to **low, moderate and high levels**. The residual moderate risks are linked to the following processes:

- P1: toilet and P4: post-treatment: sharps ending up in the soil conditioner pose a moderate risk to users. Therefore it is crucial to sensitize users of the toilets to the issue and rigorously implement different control measures for preventing (e.g. trash bins) or removing (i.e. sieving) any sharp objects in the solid fraction of the anaerobic sludge
- P3: gas-based generator: exposure to toxic gas and noise emissions are of concern for both workers and the community. However, these risks can be controlled with appropriate equipment, a good design of the operation and by respecting a buffer zone between the plant and community infrastructure. Also fire and explosion are major risks related to the generator. This issue must primarily be taken into account by the engineering of the plant. At the operational level a fire/explosion response plan needs to be developed and implemented
- Electric shock and fire/explosion are high risks that need to be managed accordingly

4.3.2 Health impact assessment

The provision of sanitation services to underserved communities is likely to reduce incidence of diarrhoeal diseases, ARI and helminth infections. In addition, the provision of electricity can impact socio-economic status and wellbeing, both of which have a strong link to community health.

- **Scale of the BM:** the impact assessment of Model 4 is based on the assumption that 30 villages in rural and peri-urban areas of Kampala will implement the BM

4.3.2.1 Impact 1: reduction in respiratory, diarrhoeal and intestinal diseases

The 2011 UDHS reported that in rural areas of Uganda 3 in 4 households use non-improved sanitation facilities and 1 in 10 households has no sanitation facilities at all [7]. Unsafe sanitation practices are closely associated with diarrhoeal diseases and helminth infections, as well as acute respiratory infections. In a recent meta-analysis by Ziegelbauer and colleagues (2012), it was found that the availability of sanitation facilities was associated with a 50% protection against infection with soil-transmitted helminths [38]. Also the link between safe sanitation systems and reduction in diarrhoeal diseases is well established [39]. Hence, the business has considerable potential to reduce the burden of diarrhoeal diseases and infection with soil-transmitted helminths in communities with poor access to safe sanitation services. In order to maximize potential health benefits, it is recommended to keep the fee for the usage of the toilets at a minimum and/or not charging a fee to children.

Impact 1, assumptions:

- **Impact level:** pathogens in human faeces generally cause disease of short duration and/or minor disability
- **People affected:** the business would be rolled out to 30 villages (average size ~300 people) where 3 in 4 households do not have access to safe sanitation (30x300x0.75=6'750)
- **Likelihood:** it is likely (odds: 61-95%) that the business positively impacts on diarrhoeal diseases and helminth infections

Table 31 – Model 4, impact 1: reduction in respiratory, diarrhoeal and intestinal diseases

	Impact level (IL)	**People affected** (PA)	**Likelihood or frequency** (LoF)	**Magnitude** (ILxPAxL)
Category	Minor positive impact	Medium population group	Likely	**Moderate positive impact**
Score	0.1	6'750	0.7	**472.5**

For maximizing the health benefits of the business, it is recommended:

- to keep the fee for the usage of the toilets at a minimum;
- to provide free access to the toilet facilities to children;
- to target communities with particularly low access to sanitation for the implementation of the business; and
- to promote hand washing practice at the exit of the facility.

4.3.2.2 Impact 2: access to electricity

➔ For the impact definition, see Model 2a, impact 1 (section 4.2.2.2).

Impact 1, assumptions:

- **Impact level:** minor positive and negative health impacts anticipated. Therefore, the impact level is insignificant
- **People affected:** 30 villages with an average of 300 individuals profits from the BM
- **Likelihood:** It is possible that access to electricity impacts on the health of people

Table 32 – Model 4, impact 2: access to electricity

	Impact level (IL)	**People affected** (PA)	**Likelihood or frequency** (LoF)	**Magnitude** (ILxPAxL)
Category	Insignificant	Large population	Possible	**Insignificant**
Score	0.0	9'000	1	**0**

4.3.3 Environmental Impact Assessment

Potential negative environmental impacts include: (1) air emissions from the anaerobic digester if not controlled properly or in case of failure, (2) solid residue from the anaerobic digestion process (digestate), which when disposed of or used improperly can have a negative impact due to high nutrient and organic matter concentrations and (3) liquid effluent from the anaerobic digestion process which when disposed of or used improperly can have a negative impact due to high nutrient and organic matter concentrations. Mitigation measures to avoid negative impacts include: (1) regular maintenance of the anaerobic digester to prevent leakages, and (2) and (3) solid and liquid residue post-treatment of the solid residue (digestate) and liquid effluent from the anaerobic digestion process. The goal of RRR based businesses should be full resource recovery of all End-products, which implies end-use of dewatered and appropriately treated sludge (digestate) and liquid effluent from post-treatment. If for some reason this is not feasible, only then should disposal of solids at sanitary landfills be considered. Further details on technology options are outlined in the "Technology Assessment Report" [1].

Table 33 – Model 4: potential environmental hazards and proposed mitigation measures

Waste stream	End-product	Technologies	Process	Pot. Env. Hazard	Mitigation measures
• Feces • Urine • FS	• Biogas -> Cooking fuel	• Single stage • Multi-stage • Batch	• Anaerobic digestion	• Air emissions • Solid residue (digestate) • Liquid effluent	• Maintenance of anaerobic digester • Solid/liquid residue post-treatment

4.4 Model 9 – On cost savings and recovery

This business model aims at cost recovery of wastewater treatment through the following value propositions: two revenue streams (treated wastewater sales and soil conditioner sales), and a cost-saving mechanism using the treatment processes to capture biogas and converting it to electricity that is subsequently used to (partially) power the plant. Wastewater needs to be treated to a quality that is accepted by Uganda's regulation for reclamation of water through irrigation of treated wastewater. Since the wastewater treatment is not clearly defined as per the business model, the risk assessment does not go into the details of the wastewater treatment plant or the production of electricity. However, it is anticipated that for the construction of a 1.5-230 million US$ wastewater treatment plant (as per business model description) a detailed occupational health management plant would be developed. Therefore, the HRIA of Model 9 is primarily focusing on down-stream issues.

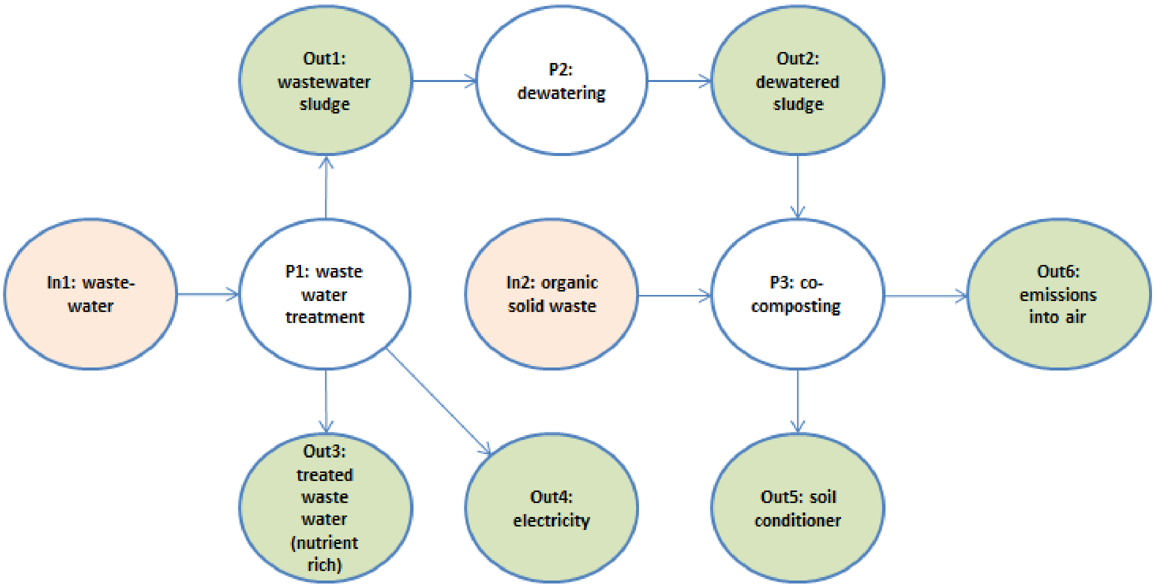


Figure 13 – Model 9: system flow diagram

Table 34 – Model 9: Inputs and associated potential health hazards

Inputs of health relevance	Potential hazards
In1: wastewater	Viruses, bacteria
	Protozoa
	Soil-transmitted helminths
	Trematodes
	Skin irritants
	Disease vectors
	Chemicals others than heavy metals
	Heavy metals
In2: organic solid waste	Pathogens
	Sharps
	Inorganic waste components

Table 35 – Model 9: Quality/safety requirements for outputs

Outputs of health relevance	Quality/safety requirements
Out1: wastewater sludge	Maximum heavy metals concentration of wastewater sludge for composting (unit: mg/kg dried matter): Cd: 3.0; Cr_{tot}: 300; Cu 500; Hg: 5.0; Ni: 100; Pb: 200; and Zn: 2,000[a]
Out2: dewatered sludge	N.a. (inside system)
Out3: treated wastewater	**Unrestricted irrigation** Root crops: • <10^3 *E. coli* per litre and <1 helminth egg per litre Leave crops: • <10^4 *E. coli* per litre and <1 helminth egg per litre Drip irrigation of high-growing crops: • <10^5 *E. coli* per litre and <1 helminth egg per litre Drip irrigation of low-growing crops: • <10^3 *E. coli* per litre and <1 helminth egg per litre

	Restricted irrigation Labour intensive agriculture: • $<10^4$ *E. coli* per litre and <1 helminth egg per litre Highly mechanized agriculture: • $<10^5$ *E. coli* per litre and <1 helminth egg per litre ➔ Chemical indicators in treated wastewater and receiving soils must not exceed thresholds as per WHO Guidelines (see Annex V)
Out4: electricity	Intrinsically safe electrical installations and proper grounding
Out5: soil conditioner	Maximum heavy metals concentration of compost used for land reclamation (unit: mg/kg dried matter): Cd: 3.0; Cr_{tot}: 250; Cu 500; Hg: 3.0; Ni: 100; Pb: 200; and Zn: 1,800[a] Maximum heavy metals concentration of compost used for agricultural use (unit: mg/kg dried matter): Cd: 1.0; Cr_{tot}: 70; Cu 150; Hg: 0.7; Ni: 60; Pb: 120; and Zn: 500[a] Pathogen load for agricultural use: • <1 helminth egg per 1 gram total solids; and $<10^3$ *E. coli* per gram total solids
Out6: emissions into air	Ambient air quality standards[b]: • $PM_{2.5}$: 10 µ/m^3 24-hour mean; 25 µ/m^3 annual mean • PM_{10}: 20 µ/m^3 24-hour mean; 50 µ/m^3 annual mean • Ozone: 100 µ/m^3 8-hour mean • NO_2: 200 µ/m^3 1-hour mean; 40 µ/m^3 annual mean • SO_2: 500 µ/m^3 10-minutes mean; 20 µ/m^3 24-hour mean

[a] European Union (2004). Heavy metals and organic compounds from waste used as organic fertilisers. Brussels: European Commission

[b] WHO (2005). Air quality guidelines - global update 2005. Geneva: World Health Organization

4.4.1 Health risk assessment

Risks associated with the business derive from the various potential hazards contained in wastewater such as pathogens and toxic chemicals (i.e. elements such as heavy metals as well as various hazardous organic compounds (see WHO 2006 guidelines; Volume II, Chapter 4.6). It is well known, that accordingly designed and operated wastewater treatment plants allow for removing pathogens to acceptable levels. The removal of heavy metals, however, is more complex and cost intensive, which makes them a great concern from an economic, health and environmental perspective. Ideally, heavy metals are kept out of wastewater streams by reducing and controlling potential sources.

The environmental sampling of water along the Nakivubo wetland found concentrations of Cu, Fe and Cd exceeding international and national threshold values (see section 3.2.3). In addition, parameters of toxic chemical in receiving soils must not exceed thresholds as per WHO 2006 Guidelines in the case of wastewater reuse for irrigation. Soil sample from the Nakivubo wetland showed that the mean Pb concentration was above national and international threshold values. Of note, different sampling locations showed high variation in heavy metal concentration. At some locations also the threshold of Zn and Fe was exceeded. Finally, Cd, Pb and Cr concentrations in yam and sugarcane also exceeded WHO threshold values, which clearly shows that irrigation with wastewater is of concern in Kampala from a health and environmental perspective.

No threshold values for soil conditioner stated in the WHO 2006 Guidelines. Maximum heavy metals concentration for compost and sewage sludge as input material for agricultural use as defined by the European Union are shown in Table 36 (unit: mg/kg dried matter) [40]. It is recommended to use those thresholds for determining whether the sewage sludge form the treatment plant is suitable for further processing in the co-composting process.

Table 36 – Maximum heavy metals concentration for compost and sewage sludge [39]

	Cd	Cr_{tot}	Cu	Hg	Ni	Pb	Zn
COMPOST							
class A+ → *org. farming*	0.7	70	70	0.4	25	45	200
class.A → *agriculture*	1	70	150	0.7	60	120	500
class.B → *land reclamation.*	3	250	400/ 500*	3	100	200	1,200/ 1,800*
SEWAGE SLUDGE							
for '*quality sludge compost*	2.0	70	300	2.0	60	100	1,200
for '*compost'*	3.0	300	500	5.0	100	200	2,000

* Guide / limit value for Cu and Zn; if the guide value in the compost is exceeded the concentration has to be indicated in the labelling

4.4.1.1 Indicated control measures

- Protective equipment
  - Workers handling any raw material (e.g. wastewater, sewage sludge or inorganic contaminants) need to wear appropriate PPE and use tools (e.g. shovels)
- Processes
  - Primary, secondary and tertiary treatment has to be applied for reducing pathogens. Different options can be combined for reaching a minimum of 7 log reduction in bacterial indicators (e.g. *E. coli*) and 3 log reductions in helminth eggs
  - In locations where the concentration of toxic chemicals such as metals in wastewater and/or receiving agricultural soils exceed national and international standards (see Annex IV), source reduction and/or physico-chemical removal processes (e.g. absorption) need to be applied.
  - For pathogen removal, the sludge needs to be dewatered and put on drying beds for: (i) 1.5-2 years at 2-20°C; (ii) >1 years at 20-35°C; or (iii) >6 months by means of alkaline treatment at pH>9, >35°C and moisture <25%
  - The sludge of the treatment plant should be compliant with the heavy metal thresholds defined by the European Union (see Table 36). Otherwise the sludge must not be further processed for producing fertilizer
  - A temperature of ≥45°C for ≥5 days (2 log reductions in bacteria and <1 viable helminth eggs per g dried matter) should be maintained for the co-composting
  - Moisture of co-composting material should be above 40% for reducing bio-aerosol emission

  - Sieving of the soil conditioner prior to packaging for removing any remaining inorganic contamination or sharp objects
- Infrastructure
  - Assure good ventilation of working areas with a high load of malodours or dust (e.g. co-composting facility)
  - Install handrails and fence dangerous areas for preventing injuries
  - Respect a buffer zone between operation and community infrastructure so that ambient air quality and noise exposure standards are not exceeded (see Table 25). The actual distance is depending on the level of emissions
- Behavioural aspects and prevention
  - Educate workers on ergonomic hazards and how to avoid musculoskeletal damage or injury due to inappropriate working practices
  - Rodent and vector-control (e.g. screening or use of larvicides, insecticides) at waste-storage sites and treatment ponds
  - Protect workers from long term exposure to sunlight
  - Farmers using the soil conditioner should be advised to wear boots and gloves when applying the compost
  - Restrict access to the operations
  - Implement a worker well-being programme that includes regular sessions (e.g. weekly) where general health concerns are reported and health protection measures are promoted (e.g. regular hand washing, purpose of PPE and sun protection, ergonomic hazards, etc.)

4.4.1.2 Residual risks

By implementing all the proposed control measures, all the identified health risks of Model 4 can be reduced to **low, moderate and high levels**. The residual moderate and high risks are linked to the following processes:

- P1: wastewater treatment plant: in settings where the concentration of toxic chemicals in wastewater and/or receiving soils exceed national and WHO Guidelines threshold values (see annex IV), the treated wastewater is not suitable for irrigation. Consequently, source reduction and/or physico-chemical removal processes have to be applied. If not, there is a very high risk for adverse health impacts (e.g. chronic disease or even cancer linked to consumption of products that are contaminated with heavy metals and potentially other toxic chemicals) linked to wastewater fed agriculture in Kampala.
- P1: wastewater treatment plant and P2: dewatering: there is moderate risk for disease vector breeding in ponds of the treatment plant and the drying beds. Therefore, special attention is needed for implementing vector control.
- P2: dewatering and P3: co-composting: in order to avoid exposure of consumers to pathogens in the soil conditioner, it will be crucial to respect the temperature and duration indicated for the drying of the sludge and the co-composting
- P3: co-composting: sharps ending up in the soil conditioner pose a moderate risk to users. Therefore it is important carefully sieve the soil conditioner before packaging and also users need to be sensitised on the potential contamination with sharp

objects. In addition, users need to be advised to wear boots and gloves when applying the soil conditioner.

- P3: co-composting: to ensure that workers are protected with respirators is important when handling the waste materials for the co-composting process. Otherwise pathogens, fungi and dust affect their respiratory system

4.4.2 Health impact assessment

The health benefits of a modern wastewater treatment plant in an environment of Kampala primarily relate to down-stream issues like reduced exposure to pathogens and toxic chemicals, including heavy metals.

- **Scale of the BM:** the impact assessment of Model 9 is assuming a wastewater treatment plant similar to BSTDW with 500 farmers and 10'000 community members being exposed to the treated wastewater

4.4.2.1 Impact 1: reduction in respiratory, diarrhoeal, intestinal and skin diseases

Farmers reusing the in-adequately treated wastewater in the Nakivubo wetland has high infection rates of helminth infections, ranging from 15-28% for the different species (see Figure 14). Hence, farmers are clearly the most important exposure group of untreated wastewater. But it does also negatively impact on the health of community members, be it through direct contact, ingestion or the consumption of contaminated products. Although no prevalence data is available on the incidence of diarrhoeal diseases and ARI, the example of the helminth infections shows that incidence of these conditions is likely to be high in communities exposed to untreated wastewater. Hence, the business has considerable potential to reduce the burden of diarrhoeal diseases, ARI and helminth infections in exposed population groups.

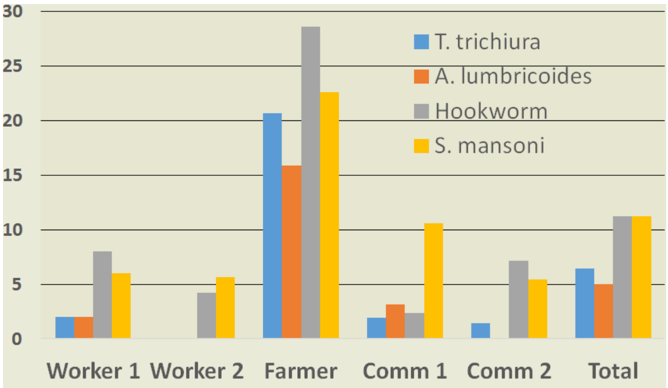


Figure 14 – Prevalences of helminth infections in the Nakivubo wetland [18]

Impact 1, assumptions:

- **Impact level:** pathogens in human faeces generally cause disease of short duration and/or minor disability
- **People affected:** the business would affect 500 farmers, 100,000 consumers and 15,000 community members
- **Likelihood:** farmers are likely and for consumers and community members it is possible that they will experience a reduction in wastewater-related disease episodes

Table 37 – Model 9, impact 1: reduction in respiratory, diarrhoeal, intestinal and skin diseases

	Impact level (IL)	**People affected** (PA)	**Likelihood or frequency** (LoF)	**Magnitude** (ILxPAxL)
Category	Minor positive impact	Large population group	Likely Unlikely	**Major positive impact**
Score: farmers	0.5	500	0.7	175
Score: consumers	0.1	100'000	0.3	3,000
Score: community	0.1	15'000	0.3	450
			TOTAL	**3,625**

4.4.2.2 Impact 2: reduction in exposure to toxic chemicals and heavy metals

Long-term exposure to toxic chemicals (e.g. heavy metals) can cause a range of health effects, ranging from neurological damage to poisoning. In general, these effects are difficult to quantify and many knowledge gaps exist. Therefore, the impact assessment applying a simplified approach: under the assumption that the business model will operate in settings with acceptable concentrations of toxic chemicals, or will eliminate these to acceptable levels, a minor positive health effect is anticipated at individual level.

Impact 2, assumptions:

- **Impact level:** health impacts linked to long-term exposure to toxic chemicals is not perceived by most individuals but can result moderate disability. A minor positive effect (0.1) is applied as an average value
- **People affected:** the business would affect 500 farmers, 100,000 consumers and 15,000 community members
- **Likelihood:** it is unlikely that farmers will have an improvement of their health status due to reduce exposure to toxic chemicals and very unlikely that consumers and community members will experience any difference

Table 38 – Model 9, impact 2: reduction in exposure to toxic chemicals

	Impact level (IL)	**People affected** (PA)	**Likelihood or frequency** (LoF)	**Magnitude** (ILxPAxL)
Category	Minor positive impact	Large population groups	Unlikely Very unlikely	**Moderate positive impact**
Score: farmers	0.5	500	0.3	75
Score: consumers	0.1	100'000	0.01	100
Score: community	0.1	15'000	0.01	15
			TOTAL	**190**

4.4.2.3 Impact 3: changes in health status due to access to electricity

➔ For the impact definition, see Model 2a, impact 2 (section 4.2.2.2).

Impact 1, assumptions:

- **Impact level:** minor positive and negative health impacts anticipated. Therefore, the impact level is insignificant
- **People affected:** 5'000 people will get access to electricity
- **Likelihood:** It is possible that access to electricity impacts on the health of people

Table 39 – Model 9, impact 3: changes in health status due to access to electricity access

	Impact level (IL)	**People affected** (PA)	**Likelihood or frequency** (LoF)	**Magnitude** (ILxPAxL)
Category	Insignificant	Large population	Possible	**Insignificant**
Score	0.0	5'000	1	**0**

4.4.3 Environmental Impact Assessment

Potential negative environmental impacts include: (1) heavy metals in effluent and/or sludge from wastewater treatment, which when disposed of or treated inadequately can have a negative impact, (2) solid residue (accumulated sludge from WW treatment) which when disposed of or treated inadequately can have a negative impact, and (3) air emissions from the anaerobic digester if not controlled properly or in case of failure. Mitigation measures to avoid negative impacts include: (1.a) upstream monitoring to ensure influent meets guidelines for heavy metal concentrations, (1.b) monitoring of effluent and solids to ensure concentration of heavy metals do not exceed regulations, and, (2) solid residue post-treatment of the solid residue (accumulated sludge from WW treatment), which is converted into a soil conditioner for endues in agriculture, and (3) regular maintenance of the anaerobic digester to prevent leakages. The goal of RRR based businesses should be full resource recovery of all End-products, which implies end-use of appropriately treated sludge (accumulated sludge from WW treatment) and in the case of this business model means as a soil conditioner for end-use in agriculture. If for some reason this is not feasible, only then should disposal of solids at sanitary landfills be considered. Further details on technology options are outlined in the “Technology Assessment Report” [1].

Table 40 – Model 9: potential environmental hazards and proposed mitigation measures

Waste stream	End-product	Technologies	Process	Pot. Env. Hazard	Mitigation measures
• WW • WW sludge	• Electricity • Soil conditioner • Water (for reclamation)	• Conventional wastewater treatment technologies • Biogas conversion technologies	• Conven-tional WW treatment • Biogas to electricity conversion	• Heavy metals in effluent and/or WW sludge • Solid residue (sludge from WW treatment) • Air emissions	• Upstream monitoring of heavy metal concentration • Monitoring of effluent and solids • Solid residue (sludge from WW treatment) post-treament • Maintenance of anaerobic digester

4.5 Model 10 – Informal to formal trajectory in wastewater irrigation

Business model 10 aims at promoting the use of untreated wastewater for irrigation and ground water recharge. From a health perspective, the business can only be promoted if the untreated wastewater is compliant with the standards set by the WHO 2006 Guidelines, which are depending to the form of reclamation (see Table 42). Also chemical indicators of the wastewater and receiving soils must be taken into account.

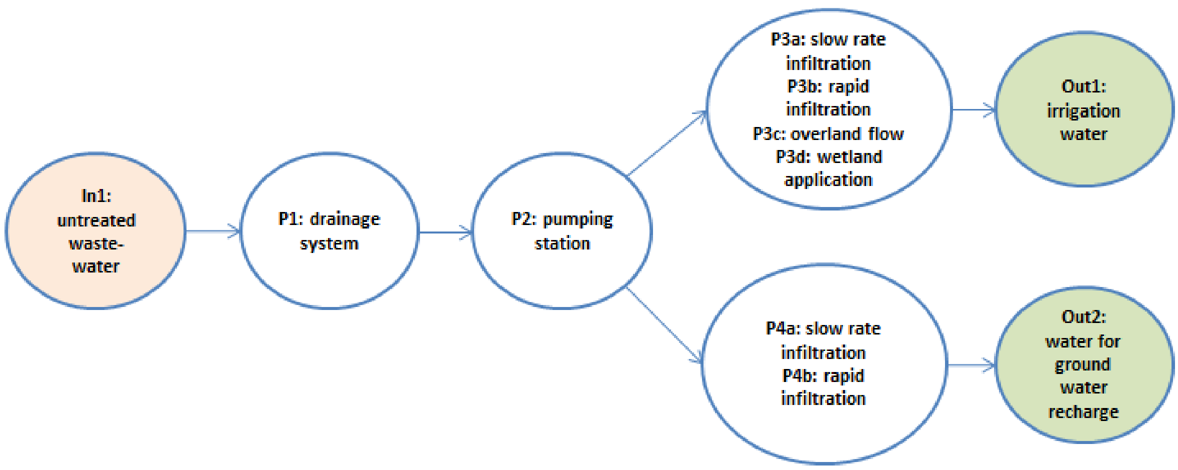


Figure 15 – Model 10: system flow diagram

Table 41 – Model 10: Inputs and associated potential health hazards

Inputs of health relevance	Potential hazards
In1: untreated wastewater	Viruses, bacteria
	Protozoa
	Soil-transmitted helminths
	Trematodes
	Skin irritants
	Disease vectors
	Chemicals others than heavy metals
	Heavy metals

Table 42 – Model 10: Quality/safety requirements for outputs

<table>
<tr><th>Outputs of health relevance</th><th>Quality/safety requirements</th></tr>
<tr><td>Out1: irrigation water</td><td>
Unrestricted irrigation
Root crops:
• <10^3 E. coli per litre and <1 helminth egg per litre
Leave crops:
• <10^4 E. coli per litre and <1 helminth egg per litre
Drip irrigation of high-growing crops:
• <10^5 E. coli per litre and <1 helminth egg per litre
Drip irrigation of low-growing crops:
• <10^3 E. coli per litre and <1 helminth egg per litre
Restricted irrigation
Labour intensive agriculture:
• <10^4 E. coli per litre and <1 helminth egg per litre
Highly mechanized agriculture:
• <10^5 E. coli per litre and <1 helminth egg per litre
Sub-surface irrigation
• <10^6 E. coli per litre and <1 helminth egg per litre
➔ Chemical indicators in treated wastewater and receiving soils must not exceed thresholds as per WHO Guidelines (see Annex V)
</td></tr>
<tr><td>Out2: water for ground water recharge</td><td>
Drinking water
<table>
<tr><th>Drinking water quality category</th><th>Number of TTC in 100 ml</th></tr>
<tr><td>Compliant</td><td>0</td></tr>
<tr><td>Tolerable</td><td>1-10</td></tr>
<tr><td>Treatment required</td><td>11-100</td></tr>
<tr><td>Unsuitable for consumption without treatment</td><td>> 100</td></tr>
</table>
Categorization of drinking water quality based on the number of TTC in a water sample of 100 ml (REF: Wisner and Adams, 2002).
</td></tr>
</table>

4.5.1 Health risk assessment

Health risks of this business are clearly related to the various biological, chemical and physical health hazards that are usually present in untreated wastewater. From a health perspective, Model 10 can only be supported in environments where wastewater is compliant with the safety requirements of the WHO 2006 Guidelines.

4.5.1.1 Indicated control measures

For determining the feasibility of the business in a given context, the wastewater quality has to be analysed. The biological and chemical parameters will reveal the possible irrigation options:

- If the wastewater exceeds 10^6 *E. coli* per litre and 1 helminth egg per litre, the wastewater is not suitable for any form of irrigation and the business must not be implemented. In addition, the receiving soils need to be compliant with WHO 2006 thresholds
- **P3a: slow rate infiltration and P3b: rapid infiltration** (i.e. sub-surface irrigation): $<10^6$ *E. coli* per litre and <1 helminth egg per litre. In addition, the receiving soils need to be compliant with WHO 2006 thresholds
- **P3c: overland flow**: root crops ($<10^3$ *E. coli* per litre and <1 helminth egg per litre) or leave crops ($<10^4$ *E. coli* per litre and <1 helminth egg per litre). In addition, the receiving soils need to be compliant with WHO 2006 thresholds
- **P3d: wetland application**: root crops ($<10^4$ *E. coli* per litre and <10 helminth egg per litre) or leave crops ($<10^5$ *E. coli* per litre and <10 helminth egg per litre). In addition, the receiving soils need to be compliant with WHO 2006 thresholds

In case the business is determined to be feasible, the following control measures should be implemented (the full risk assessment matrix is available in Appendix I):

- Any slow and rapid infiltration system requires a hydrology study in order to exclude any contamination of drinking water sources
- The drainage system needs to be complemented with a pre-treatment facility (e.g. screening and grease traps) for preventing backups and overflows. In addition, regular cleaning of the drainage system is necessary for preventing clogging and overflow.
- Advice farmers who apply the wastewater to wear boots and gloves when working in the irrigated fields.
- Advice farmers who apply the wastewater to respect 2 days between last irrigation and harvesting.
- Advice farmers who apply the wastewater to wash harvested crops with fresh water

4.5.1.2 Residual risks

Even in the case where the quality requirements for the wastewater are met, a moderate to high risk remains linked to the reuse of the wastewater. This is primarily explained by the fact the even with a sophisticated quality monitoring system in place, it is very likely that the wastewater will show strong fluctuations in quality (e.g. in case of heavy rainfalls), which is difficult to control down-stream. Also with a multi-barrier approach in place, i.e. farmers applying additional control measures, there is considerable risk of exposure to pathogens and chemicals at user and consumer level.

4.5.2 Health impact assessment

In the context of Kampala, where wastewater shows high loads of pathogen and toxic chemicals, the promotion of the use of un- or partially treated wastewater would result in an increase of adverse health impacts at farmer and community level. The extent of negative health impacts of the business depends very much on the quality of the wastewater and the applied irrigation scheme. In view of the many options given for the Model 10 (in terms of scale and application), no semi-quantitative impact assessment can be done. However, from a health perspective, it is recommended not to implement Model 10 in Kampala area.

4.5.3 Environmental Impact Assessment

Potential negative environmental impacts include: (1) groundwater contamination with heavy metals and/or pathogens, due to inadequately treated wastewater, and (2) contamination of irrigated crops with heavy metals and/or pathogens, due to heavy metal being present in incoming wastewater.. Mitigation measures to avoid negative impacts include: (1.a) upstream monitoring to ensure influent meets guidelines for heavy metal concentrations, (1.b) monitoring of effluent and solids to ensure concentration of heavy metals do not exceed regulations, and (2) adhering to appropriate levels of multiple barrier protection, such as the WHO “Guidelines for the safe use of Wastewater, Excreta and Greywater, 2006”, which extensively describe the limitations, and environmental and health concerns for this type of application. Further details on technology options are outlined in the “Technology Assessment Report” [1].

Table 43 – Model 10: potential environmental hazards and proposed mitigation measures

Waste stream	End-product	Technologies	Process	Pot. Env. Hazard	Mitigation measures
• WW	• Water (for reclamation) • Water for groundwater recharge	• Slow rate infiltration • Rapid infiltration • Overland flow • Wetland application	• Land treatment	• Groundwater contamination (heavy metals/pathogens) • Contamination of irrigated crops with heavy metals and/or pathogens	• Upstream monitoring of heavy metal concentration • Monitoring of effluent and solids • Crop selection • 2006 WHO guidelines

4.6 Model 15 – Large-scale composting for revenue generation

This business model is a small to medium scale production that aims at (i) reducing greenhouse gas emission through processing of municipal solid waste; and (ii) collecting and treating MSW and faecal sludge from the city for producing organic fertilizer. The business would be implemented in urban Kampala linked to the increased availability of MSW.

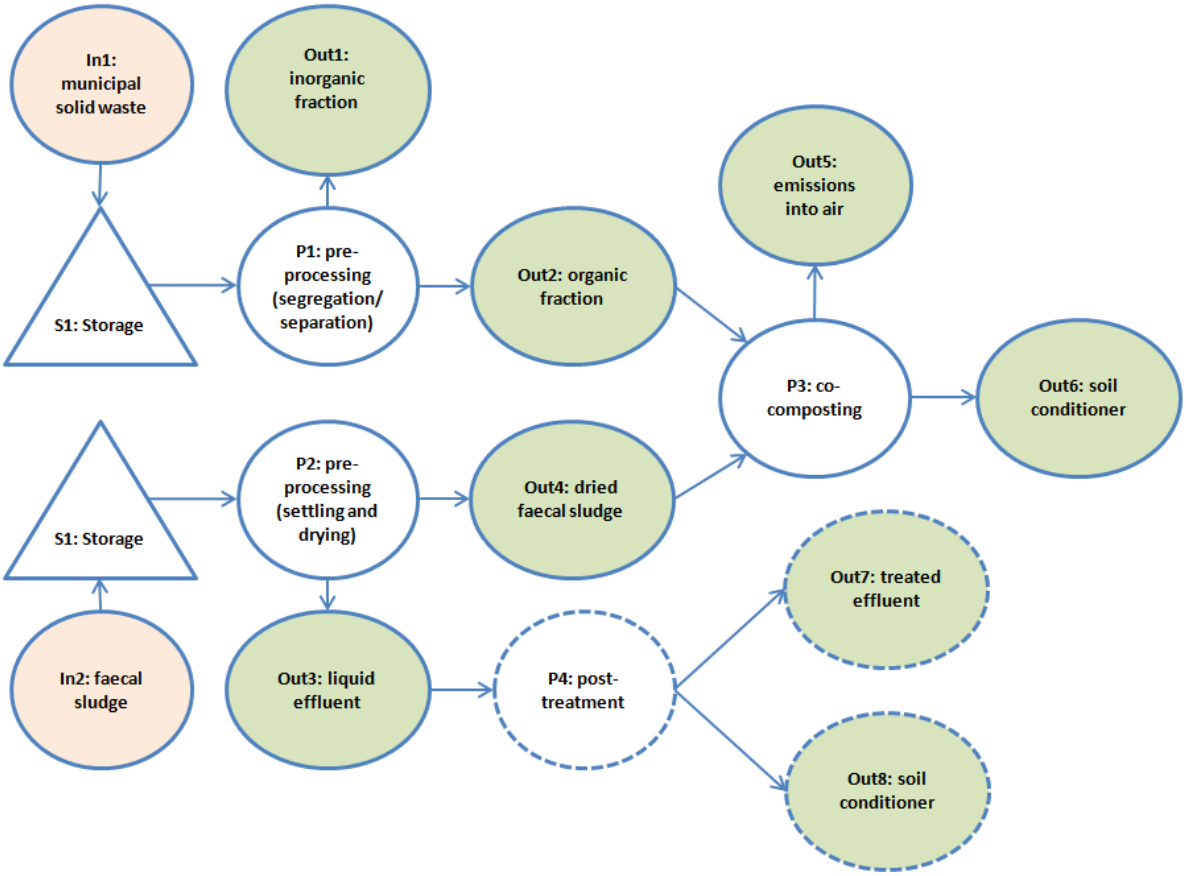


Figure 16 – Model 15: system flow diagram

Table 44 – Model 15: Inputs and associated potential health hazards

Inputs of health relevance	Potential hazards
In1: municipal solid waste	Contamination with pathogens deriving from human and animal waste (viruses and bacteria are of primary concern)
	Contamination with sharp objects
	Contamination with medical waste
	Contamination with chemical waste
In2: faecal sludge	Pathogens
	Contamination with sharp objects and inorganic waste

Table 45 – Model 15: Quality/safety requirements for outputs

Outputs of health relevance	Quality/safety requirements
Out1: inorganic fraction	None since considered as waste → appropriate disposal/recycling
Out2: organic fraction	N.a. (within the system)
Out3: liquid effluent	N.a. (within the system)
Out4: dried sludge	N.a. (within the system)
Out5: emissions into air	Ambient air quality standards[a]: • $PM_{2.5}$: 10 µ/m^3 24-hour mean; 25 µ/m^3 annual mean • PM_{10}: 20 µ/m^3 24-hour mean; 50 µ/m^3 annual mean

	• Ozone: 100 µ/m³ 8-hour mean • NO_2: 200 µ/m³ 1-hour mean; 40 µ/m³ annual mean • SO_2: 500 µ/m³ 10-minutes mean; 20 µ/m³ 24-hour mean
Out7: treated effluent	**Unrestricted irrigation** <u>Root crops:</u> • <10^3 *E. coli* per litre and <1 helminth egg per litre <u>Leave crops:</u> • <10^4 *E. coli* per litre and <1 helminth egg per litre <u>Drip irrigation of high-growing crops:</u> • <10^5 *E. coli* per litre and <1 helminth egg per litre <u>Drip irrigation of low-growing crops:</u> • <10^3 *E. coli* per litre and <1 helminth egg per litre **Restricted irrigation** <u>Labour intensive agriculture:</u> • <10^4 *E. coli* per litre and <1 helminth egg per litre <u>Highly mechanized agriculture:</u> • <10^5 *E. coli* per litre and <1 helminth egg per litre ➔ Chemical indicators in treated wastewater and receiving soils must not exceed thresholds as per WHO Guidelines (see Annex V)
Out8: soil conditioner	<u>For agricultural use:</u> • <1 helminth egg per 1 gram total solids; and <10^3 *E. coli* per gram total solids

[a] WHO (2005). Air quality guidelines - global update 2005. Geneva: World Health Organization

4.6.1 Health risk assessment

Health risks of this business are associated with the two types of inputs. MSW is usually contaminated with pathogens deriving from human (e.g. diapers) and potentially animal waste. Viruses and bacteria are of primary concern. In addition, sharp objects (e.g. razor blades), chemical waste (e.g. batteries) or even medical waste may be included in MSW. Pathogens are the primary hazard of the second input, faecal sludge, as well as potential contamination thereof with sharp object (e.g. razor blades). Besides the health hazards associated with the inputs, the operation of a co-composting plant involves emissions into the air such as malodours, thermophilic fungi and dust. Also the liquid effluents need to be treated appropriately. However, since the post-treatment of the liquid effluent is not clearly defined by the business model, the risk assessment is limited to the description of the efficiency of different post-treatment options but does not define which combination has to be selected. For the impact assessment it is assumed that the sludge and effluent of the anaerobic digestion are disposed of safely, i.e. appropriate disposal in case of no onsite post-treatment or treated effluent and soil conditioner that are compliant with quality/safety requirements as per the given scenario.

4.6.1.1 Indicated control measures

- Protective equipment
    - Workers handling any raw material (e.g. MSW and faecal matter) need to wear appropriate PPE and use tools (e.g. shovels)
- Processes

- Separation of any components that are contaminated with biological (e.g. human waste such as diapers or sanitary products), chemical (e.g. batteries) or inorganic (e.g. sharp objects such as razor blades) wastes. To be transferred into the inorganic fraction and disposed of appropriately
    - For pathogen removal, the faecal sludge needs to be put on drying beds for: (i) 1.5-2 years at 2-20°C; (ii) >1 years at 20-35°C; or (iii) >6 months by means of alkaline treatment at pH>9, >35°C and moisture <25%
    - Depending on the further use of the effluent of the faecal sludge, off-site and on-site post-treatment options are available (see section 4.2.1.1)
    - A temperature of ≥45°C for ≥5 days (2 log reductions in bacteria and <1 viable helminth eggs per g dried matter) should be maintained for the co-composting
    - Moisture of co-composting material should be above 40% for reducing bio-aerosol emission
    - Sieving of the soil conditioner prior to packaging for removing any remaining inorganic contamination or sharp objects
- Infrastructure
    - Assure good ventilation of working areas with a high load of malodours or dust (e.g. co-composting facility)
    - Install handrails and fence dangerous areas for preventing injuries
    - Respect a buffer zone between operation and community infrastructure so that ambient air quality and noise exposure standards are not exceeded (see Table 25). The actual distance is depending on the level of emissions
- Behavioural aspects and prevention
    - Assure that MSW is not contaminated with any medical waste!
    - Educate workers on ergonomic hazards and how to avoid musculoskeletal damage or injury due to inappropriate working practices
    - Insect vector- and rodent-control (e.g. screening or use of larvicides, insecticides) at storage sites
    - Protect workers from long term exposure to sunlight
    - Farmers using the soil conditioner should be advised to wear boots and gloves when applying the compost
    - Restrict access to the operations
    - Implement a worker well-being programme that includes regular sessions (e.g. weekly) where general health concerns are reported and health protection measures are promoted (e.g. regular hand washing, purpose of PPE and sun protection, ergonomic hazards, etc.)

4.6.1.2 Residual risks

By implementing all the proposed control measures, the identified health risks of Model 15 can be reduced to **low and moderate levels**. The residual risks are linked to the following processes:

- P1: pre-processing of MSW: rigorous screening and removing of any human, animal or chemical waste, as well as sharp objects is essential for assuring quality and safety of the organic fraction

- P2: settling and drying, and P3: co-composting: in order to avoid exposure of consumers to pathogens in the soil conditioner, it will be crucial to respect the temperature and duration indicated for the drying of the sludge and the co-composting
- P3: co-composting: to ensure that workers are protected with respirators is important when handling the waste materials for the co-composting process. Otherwise pathogens, fungi and dust affect their respiratory system
- P3: co-composting and P4: post-treatment: sharps ending up in the soil conditioner pose a moderate risk to users. Soil conditioner must be sieved before packaging and users need to be sensitised about the potential presence of sharp objects and pathogens in the soil conditioner. In addition, users need to be advised to wear boots and gloves when applying the soil conditioner.
- **Medical waste must be collected separately for keeping it out of the BM**

4.6.2 Health impact assessment

By collecting and processing faecal sludge, the business is a purification process. Hence, exposure to faecal pathogens may be reduced at community level. Moreover, the business could indirectly impact people who are currently exposed to landfills (waste pickers or surrounding communities), since it will reduce the load of MSW ending up on landfills.

- **Scale of the BM:** the impact assessment of Model 15 is assuming that two centralised co-composting plants are installed in Kampala, each collecting faeces from 2’000 households

4.6.2.1 Impact 1: reduction in respiratory, diarrhoeal and intestinal diseases

The business entails safe collection and disposal of faecal sludge. Consequently, there is the potential that the business’ activity will result in a reduction of unsafe disposal of faecal matter into the environment. Model 15 is more suitable for an urban environment with high density in MSW. According to the UDHS, only 2% of the households in the urban environment do not have any sanitation facility at all, and thus only little faeces ends up directly in the environment [7]. Therefore, most of the faeces is either stored in onsite systems or transferred to the Bugolobi treatment plant, which receives 742 m^3 faecal sludge on a daily basis [37]. In consideration of the scale of the business and the total amount of wastewater in Kampala, the likelihood of a positive health impacts linked to the business is small.

Impact 1, assumptions:

- **Impact level:** pathogens in human faeces generally cause disease of short duration and/or minor disability
- **People affected:** the business would primarily affect the 500 farmers working in the Nakivubo wetland
- **Likelihood:** it is very unlikely that the business will make a difference in disease incidence

Table 46 – Model 15, impact 1: reduction in respiratory, diarrhoeal and intestinal diseases

	Impact level (IL)	**People affected** (PA)	**Likelihood or frequency** (LoF)	**Magnitude** (ILxPAxL)
Category	Minor positive impact	Specific population group	Unlikely	**Minor positive impact**
Score: farmers	0.1	500	0.05	**2.5**

4.6.2.2 *Impact 2: health benefits due to reduced MSW loads on landfills*

In Kampala, landfills are associated with a range of negative health impacts ranging from the poor working conditions of the waste pickers to downstream issues such as contamination of surface waters. Hence, a reduction of the load of MSW that arrives on landfills has the potential to have an indirect positive impact on health.

Waste removal capacity of two centralized co-composting plants as proposed by Model 15 is anticipated to be 10-100 tonnes per day, which is about 10% of the daily volume of MSW collected in Kampala [37]. Consequently, the business is unlikely to make a considerable difference at the level of existing landfills.

Impact 2, assumptions:

- **Impact level:** various pathologies are associated with landfills
- **People affected:** an estimated 500 waste pickers work on the landfills that would be affected by the business
- **Likelihood:** it is unlikely that the business will make a difference in disease incidence

Table 47 – Model 15, impact 2: health benefits due to reduced MSW loads on landfills

	Impact level (IL)	**People affected** (PA)	**Likelihood or frequency** (LoF)	**Magnitude** (ILxPAxL)
Category	Minor positive impact	Specific population group	Unlikely	**Minor positive impact**
Score: farmers	0.5	500	0.3	**75**

4.6.3 Environmental Impact Assessment

Potential negative environmental impacts include: (1) accumulated waste resulting from separation of inorganic fractions from MSW prior to composting and disposed of or used improperly (2) leachate from the composting process, which if moisture is not well controlled can leach into the environment, (3) insufficient pathogen inactivation, which may occur when temperatures are not well control over a sufficient period of time, and (4) liquid effluent from FS treatment, which when leaching into the environment can have a negative impact due to high nutrient and organic matter concentrations. Mitigation measures to avoid negative impacts include: (1) storage, transport and disposal at a designated recycling facility or solid waste discharge site (sanitary landfill), (2) appropriate moisture control of the compost heap and/or collection of leachate and post treatment, (3) temperature control of the compost heap to ensure sufficient pathogen inactivation, and (4) post-treatment of the liquid effluent from FS dewatering processes. The goal of RRR based businesses should be full resource recovery of all End-products, which implies end-use of appropriately treated liquid effluent from post-treatment of liquid effluent from FS dewatering processes. If for some reason this is not feasible, only then should treated liquid effluent from FS dewatering processes get discharged into the environment presuming that it complies with local standards for discharge into the environment. Further details on technology options are outlined in the "Technology Assessment Report" [1].

Table 48 – Model 15: potential environmental hazards and proposed mitigation measures

Waste stream	End-product	Technologies	Process	Pot. Env. Hazard	Mitigation measures
• MSW • FS	• Soil Conditioner	• Solid/liquid separation • Drying beds • Co-composting	• Co-com-posting (MSW + FS)	• Accumulated inorganic waste • Leachate from composting • Insufficient pathogen inactivation • Liquid effluent (from FS treatment)	• Storage/transport/disposal (sanitary landfill) • Moisture control • Leachate treatment • Temperature control (compost heap) • Post-treatment of liquid effluent

4.7 Model 17 – High value fertilizer production for profit

The difference between Model 17 and Model 15 (analysed above) are:

- the input faecal sludge is combined with animal manure; and
- nitrogen (N), phosphorus (P) and potassium (K) (NPK) are added for the co-composting in order to produce branded/certified organic fertilizer

From a health protection and health impact perspective, these two modifications to Model 15 do not make any difference. Therefore, the HRIA of Model 15 also applies to Model 17.

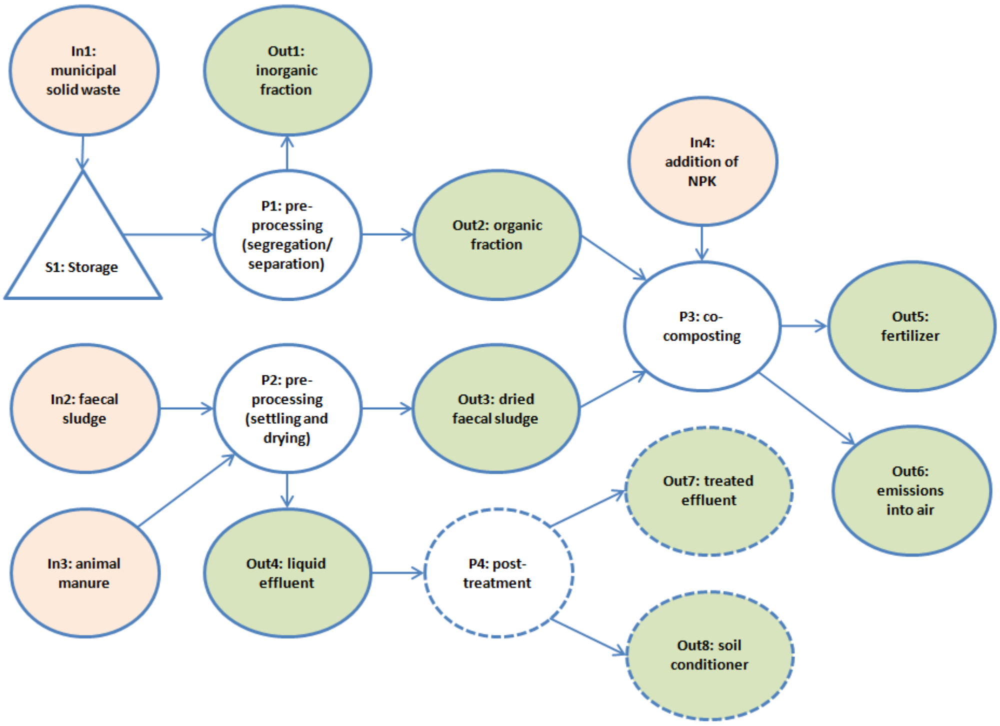


Figure 17 – Model 17: system flow diagram

Table 49 – Model 17: Inputs and associated potential health hazards

Inputs of health relevance	Potential hazards
In1: municipal solid waste	Contamination with pathogens deriving from human and animal waste (viruses and bacteria are of primary concern)
	Contamination with sharp objects
	Contamination with medical waste
	Contamination with chemical waste
In2: faecal sludge	Pathogens
	Contamination with sharp objects and inorganic waste
In3: animal manure	Pathogens
In4: addition of NPK	None

Table 50 – Model 17: Quality/safety requirements for outputs

Outputs of health relevance	Quality/safety requirements
Out1: inorganic fraction	None since considered as waste → appropriate disposal/recycling
Out2: organic fraction	N.a. (within system)
Out3: dried faecal sludge	N.a. (within the system)
Out4: liquid effluent	N.a. (within the system)
Out5: dried sludge	N.a. (within the system)
Out5: fertilizer	For agricultural use: • <1 helminth egg per 1 gram total solids; and <10^3 *E. coli* per gram total solids
Out6: emissions into air	Ambient air quality standards[a]: • $PM_{2.5}$: 10 µg/m^3 24-hour mean; 25 µg/m^3 annual mean • PM_{10}: 20 µg/m^3 24-hour mean; 50 µg/m^3 annual mean

	• Ozone: 100 µ/m^3 8-hour mean • NO_2: 200 µ/m^3 1-hour mean; 40 µ/m^3 annual mean • SO_2: 500 µ/m^3 10-minutes mean; 20 µ/m^3 24-hour mean
Out7: treated effluent	**Unrestricted irrigation** Root crops: • <10^3 *E. coli* per litre and <1 helminth egg per litre Leave crops: • <10^4 *E. coli* per litre and <1 helminth egg per litre Drip irrigation of high-growing crops: • <10^5 *E. coli* per litre and <1 helminth egg per litre Drip irrigation of low-growing crops: • <10^3 *E. coli* per litre and <1 helminth egg per litre **Restricted irrigation** Labour intensive agriculture: • <10^4 *E. coli* per litre and <1 helminth egg per litre Highly mechanized agriculture: • <10^5 *E. coli* per litre and <1 helminth egg per litre ➔ Chemical indicators in treated wastewater and receiving soils must not exceed thresholds as per WHO Guidelines (see Annex V)
Out8: soil conditioner	For agricultural use: • <1 helminth egg per 1 gram total solids; and <10^3 *E. coli* per gram total solids

[a] WHO (2005). Air quality guidelines - global update 2005. Geneva: World Health Organization

4.7.1 Health risk assessment

➔ Same as for Model 15 (section 4.6.1)

4.7.2 Health impact assessment

➔ Same as for Model 15 (section 4.6.2)

4.7.3 Environmental Impact Assessment

Potential negative environmental impacts include: (1) accumulated waste resulting from separation of inorganic fractions from MSW prior to composting and disposed of or used improperly (2) leachate from the composting process, which if moisture is not well controlled can leach into the environment, (3) insufficient pathogen inactivation, which may occur when temperatures are not well control over a sufficient period of time, and (4) liquid effluent from FS treatment, which when leaching into the environment can have a negative impact due to high nutrient and organic matter concentrations. Mitigation measures to avoid negative impacts include: (1) storage, transport and disposal at a designated recycling facility or solid waste discharge site (sanitary landfill), (2) appropriate moisture control of the compost heap and/or collection of leachate and post treatment, (3) temperature control of the compost heap to ensure sufficient pathogen inactivation, and (4) post-treatment of the liquid effluent from FS dewatering processes. The goal of RRR based businesses should be full resource recovery of all End-products, which implies end-use of appropriately treated liquid effluent from post-treatment of liquid effluent from FS dewatering processes. If for some reason this is not feasible, only then should treated liquid effluent from FS dewatering processes get discharged into the environment presuming that it complies with local standards for discharge into the environment. Further details on technology options are outlined in the “Technology Assessment Report” [1].

Table 51 – Model 17: potential environmental hazards and proposed mitigation measures

Waste stream	End-product	Technologies	Process	Pot. Env. Hazard	Mitigation measures
• MSW • FS	• Fertilizer (NPK added)	• Solid/liquid separation • Drying beds • Co-composting	• Co-com-posting (MSW + FS)	• Accumulated inorganic waste • Leachate from composting • Insufficient pathogen inactivation • Liquid effluent (from FS treatment)	• Storage/transport/disposal (sanitary landfill) • Moisture control • Leachate treatment • Temperature control (compost heap) • Post-treatment of liquid effluent

4.8 Model 19 – Compost production for sanitation service delivery

The business model on compost production for sanitation service delivery builds on separating human excreta into liquid and solid portions at source, no water for flushing the toilet, and simple nutrient recovery methods to secure a pathogen free product for sale in the market. The model can be replicated and scaled up and out in communities with no access to toilets and also for public toilets.

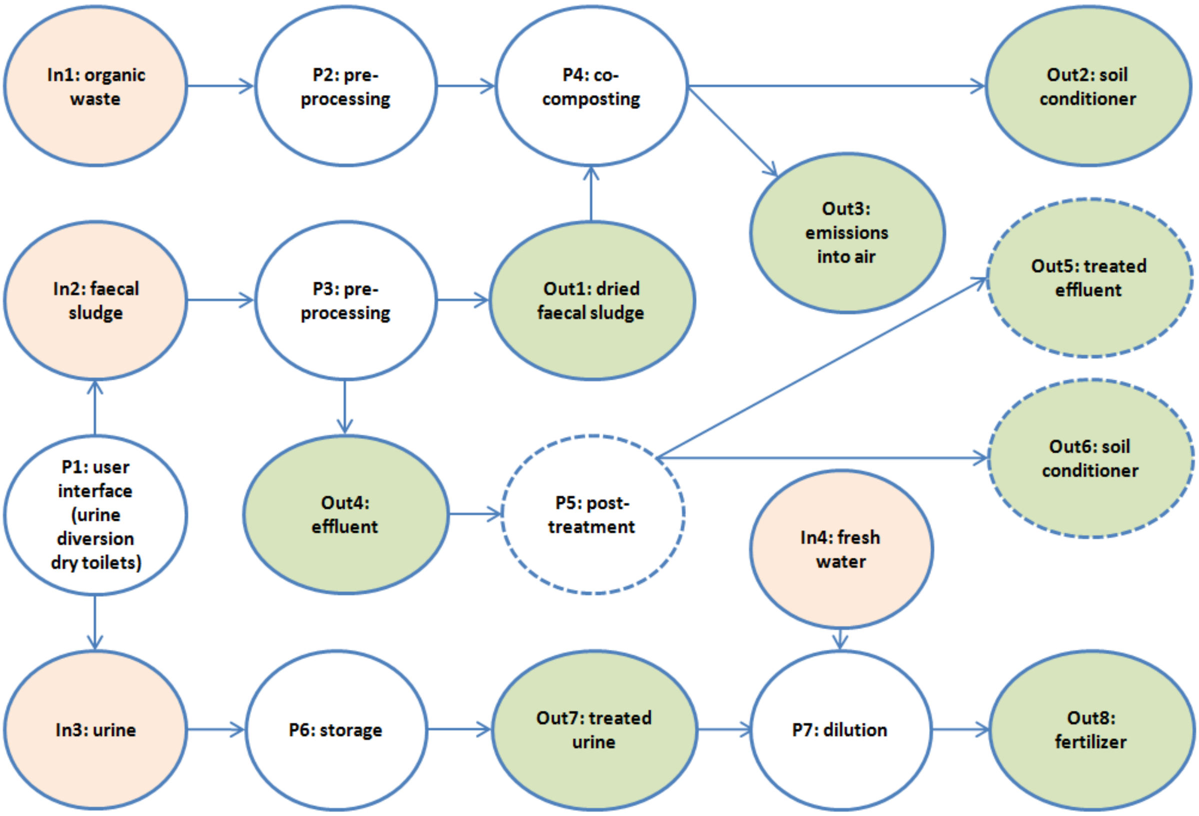


Figure 18 – Model 19: system flow diagram

Table 52 – Model 19: Inputs and associated potential health hazards

Inputs of health relevance	Potential hazards
In1: organic waste	Contamination with pathogens deriving from human and animal waste (viruses and bacteria are of primary concern)
	Contamination with sharp objects
	Contamination with medical waste
	Contamination with chemical waste
In2: faecal sludge	Pathogens
	Contamination with sharp objects and inorganic waste
In3: urine	Pathogens
In4: fresh water	None

Table 53 – Model 19: Quality/safety requirements for outputs

Outputs of health relevance	Quality/safety requirements
Out1: dried faecal sludge	N.a. (within the system)
Out2 and Out6: soil conditioner	For agricultural use: • <1 helminth egg per 1 gram total solids; and <10^3 E. coli per gram total solids
Out3: emissions into air	Ambient air quality standards[a]: • $PM_{2.5}$: 10 µg/m^3 24-hour mean; 25 µg/m^3 annual mean • PM_{10}: 20 µg/m^3 24-hour mean; 50 µg/m^3 annual mean • Ozone: 100 µg/m^3 8-hour mean • NO_2: 200 µg/m^3 1-hour mean; 40 µg/m^3 annual mean • SO_2: 500 µg/m^3 10-minutes mean; 20 µg/m^3 24-hour mean
Out4: liquid effluent	N.a. (within the system)

Out5: treated effluent	**Unrestricted irrigation** Root crops: • <10^3 E. coli per litre and <1 helminth egg per litre Leave crops: • <10^4 E. coli per litre and <1 helminth egg per litre Drip irrigation of high-growing crops: • <10^5 E. coli per litre and <1 helminth egg per litre Drip irrigation of low-growing crops: • <10^3 E. coli per litre and <1 helminth egg per litre **Restricted irrigation** Labour intensive agriculture: • <10^4 E. coli per litre and <1 helminth egg per litre Highly mechanized agriculture: • <10^5 E. coli per litre and <1 helminth egg per litre ➔ Chemical indicators in treated wastewater and receiving soils must not exceed thresholds as per WHO Guidelines (see Annex V)
Out7: treated urine	N.a. (within the system)
Out8: fertilizer	Extremely low pathogen loads (viruses and protozoa of major concern)

[a] WHO (2005). Air quality guidelines - global update 2005. Geneva: World Health Organization

4.8.1 Health risk assessment

Health risks of this business are primarily associated with the processing of faecal sludge. Pathogens and contamination with organic waste such as sharp objects are of major concern. Pathogens contained in urine are also of concern, though to a relatively minor extent. Also organic waste input may be contaminated with inorganic waste components. Besides the health hazards associated with the inputs, the operation of a co-composting plant involves emissions into the air such as malodours, thermophilic fungi and dust. Also the liquid effluents need to be treated appropriately. However, since the post-treatment of the liquid effluent is not clearly defined by the business model, the risk assessment is limited to the description of the efficiency of different post-treatment options but does not define which combination has to be selected. For the impact assessment it is assumed that the effluents are disposed of safely, i.e. appropriate disposal in case of no onsite post-treatment or treated effluent and soil conditioner that are compliant with quality/safety requirements as per the given reuse scenario.

4.8.1.1 Indicated control measures

The full risk assessment matrix is available in Appendix I. Indicated control measures are as follows:

- Protective equipment
    - Workers handling any raw material (e.g. faecal matter, urine or organic waste) need to wear appropriate PPE and use tools (e.g. shovels)
- Processes
    - Quality check of organic waste for separation of any components that are contaminated with biological (e.g. human waste such as diapers or sanitary

products), chemical (e.g. batteries) or inorganic (e.g. sharp objects such as razor blades) wastes. To be disposed of appropriately
  - For pathogen removal, the faecal sludge needs to be put on drying beds for: (i) 1.5-2 years at 2-20°C; (ii) >1 years at 20-35°C; or (iii) >6 months by means of alkaline treatment at pH>9, >35°C and moisture <25%
  - A temperature of ≥45°C for ≥5 days (2 log reductions in bacteria and <1 viable helminth eggs per g dried matter) should be maintained for the co-composting
  - Moisture of co-composting material should be above 40% for reducing bio-aerosol emission
  - Sieving of the soil conditioner prior to packaging for disposing any remaining inorganic contamination or sharp objects
  - Avoid any contamination of the urine with faecal matter
  - Remove urine that is contaminated with faecal matter or other solid or liquid waste components
  - The following storage times and temperatures are indicated depending on the use of the urine-based fertilizer:
    - Unrestricted, i.e. all crops: ≥6 month at ≥20°C
    - Food and fodder crops that are to be processed: ≥1 month at ≥4°C
    - Food crops that are to be processed, fodder crops (not grass lands): ≥6 month at ≥4°C
    - Food crops that are to be processed, fodder crops (not grass lands): ≥1 month at ≥20°C
- Infrastructure
  - In case the safety of the product cannot be assured, place clearly visible signs on toilets that prohibit disposal of any sharp object and inorganic waste into the toilet
  - Provide trash bins for disposal of sharp objects and inorganic waste components in each toilet
  - Assure good ventilation of working areas with a high load of malodours or dust (e.g. co-composting facility)
  - Install handrails and fence dangerous areas for preventing injuries
  - Install facilities where the soil conditioner can be sieved carefully for removing any sharp objects
  - Respect a buffer zone between operation and community infrastructure so that ambient air quality and noise exposure standards are not exceeded (see Table 25). The actual distance is depending on the level of emissions
  - Depending on the further use of the effluent of the faecal sludge, off-site and on-site post-treatment options are available (see section 4.2.1.1)
- Behavioural aspects and prevention
  - Place clearly visible danger signs on the packaging, indicating the risk of sharp objects and that users need to wear gloves and boots when applying the soil conditioner and urine
  - Educate workers on ergonomic hazards and how to avoid musculoskeletal damage or injury due to inappropriate working practices
  - Insect vector- and rodent-control (e.g. screening or use of larvicides, insecticides) at storage sites
  - Protect workers from long term exposure to sunlight

- Farmers using the soil conditioner should be advised to wear boots and gloves when applying the compost
- Farmers applying urine-based fertilizer should be advised to wear boots and gloves. In addition, the urine-based fertilizer should be applied close to the ground or worked into the soil
- The application of the urine-based fertilizer should be halted one month before harvesting
- Restrict access to the operations
- Implement a worker well-being programme that includes regular sessions (e.g. weekly) where general health concerns are reported and health protection measures are promoted (e.g. regular hand washing, purpose of PPE and sun protection, ergonomic hazards, etc.)

4.8.1.2 Residual risks

By implementing all the proposed control measures, the identified health risks of Model 19 can be reduced to **low and moderate levels**. The residual risks are linked to the following processes:

- P1: user interface: sharps ending up in the soil conditioner pose a moderate risk to users. Therefore it is crucial to sensitize users of the toilets to the issue and rigorously implement different control measures for preventing sharp objects or other inorganic waste to be disposed of in the toilets (i.e. clearly visible signs, provide trash bins)
- P3: settling and drying, and P4: co-composting: in order to avoid exposure of consumers to pathogens in the soil conditioner, it will be crucial to respect the temperature and duration indicated for the drying of the sludge and the co-composting
- P4: co-composting: to ensure that workers are protected with respirators is important when handling the waste materials for the co-composting process. Otherwise pathogens, fungi and dust affect their respiratory system
- P4: co-composting and P5: post-treatment: sharps ending up in the soil conditioner pose a moderate risk to users. Soil conditioner must be sieved before packaging and users need to be sensitised about the potential presence of sharp objects and pathogens in the soil conditioner. In addition, users need to be advised to wear boots and gloves when applying the soil conditioner.
- P6: storage of urine: in order to avoid exposure of consumers to pathogens bound in urine, it will be crucial to respect the temperature and duration indicated for the storage of the urine depending on the use of the urine-based fertilizer

4.8.2 Health impact assessment

The provision of sanitation services to underserved communities is likely to reduce incidence of diarrhoeal diseases, ARI and helminth infections.

- **Scale of the BM:** the impact assessment of Model 19 is based on the assumption that 30 villages in rural and peri-urban areas of Kampala will implement the BM

4.8.2.1 Impact 1: reduction in respiratory, diarrhoeal and intestinal diseases

➔ For the impact definition, see Model 4, impact 1 (section 4.3.2.1).

Impact 1, assumptions:

- **Impact level:** pathogens in human faeces generally cause disease of short duration and/or minor disability
- **People affected:** the business would be rolled out to 30 villages (average size ~300 people) where 3 in 4 households do not have access to safe sanitation (30x300x0.75=6'750)
- **Likelihood:** it is likely (odds: 61-95%) that the business positively impacts on diarrhoeal diseases and helminth infections

Table 54 – Model 19, impact 1: reduction in respiratory, diarrhoeal and intestinal diseases

	Impact level (IL)	**People affected** (PA)	**Likelihood or frequency** (LoF)	**Magnitude** (ILxPAxL)
Category	Minor positive impact	Medium population group	Likely	**Moderate positive impact**
Score	0.1	6'750	0.7	**472.5**

For maximizing the health benefits of the business, it is recommended:

- to keep the fee for the usage of the toilets at a minimum;
- to provide free access to the toilet facilities to children;
- to target communities with particularly low access to sanitation for the implementation of the business; and
- to promote hand washing practice at the exit of the facility.

4.8.3 Environmental Impact Assessment

Potential negative environmental impacts include: (1) "burning" of crops due to ammonia concentrations above the maximum limit for respective crops, (2) application of nitrogen above soil and crop needs, resulting in ammonia being oxidised to nitrate, leaching through soil and ending up in ground and/or surface waters (3) insufficient pathogen inactivation, which may occur when temperatures are not well control over a sufficient period of time, and (4) leachate from the composting process, which if moisture is not well controlled can leach into the environment. Mitigation measures to avoid negative impacts include: (1) and (2) urine dilution with water to ensure that the ammonia concentration for the respective crop is appropriate for plants and soil conditions, (3) appropriate moisture control of the compost heap and/or collection of leachate and post treatment, and (4) temperature control of the compost heap to ensure sufficient pathogen inactivation. Further details on technology options are outlined in the "Technology Assessment Report" [1].

Table 55 – Model 19: potential environmental hazards and proposed mitigation measures

Waste stream	End-product	Technologies	Process	Pot. Env. Hazard	Mitigation measures
• Urine • Feces	• Stored urine • Soil conditioner	• UDDTs • Co-composting	• Urine application • Co-com-posting	• Ammonia intoxication • Ammonia oxidization • Insufficient pathogen inactivation • Leachate from co- composting	• Urine dilution with water • Moisture control • Leachate treatment • Temperature control (compost heap)

5 References

1. Winkler MS, Krieger GR, Divall MJ, Cissé G, Wielga M, Singer BH, Tanner M, Utzinger J. Untapped potential of health impact assessment. Bulletin of the World Health Organization 2013; 91: 298-305.
2. Schoebitz L, Niwagaba C, Nguyen VA, Tran HH, Dang TH, Zurbruegg C, Strande L. Resource, Recovery and Reuse Project. From Research to Implementation. Component 4 – Technology Assessment: Bangalore, India; Hanoi, Vietnam; Kampala/Uganda; Lima, Peru. Dübendorf, Switzerland: Federal Institute of Aquatic Science and Technology (Eawag) 2015.
3. WHO. Guidelines for the safe use of wastewater, excreta and greywater, third edition. Geneva: World Health Organization 2006.
4. Rowe G, Wright G. The Delphi technique as a forecasting tool: issues and analysis. International Journal of Forecasting 1999; 15: 353-375.
5. WHO. Sanitation safety planning manual: draft for pilot testing. Geneva: World Health Organization 2013.
6. Winkler MS, Divall MJ, Krieger GR, Balge MZ, Singer BH, Utzinger J. Assessing health impacts in complex eco-epidemiological settings in the humid tropics: advancing tools and methods. Environmental Impact Assessment Review 2010; 30: 52-61.
7. Uganda Bureau of Statistics, MEASURE DHS. Uganda demographic and health survey 2011. Kampala, Uganda and Calverton, U.S.: Uganda Bureau of Statistics and MEASURE DHS 2011.
8. Howard G, Pedley S, Barrett M, Nalubega M, Johal K. Risk factors contributing to microbiological contamination of shallow groundwater in Kampala, Uganda. Water research 2003; 37: 3421-3429.
9. Nsubuga FB, Kansiime F, Okot-Okumu J. Pollution of protected springs in relation to high and low density settlements in Kampala- Uganda. Physics and Chemistry of the Earth 2004; 29: 1153-1159.
10. WHO. Fact sheet N°330: diarrhoeal disease. Geneva: World Health Organization 2013.
11. Boschi-Pinto C, Velebit L, Shibuya K. Estimating child mortality due to diarrhoea in developing countries. Bulletin of the World Health Organization 2008; 86: 657-736.
12. Bwire G, Malimbo M, Maskery B, Kim YE, Mogasale V, Levin A. The burden of cholera in Uganda. PLoS neglected tropical diseases 2013; 7: e2545-e2545.
13. Neil KP, Sodha SV, Lukwago L, O-Tipo S, Mikoleit M, Simington SD, Mukobi P, Balinandi S, Majalija S, Ayers J *et al*. A large outbreak of typhoid fever associated with a high rate of intestinal perforation in Kasese district, Uganda, 2008-2009. Clinical infectious diseases : an official publication of the Infectious Diseases Society of America 2012; 54: 1091-1099.
14. Bethony J, Brooker S, Albonico M, Geiger SM, Loukas A, Diemert D, Hotez PJ. Soil-transmitted helminth infections: ascariasis, trichuriasis, and hookworm. The Lancet 2006; 367: 1521-1532.
15. Ministry of Health Uganda. National master plan for neglected tropical diseases programme 2013-2017. Kampala, Uganda: Ministry of Health 2012.
16. Karagiannis-Voules DA, Biedermann P, Langer E, Garba A, Mathieu E, Ekpo U, Mwinzi P, Polderman A, Tchuenté LAT, Raso G *et al*. Spatial distribution of soil-transmitted helminths in sub-Saharan Africa: a systematic review and geostatistical meta-analysis. The Lancet 2014: (in press).
17. Fuhrimann S, Winkler MS, Cissé G. Prevalence and intensity of intestinal parasitic infections in the Nakivubo channel and wetland, Kampala, Uganda: preliminary report. Basel: Swiss Tropical and Public Health Institute 2013.

18. Fuhrimann S, Winkler MS, Halage A, Kabatereine NB, Utzinger J, Cissé G. Health risk assessment along the wastewater and faecal sludge chain in Kampala city. Basel: Swiss Tropical and Public Health Institute 2014.
19. Lai Y, Biedermann P, Ekpo UF, Garba A, Mathieu E, Midzi N, Mwinzi P, N'Goran EK, Raso G, Sacko M *et al*. The spatial distribution of schistosomiasis and treatment needs in sub-Saharan Africa: a systematic review and geostatistical analysis. PLoS Medicine 2014: (in press).
20. McElligott JT, Naaktgeboren C, Makuma-Massa H, Summer AP, Deal JL. Prevalence of intestinal protozoa in communities along the Lake Victoria region of Uganda. International journal of infectious diseases : IJID : official publication of the International Society for Infectious Diseases 2013; 17: e658-659.
21. WHO. COPD: factsheet No. 315. Geneva. Geneva: World Health Organization 2013.
22. WHO. Non-communicable diseases country profiles 2014: Uganda. Geneva: World Health Organization 2014.
23. Sachs J, Malaney P. The economic and social burden of malaria. Nature 2002; 415: 680-685.
24. Yeka A, Gasasira A, Mpimbaza A, Achan J, Nankabirwa J, Nsobya S, Staedke SG, Donnelly MJ, Wabwire-Mangen F, Talisuna A *et al*. Malaria in Uganda: challenges to control on the long road to elimination: I. epidemiology and current control efforts. Acta tropica 2012; 121: 184-195.
25. WHO. Trachoma: fact sheet N°382. Geneva: World Health Organization 2014.
26. Beller Consult, Mott MacDonald. Sanitation Strategy & Master Plan for Kampala City: 2003-2033. Kampala: Beller Consult and Mott MacDonald 2004.
27. Kulabako RN, Nalubega M, Wozei E, Thunvik R. Environmental health practices, constraints and possible interventions in peri-urban settlements in developing countries--a review of Kampala, Uganda. International journal of environmental health research 2010; 20: 231-257.
28. Fichtner Water & Transportation, Associates ME. Sanitation Program Kampala, Uganda. Kampala, Uganda: 2008.
29. Kayima J, Kyakula M, Komakech W, Echimu SP. A study of the degree of Pollution in Nakivubo Channel, Kampala, Uganda. Journal of Applied Sciences and Environmental Management 2008; 12: 93-98.
30. Niwagaba CB, May. Kampala RRR baseline survey: summary. Kampala: Makarere University 2011.
31. Stalder M. Microbial and industrial contamination along the major wastewater chain in Kampala, Uganda: Master Thesis. Basel and Zurich: Swiss Tropical and Public Health Institute, and Swiss Federal Institute of Technology 2014.
32. Fullerton DG, Bruce N, Gordon SB. Indoor air pollution from biomass fuel smoke is a major health concern in the developing world. Transactions of the Royal Society of Tropical Medicine and Hygiene 2008; 102: 843-851.
33. Pilusa TJ, Huberts R, Muzenda E. Emissions analysis from combustion of eco-fuel briquettes for domestic applications. Journal of Energy in Southern Africa 2013; 24: 30-36.
34. Rehfuess EA, Bruce NG, Smith KR (2011). *Solid fuel use: health effect*. Encyclopedia of Environmental Health. Nriagu JO. Burlington: Elsevier pp. 150161.
35. Shen GF, Xue M, Chen YC, Yang CL, Li W, Shen HZ, Huang Y, Zhang YY, Chen H, Zhu Y *et al*. Comparison of carbonaceous particulate matter emission factors among different solid fuels burned in residential stoves. Atmospheric Environment 2014; 89: 337-345.
36. Smith KR, Rogers J, Cowlin SC. Household fuels and ill-health in developing countries: what improvements can be brought by LP gas? Paris: World LP Gas Communication SARL 2005.
37. Schoebitz L, Niwagaba C, Strande L. RRR-Project From Research to Implementation Component: Waste Supply and Availability Report Kampala. Dübendorf, Switzerland: Federal Institute of Aquatic Science and Technology (Eawag) 2014.

38. Ziegelbauer K, Speich B, Mausezahl D, Bos R, Keiser J, Utzinger J. Effect of Sanitation on Soil-Transmitted Helminth Infection: Systematic Review and Meta-Analysis. Plos Medicine 2012; 9: 17.
39. Wolf J, Pruss-Ustun A, Cumming O, Bartram J, Bonjour S, Cairncross S, Clasen T, Colford JM, Curtis V, De France J *et al*. Assessing the impact of drinking water and sanitation on diarrhoeal disease in low- and middle-income settings: systematic review and meta-regression. Tropical Medicine & International Health 2014; 19: 928-942.
40. European Union. Heavy metals and organic compounds from waste used as organic fertilisers. Brussels: European Commission 2004.

6 Appendices

6.1 Appendix I – Health risk assessment tables

6.1.1 Model 1a – Dry fuel manufacturing: agro-industrial waste to briquettes

					Control measures				**Risk assessment**		
Element of the process	**Category**	**Hazard(s)**	**Hazardous event**	**Exposure route**		**TE**	**Acc**	**Mitigation potential**	**IL**	**LoF**	**Residual risk**
S1: storage P1: pre-processing (handling and separation) P2: drying	Biological hazards	Pathogens	Agro-waste is contaminated with faeces or urine	Hand to mouth	PPE	3	3	High	4	1	**Low risk (4)**
					Use of tools	3	3	High			
					Separation and discharge of any faecally contaminated agro-waste	2	3	Moderate			
				Inhalation	PPE	3	2	High			
		Rodents and insect vectors	Rodents or insect vectors are attracted by agro-waste and are thus a risk for diseases transmission	Hand to mouth, vectors living on rodents	Rodent and vector control at storage sites	3	2	Moderate	2	2	**Low risk (4)**
					Use of tools	2	3	Moderate			
	Chemical hazards	Toxic gases	**At consumer level:** burning of inorganic contaminants bound in briquettes at household level	Inhalation	Separation and discharge of any inorganic contaminants	2	3	Moderate	4	1	**Low risk (4)**
	Physical hazards	Sharp objects	Skin cuts when handling agro-waste	Skin contact	PPE	3	3	High	4	1	**Low risk (4)**
P3: Carbonization	Chemical hazards	Toxic gases	Inhalation of toxic gases at workplace and community	Inhalation	PPE (gas mask respirators)	3	2	Moderate	4	3	**Moderate risk (12)**

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures				Risk assessment		
						TE	Acc	Mitigation potential	IL	LoF	Residual risk
			level		Install CO monitors around the plant	2	2	Moderate			
					Respect a buffer zone between operation and community infrastructure so that ambient air quality standards are not exceeded (see table with quality/safety requirements for outputs)	3	2	Moderate			
	Physical hazards	Heat	Worker gets in contact with fire or hot surface	Skin contact	PPE	3	3	High	2	2	**Low risk (4)**
					Use of tools	3	3	High			
					Heat shields	3	3	High			
P4: Briquetting P5: Drying and packaging	Physical hazards	Dust	Long time exposure to dust	Inhalation	PPE	3	2	Moderate	2	2	**Low risk (4)**
		Injuries	Accidents while operating technical processes	Injury to the body	Education of workers handling technical processes	2	2	Moderate	8	1	**Moderate risk (8)**
					PPE	3	3	High			
		Noise	Noise in exceed of OH limits	Air	PPE	3	2	Moderate	2	2	**Low risk (4)**
			Noise exposure at community level	Air	Respect a buffer zone between the operation and community houses so that noise levels at community level do not exceed 55dB during the day and 45dB at night. The actual distance is depending on the noise emitted by the operation and can easily be calculated.	3	2	Moderate	2	2	**Low risk (4)**

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures				Risk assessment		
						TE	Acc	Mitigation potential	IL	LoF	Residual risk
Generalities	Physical hazard	Radiation	Long-time exposure of workers to direct sunlight	Environmental	Protect workers from long-term exposure to sun light	2	2	Moderate	4	2	**Moderate risk (8)**
	Various	Various	Workers are getting ill due to exposure to pathogens and chemical hazards or unhealthy working practices	Various	Implement a worker well-being programme that includes regular sessions where general health concerns are reported and health protection measures are promoted (e.g. regular hand washing, purpose of PPE and sun protection, ergonomic hazards etc.)	2	2	Moderate	4	3	**Moderate risk (12)**
	Various	Various	People from the community access the plant and get hurt, are exposed to pathogens or other hazards	Injury to the body, hand to mouth, inhalation	Restrict access to operations for external individuals	3	3	High	4	1	**Low risk (4)**
	Physical hazard	e.g. rotating parts	Workers interfere with processes they are not familiar with and get hurt	Injury to the body	Restrict access to technical processes to workers that are operating the process	3	3	High	4	1	**Low risk (4)**
	Physical hazard	Ergonomic hazards	Workers suffer of musculoskeletal damage due to inappropriate working practices	Injury to the body	Worker education for preventing musculoskeletal damage due to inappropriate working practices	2	2	Moderate	4	2	**Moderate risk (8)**

6.1.2 Model 2a – Energy service companies at scale: agro-waste to energy (electricity)

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures				Risk assessment		
						TE	Acc	Mitigation potential	IL	LoF	Residual risk
P1: pre-processing (handling and separation)	Biological hazards	Pathogens	Agro-waste is contaminated with faeces or urine	Hand to mouth; inhalation	PPE	3	3	High	4	1	**Low risk (4)**
					Use of tools	3	3	High			
	Physical hazards	Sharp objects	Skin cuts when handling agro-waste	Skin contact	PPE	3	3	High	4	1	**Low risk (4)**
S1: storage	Biological hazards	Rodents → disease transmissi on	Rodents attracted by agro-waste	Hand to mouth, vectors living on rodents	Use of tools	2	3	Moderate	2	2	**Low risk (4)**
		Disease vectors	Flies feeding on faecal matter and transmitting disease	Vectors	Avoid vector breeding in storage areas (e.g. screening or insecticides)	3	2	Moderate	4	1	**Low risk (4)**
		Malodours	Permanent exposure of workers to malodours	Inhalation	PPE	3	2	Medium	2	4	**Moderate risk (8)**
			Exposure of community to malodours		Assure good ventilation	2	3	Medium	2	3	**Moderate risk (6)**
					Respect a buffer zone between operation and community infrastructure in order to prevent community annoyance due to malodours	3	2	Medium	4	3	**Moderate risk (12)**
P2: gasification P3: gas-based generator	Biological hazards	Disease vectors	Vector breeding sites in stagnant components of cooling water cycle	Vectors	Screening/covering of open water bodies	3	3	High	4	1	**Low risk (4)**
	Chemical hazards	Toxic gases	Inhalation of toxic gases at workplace level	Inhalation	PPE (gas mask respirators)	3	2	Moderate	4	3	**Moderate risk (12)**

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures	TE	Acc	Mitigation potential	IL	LoF	Residual risk
					Install CO monitors around the plant	2	2	Moderate			
					Assure ventilation of plant	2	3	Moderate			
					Ensure that exhausts are released to the outside	3	3	High			
			Inhalation of toxic gases at community level	Inhalation	Respect a buffer zone between operation and community infrastructure so that ambient air quality standards are not exceeded (see table with quality/safety requirements for outputs)	3	2	Moderate	4	3	**Moderate risk (12)**
		Chemicals	Chemicals in scrubbing water	Skin contact or inhalation	Installation of a bin/tank to collect and treat the toxic liquids	3	2	Moderate	4	2	**Moderate risk (8)**
	Physical hazards	Fire/explosion	A fire or explosion occurs due to gas leakage, etc.		Develop fire/explosion response plan (e.g. installation of fire detection/suppression equipment; anti-back firing systems; separate fuel storage; escape routes; and purging system with nitrogen)	3	3	High	16	1	**High risk (16)**
		Heat	Worker gets in contact with fire or hot surface	Skin contact	PPE	3	3	High	2	2	**Low risk (4)**
					Use of tools	3	3	High			
					Heat shields	3	3	High			
		Dust/ashes	Exposure to dust when	Inhalation	Water spraying at ash	2	3	Moderate	1	3	**Low risk**

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures	TE	Acc	Mitigation potential	IL	LoF	Residual risk
			discharging ashes		discharge						(3)
					PPE	3	3	High			
		Injuries	Accidents while operating technical processes	Injury to the body	Education of workers handling technical processes	2	2	Medium	4	1	Low risk (4)
					PPE	3	3	High			
		Noise	Noise in exceed of OH limits	Air	PPE	3	2	Medium	4	3	Moderate risk (12)
			Noise exposure at community level	Air	Respect a buffer zone between the operation and community houses so that noise levels at community level do not exceed 55dB during the day and 45dB at night. The actual distance is depending on the noise emitted by the operation and can easily be calculated.	3	2	Medium	4	3	Moderate risk (12)
		Electricity	Electric shock of a worker	Skin contact	Use of intrinsically safe electrical installations; non-sparking tools and proper grounding.	3	3	High	16	1	High risk (16)
P4: Anaerobic digestion	Biological hazards	Pathogens	N. a.	N.a.	Anaerobic digestion at >35°C for >9day (1 log reduction *E. coli* and 0 log reduction in helminth eggs) [a]	Since anaerobic digestion is done under mesophilic conditions, it is not considered as a control measure					
			Accidental contact while	Hand to	PEE	3	3	High	2	2	Low risk

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures	TE	Acc	Mitigation potential	IL	LoF	Residual risk
			handling the animal manure/slurry	mouth	Use of tools	3	3	High			(4)
	Chemical hazards	Toxic gases	Inhalation of toxic gases at workplace level	Inhalation	PPE	3	2	Medium	4	1	**Low risk (4)**
					Prevent any gas leakage	3	3	High			
					Install CO monitors around the plant	2	2	Medium			
					Assure ventilation of plant	2	3	Medium			
			Inhalation of toxic gases at community level		Respect a buffer zone between operation and community infrastructure so that ambient air quality standards are not exceeded (see table with quality/safety requirements for outputs)	3	2	Medium	4	1	**Low risk (4)**

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures				Risk assessment		
						TE	Acc	Mitigation potential	IL	LoF	Residual risk
P5: post-treatment	Biological hazards	Pathogens	Downstream exposure: - Accidental intake of contaminated liquid effluent from the plant - Ingestion of produce that is irrigated with unsafe liquid effluent or fertilized with unsafe soil conditioner	Acciden-tal ingestion	Depending on the further use of the outputs of the post-treatment, the following post-treatment options are proposed: <u>Off-site (i.e. discharge):</u> ➢ Drain/transfer effluents/sludge into an existing WWTP for co-treatment ➢ Discharge sludge on landfill <u>On-site (in case of agricultural reuse of the outputs, a combination of the following options will be required for achieving the required quality standard (see table with quality/safety requirements for outputs)):</u> ➢ Septic tank (≥1 log reduction of *E. coli* and ≥2 log reduction in helminth eggs) ➢ Anaerobic baffled reactor (≥1 log reduction of *E. coli* and ≥2 log reduction in helminth eggs) ➢ Anaerobic filter(≥1 log reduction of *E. coli* and ≥2 log reduction in helminth eggs) ➢ Constructed/vertical flow wetland (≥0.5-3 log reduction of *E. coli* and ≥1-3 log reduction in helminth eggs) ➢ Planted gravel Filter ➢ Unplanted gravel Filter ➢ Planted/unplanted drying beds (1-3 log reduction in helminth eggs)						
			Accidental contact with pathogens while operating the post-treatment components	Hand-to-mouth	PPE	3	3	High	4	2	**Moderate risk (8)**
		Disease vectors	Treatment ponds serve as vector breeding sites	Insect bites	Prevent mosquito breeding in ponds	2	2	Moderate	4	2	**Moderate risk (8)**
Generalities	Physical hazard	Radiation	Long-time exposure of workers to direct sunlight	Environm ental	Protect workers from long-term exposure to sun light	2	2	Medium	8	1	**Moderate risk (8)**
	Various	Various	Workers are getting ill due	Various	Implement a worker well-	2	2	Medium	4	3	**Moderate**

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures				Risk assessment		
						TE	Acc	Mitigation potential	IL	LoF	Residual risk
			to exposure to pathogens and chemical hazards or unhealthy working practices		being programme that includes regular sessions where general health concerns are reported and health protection measures are promoted (e.g. regular hand washing, purpose of PPE and sun protection, ergonomic hazards etc.)						**risk (12)**
	Various		People from the community access the plant and get hurt, are exposed to pathogens or other hazards	Injury to the body, hand to mouth, inhalation	Restrict access to operations	3	3	High	8	1	**Moderate risk (8)**
	Physical hazard		Workers interfere with processes they are not familiar with and get hurt	Injury to the body	Restrict access to technical processes to workers that are operating the process	3	3	High	8	1	**Moderate risk (8)**
	Physical hazard		Workers suffer of musculoskeletal damage due to inappropriate working practices	Injury to the body	Worker education for preventing musculoskeletal damage due to inappropriate working practices	2	2	Medium	4	2	**Moderate risk (8)**

6.1.3 Model 4 – Onsite energy generation by sanitation service providers

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures				Risk assessment		
						TE	Acc	Mitigation potential	IL	LoF	Residual risk
P1: Toilets	Physical hazards	Sharp objects	**At consumer level:** Exposure of users of the soil conditioner to sharp object (blades, syringes)	Skin contact	Place clearly visible signs on toilets that prohibit disposal of any sharp object and inorganic waste into the toilet	2	2	Moderate	4	3	**Moderate risk (12)**
					Provide trash bins for disposal of sharp objects and inorganic waste components in each toilet	2	2	Moderate			
P2: anaerobic digestion	Biological hazards	Pathogens	N. a.	N.a.	Anaerobic digestion at >35°C for >9day (1 log reduction *E. coli* and 0 log reduction in helminth eggs) [a]	Since anaerobic digestion is done under mesophilic conditions, it is not considered as a control measure					
			Accidental contact while handling the faecal sludge/slurry	Hand to mouth	PEE	3	3	High	2	2	**Low risk (4)**
					Use of tools	3	3	High			
	Chemical hazards	Toxic gases	Inhalation of toxic gases at workplace level	Inhalation	PPE	3	2	Medium	4	1	**Low risk (4)**
					Prevent gas leakage	3	3	High			
					Install CO monitors around the plant	2	2	Medium			
					Assure ventilation of plant	2	3	Medium			
			Inhalation of toxic gases at community level		Respect a buffer zone between operation and community infrastructure so that ambient air quality standards are not exceeded (see table with quality/safety	3	2	Medium	4	1	**Low risk (4)**

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures				Risk assessment		
						TE	Acc	Mitigation potential	IL	LoF	Residual risk
					requirements for outputs)						
	Physical hazards	Sharp objects	Exposure to sharp objects when handling the anaerobic sludge	Skin contact	PPE	3	3	High	4	1	**Low risk (4)**
					Use of tools	3	3	High			
P3: gas-based generator	Chemical	Toxic gases	Inhalation of toxic gases at workplace level	Inhalation	Ensure that exhausts are released to the outside	3	3	High	4	1	**Low risk (4)**
					Install CO monitors around the plant	2	2	Moderate			
	Physical hazards	Fire/explosion	A fire or explosion occurs due to gas leakage, etc.		Develop and implement fire/explosion response plan	3	3	High	16	1	**High risk (16)**
		Heat	Worker gets in contact with fire or hot surface	Skin contact	PPE	3	3	High	2	2	**Low risk (4)**
					Heat shields	3	3	High			
		Injuries	Accidents while operating technical processes	Injury to the body	Education of workers handling technical processes	2	2	Medium	4	1	**Low risk (4)**
					PPE	3	3	High			
		Noise	Noise in exceed of OH limits	Air	PPE	3	2	Medium	4	3	**Moderate risk (12)**
			Noise exposure at community level		Respect a buffer zone between the operation and community houses so that noise levels at community level do not exceed 55dB during the day and 45dB at night. The actual distance is depending on the noise emitted by the operation and can easily be calculated.	3	2	Medium	4	3	**Moderate risk (12)**

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures	TE	Acc	Mitigation potential	IL	LoF	Residual risk
		Electricity	Electric shock of a worker	Skin contact	Use of intrinsically safe electrical installations; non-sparking tools and proper grounding.	3	3	High	16	1	**High risk (16)**
P4: post-treatment	Biological hazards	Pathogens	Downstream exposure: - Accidental intake of contaminated liquid effluent from the plant - Ingestion of produce that is irrigated with unsafe liquid effluent or fertilized with unsafe soil conditioner	Acciden-tal ingestion	Depending on the further use of the outputs of the post-treatment, the following post-treatment options are proposed: Off-site (i.e. discharge): ➢ Drain/transfer effluents/sludge into an existing WWTP for co-treatment ➢ Discharge sludge on landfill On-site (in case of agricultural reuse of the outputs, a combination of the following options will be required for achieving the required quality standard (see table with quality/safety requirements for outputs)): ➢ Septic tank (≥1 log reduction of *E. coli* and ≥2 log reduction in helminth eggs) ➢ Anaerobic baffled reactor (≥1 log reduction of *E. coli* and ≥2 log reduction in helminth eggs) ➢ Anaerobic filter(≥1 log reduction of *E. coli* and ≥2 log reduction in helminth eggs) ➢ Constructed/vertical flow wetland (≥0.5-3 log reduction of *E. coli* and ≥1-3 log reduction in helminth eggs) ➢ Planted gravel Filter ➢ Unplanted gravel Filter ➢ Planted/unplanted drying beds (1-3 log reduction in helminth eggs)						
			Accidental contact with pathogens while operating the post-treatment components	Hand-to-mouth	PPE	3	3	High	4	2	**Moderate risk (8)**
		Disease vectors	Treatment ponds serve as vector breeding sites	Insect bites	Prevent mosquito breeding in ponds	2	2	Moderate	4	2	**Moderate risk (8)**
	Physical hazard	Sharp objects	**At consumer level:** Exposure of users of the soil conditioner to sharp	Skin contact	Careful sieving of the sludge/soil conditioner before packaging	2	3	Moderate	4	3	**Moderate risk (12)**

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures				Risk assessment		
						TE	Acc	Mitigation potential	IL	LoF	Residual risk
			object (blades, syringes)		Place clearly visible danger signs on the packaging, indicating the risk of sharp objects and that users need to wear gloves and boots when applying the product	2	1	Low			
Generalities	Various		People from the community access the plant and get hurt, are exposed to pathogens or other hazards	Injury to the body, hand to mouth, inhalation	Restrict access to operations for external individuals	3	3	High	8	1	**Moderate risk (8)**
	Physical hazard		Workers suffer of musculoskeletal damage due to inappropriate working practices	Injury to the body	Worker education for preventing musculoskeletal damage due to inappropriate working practices	2	2	Medium	2	2	**Low risk (4)**

6.1.4 *Model 9 – On cost savings and recovery*

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures				Risk assessment		
						TE	Acc	Mitigation potential	IL	LoF	Residual risk
P1: wastewater treatment plant	Biological hazards	Pathogens	**Downstream exposure:** - Accidental intake of contaminated liquid effluent from the plant - Ingestion of produce that is irrigated with unsafe liquid effluent	Acciden-tal ingestion	Primary, secondary and tertiary treatment has to be applied for reducing pathogens. Different options can be combined for reaching a minimum of 7 log reduction in bacterial indicators (e.g. *E. coli*) and 3 log reductions in helminth eggs.	3	3	High	4	1	**Low risk (4)**
		Pathogens	Accidental contact with pathogens while operating the wastewater treatment plant	Hand-to-mouth and inhalation	PPE	3	3	High	4	1	**Low risk (4)**
					Use of tools	3	3	High			
		Disease vectors	Treatment ponds serve as vector breeding sites	Insect bites	Prevent mosquito breeding in ponds	2	2	Moderate	4	3	**Moderate risk (12)**
	Chemical hazards	Chemicals, including heavy metals	**Downstream exposure:** Treated wastewater is used for irrigation, where heavy metals may impact on soil quality and accumulate in crops	Ingestion	In case chemical indicators of the wastewater or receiving soils exceed WHO Guidelines threshold (see annex V):						
					Option A.) Apply a physico-chemical removal process (e.g. absorption)	3	1	Low	4	4	**High risk (16)**
					Option B.) Do not promote the treated wastewater for irrigation	2	1	Low	4	4	**High risk (16)**
		Heavy metals	**Downstream exposure:** Poor sludge quality results in contaminated fertilizer	Ingestion	In case the sludge does not comply with heavy metal thresholds (see	2	1	Low	4	4	**High risk (16)**

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures				Risk assessment		
						TE	Acc	Mitigation potential	IL	LoF	Residual risk
					Annex V) physico-chemical removal process must be applied. **Otherwise the sludge must not be further processed for producing fertilizer**						
	Physical hazards	Sharp objects	Workers are hurt or drown during operation of the plant	Injury to the body	PPE	3	3	High	5	1	**Moderate risk (5)**
					Use of tools	3	3	High			
					Installation of handrails and fencing of dangerous areas	3	3	High			
P2: dewatering	Biological hazards	Pathogens	Pathogens enter the co-composting process and ultimately pose risk to the users of the compost	Hand to mouth	Storage treatment at 2-20°C: 1.5-2 years [a]	3	2	Medium	4	3	**Moderate risk (12)**
					Storage treatment at 20-35°C: >1 years [a]	3	2	Medium			
					Storage treatment at pH>9 (alkaline treatment): >35°C; and moisture <25%: >6 months [a]	3	2	Medium			
			Accidental contact while handling the sludge	Hand to mouth	PPE	3	3	High	4	2	**Moderate risk (8)**
					Use of tools	3	3	High			
		Disease vectors	Flies feeding on faecal matter and transmitting disease	Vectors	Screening of drying beds	3	2	Medium	4	2	**Moderate risk (8)**
P3: co-composting	Biological hazards	Pathogens	Sludge and organic-waste is contaminated with pathogens (e.g. chicken waste → campylobacter, salmonella)	Hand to mouth	PPE	3	3	High	4	1	**Low risk (4)**
					Use of tools	3	3	High			
			Downstream exposure:	Hand to	≥45°C for ≥5 days (2 log	3	2	Moderate	4	2	**Moderate**

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures				Risk assessment		
						TE	Acc	Mitigation potential	IL	LoF	Residual risk
			Those that apply the compost are exposed to pathogens such as *E. coli* and helminth eggs	mouth and inhalation	reductions in bacteria and <1 viable helminth eggs per g dried matter)						**risk (8)**
					Advice farmers to wear boots and gloves when applying the compost	3	2	Moderate			
		Thermophilic fungi and actino-mycetes	Inhalation of airborne spores	Inhalation	PPE	3	2	Moderate	4	3	**Moderate risk (12)**
					Moisture (>40%) control for reducing bio-aerosol emission	3	2	Moderate			
		Malodors	Exposure to malodors	Inhalation	PPE	2	2	Moderate	2	2	**Low risk (4)**
					Good ventilation of working area	2	3	Moderate			
	Physical	Dust	Long-term exposure to dust	Inhalation	PPE	3	2	Moderate	2	2	**Low risk (4)**
		Sharp objects and inorganic waste	Skin cuts when handling organic solid waste	Skin contact	Separate and discharge contaminated organic solid waste	2	2	Moderate	4	2	**Moderate risk (8)**
Generalities	Biological	Vector-borne diseases	Mosquitoes breed in ponds and consequently increase the risk for transmission of vector-borne diseases	Mosquito bites	Prevent mosquito breeding in treatment ponds	2	2	Moderate	4	2	**Moderate risk (8)**
	Physical		Physical injury of workers		Prevent the risk of drowning in ponds by means of PPE, worker education and only employ workers that know how to swim	3	3	High	8	1	**Moderate risk (6)**

6.1.5 Model 10 – Informal to formal trajectory in wastewater irrigation

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures				Risk assessment		
						TE	Acc	Mitigation potential	IL	LoF	Residual risk
P1: drainage system P2: pumping station	Biological hazards	Pathogens	**Downstream exposure**: Flooding event results in exposure to pathogens	Hand to mouth and acciden-tal ingestion	Complement drainage system with a pre-treatment facility (e.g. screening and grease traps) for preventing backups and overflows.	3	3	High	4	1	**Low risk (4)**
					Regular cleaning of the drainage system for preventing clogging and overflow	2	3	Moderate	4	1	**Low risk (4)**
					Regulate the flow of the pumping station for preventing overflowing in subsequent processes	3	3	High	4	1	**Low risk (4)**
P3a: slow rate infiltration P3b: rapid infiltration	Biological hazards	Pathogens	**Downstream exposure:** - Accidental intake of contaminated liquid effluent from the plant - Ingestion of produce that is irrigated with unsafe liquid effluent	Hand to mouth and acciden-tal ingestion	**Monitor wastewater quality, which needs to comply with the following parameters given for sub-surface irrigation** $<10^6$ *E. coli* per litre and <1 helminth egg per litre	2	2	Moderate	4	2	**Moderate risk (8)**
			Groundwater is contaminated by the infiltrated untreated wastewater	Ground-water contamin ation	Hydrology study to be done before building an infiltration technology						
	Chemical hazards	Chemicals, including heavy metals	**Downstream exposure:** Treated wastewater is used for irrigation, where heavy metals may impact on soil quality and	Ingestion	**Monitor chemical parameters in wastewater and receiving soils which must not exceed** WHO						

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures				Risk assessment		
						TE	Acc	Mitigation potential	IL	LoF	Residual risk
			accumulate in crops		Guidelines threshold (see annex X)						
			Groundwater is contaminated by the infiltrated untreated wastewater	Ground-water contamination	Hydrology study to be done before building an infiltration technology						
P3c: overland flow	Biological hazards	Pathogens	**Downstream exposure:** - Accidental intake of contaminated water from the plant - Ingestion of produce that is irrigated with unsafe liquid effluent - Skin penetration by pathogens transferred by water - Skin diseases	Hand to mouth, acciden-tal ingestion, skin penetration and skin contact	**Monitor wastewater quality, which needs to comply with the parameters given for root crops (**<10^3 *E. coli* per litre and <1 helminth egg per litre) **or leave crops** (<10^4 *E. coli* per litre and <1 helminth egg per litre).	2	2	Moderate	4	4	**High risk (16)**
					Advice farmers to wear boots and gloves when working in the irrigated fields.						
					Advice farmers to respect 2 days between last irrigation and harvesting.						
					Advise farmers to wash harvested crops with fresh water						
	Chemical hazards	Chemicals, including heavy metals	**Downstream exposure:** Treated wastewater is used for irrigation, where heavy metals may impact on soil quality and accumulate in crops	Ingestion	**Monitor chemical parameters in wastewater and receiving soils which must not exceed** WHO Guidelines threshold (see annex X)						

					Control measures				Risk assessment		
Element of the process	**Category**	**Hazard(s)**	**Hazardous event**	**Exposure route**		**TE**	**Acc**	**Mitigation potential**	**IL**	**LoF**	**Residual risk**
P3d: wetland application	Biological hazards	Pathogens	**Downstream exposure:** - Accidental intake of contaminated water from the plant - Ingestion of produce that is irrigated with unsafe liquid effluent - Skin penetration by pathogens transferred by water - Skin diseases	Hand to mouth, acciden-tal ingestion, skin penetratio n and skin contact	**Monitor wastewater quality prior to entering the wetland, which needs to comply with the parameters given for root crops (**$<10^4$ *E. coli* per litre and <10 helminth egg per litre) or **leave crops** ($<10^5$ *E. coli* per litre and <10 helminth egg per litre).	2	2	Moderate	4	3	**Moderate risk (12)**
					Advice farmers to wear boots and gloves when working in the irrigated fields.						
					Advice farmers to respect 2 days between last irrigation and harvesting.						
					Advise farmers to wash harvested crops with fresh water						
P4a: slow rate infiltration P3b: rapid infiltration	Biological hazards	Pathogens	Groundwater is contaminated by the infiltrated untreated wastewater	Ground-water contamin ation	Hydrology study to be done before building an infiltration technology						
	Chemical hazards	Chemicals, including heavy metals	Groundwater is contaminated by the infiltrated untreated wastewater	Environm ental							

6.1.6 Model 15 – Large-scale composting for revenue generation

6.1.7 Model 17 – High value fertilizer production for profit

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures				Risk assessment		
						TE	Acc	Mitigation potential	IL	LoF	Residual risk
S1: storage	Biological hazards	Rodents → disease transmissi on	Rodents attracted by MSW	Hand to mouth, vectors living on rodents	Use of tools	3	3	High	2	2	**Low risk (4)**
		Disease vectors	Flies feeding on faecal matter and transmitting disease	Vectors	Screening of storage facility	2	2	Moderate	4	2	**Moderate risk (8)**
P1: pre-processing (segregation/ separation)	Biological hazards	Pathogens	MSW is contaminated with pathogens deriving from human and animal waste	Hand to mouth	PPE	3	3	High	4	2	**Moderate risk (8)**
					Use of tools	3	3	High			
					Separation of any components that are contaminated with human and/or animal waste (e.g. diapers, sanitary products). To be discharged into the inorganic fraction and disposed of appropriately.	2	2	Moderate			
				Inhalation	PPE	3	2	Moderate			
	Chemical hazards	Chemicals	Compost is contaminated with toxic matter	Toxic matter	Separation of any waste components that contain (e.g. batteries) or are contaminated with chemicals. To be discharged into the inorganic fraction and disposed of appropriately.	3	3	High	2	2	**Low risk (4)**

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures				Risk assessment		
						TE	Acc	Mitigation potential	IL	LoF	Residual risk
	Physical hazards	Sharp objects	Skin cuts when handling MSW	Skin contact	PPE	3	3	High	4	1	**Low risk (4)**
					Use of tools	3	3	High			
					Separation of any sharp objects (e.g. razor blades). To be discharged into the inorganic fraction and disposed of appropriately.	2	3	Moderate			
		Malodours	Permanent exposure of workers to malodours	Inhalation	PPE	2	2	Moderate	2	3	**Moderate risk (6)**
					Rapid processing of MSW after arrival	2	2	Moderate			
P2: pre-processing (settling and drying)	Biological hazards	Pathogens	High loads of pathogens enters the composting process	Hand to mouth and inhalation	Storage treatment at 2-20°C: 1.5-2 years [a]	3	2	Medium	4	3	**Moderate risk (12)**
					Storage treatment at 20-35°C: >1 years [a]	3	2	Medium			
					Storage treatment at pH>9 (alkaline treatment): >35°C; and moisture <25%: >6 months [a]	3	2	Medium			
			Accidental contact while handling the sludge	Hand to mouth	PPE	3	3	High	4	2	**Moderate risk (8)**
					Use of tools	3	3	High			
		Disease vectors	Flies feeding on faecal matter and transmitting disease	Vectors	Screening of drying beds	3	2	Medium	4	2	**Moderate risk (8)**
P3: co-composting	Biological hazards	Thermophilic fungi and actino-mycetes	Inhalation of airborne spores	Inhalation	PPE	3	2	Moderate	4	2	**Moderate risk (8)**
					Moisture (>40%) control for reducing bio-aerosol emission	3	2	Moderate			
		Pathogens	Exposure to pathogens bound in the organic waste	Hand to mouth	PPE	3	3	High	4	1	**Low risk (4)**
					Use of tools	3	3	High			

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures				Risk assessment		
						TE	Acc	Mitigation potential	IL	LoF	Residual risk
			Downstream exposure: Those that apply the compost are exposed to pathogens such as *E. coli* and helminth eggs	Hand to mouth and inhalation	≤45°C for ≤5 days (2 log reductions in bacteria and <1 viable helminth eggs per g dried matter)	3	2	Moderate	4	2	**Moderate risk (8)**
					Advice consumers to wear boots and gloves when applying the compost.	3	2	Moderate			
		Malodours	Exposure to malodours	Inhalation	PPE	2	2	Moderate	2	2	**Low risk (4)**
					Good ventilation of working area	2	3	Moderate			
	Physical	Dust	Long-term exposure to dust	Inhalation	PPE	3	2	Moderate	2	2	**Low risk (4)**
P4: post-treatment	Biological hazards	Pathogens	Downstream exposure: - Accidental intake of contaminated liquid effluent from the plant - Ingestion of produce that is irrigated with unsafe liquid effluent or fertilized with unsafe soil conditioner	Acciden-tal ingestion	Depending on the further use of the outputs of the post-treatment, the following post-treatment options are proposed: Off-site (i.e. discharge): ➢ Drain/transfer effluents/sludge into an existing WWTP for co-treatment ➢ Discharge sludge on landfill On-site (in case of agricultural reuse of the outputs, a combination of the following options will be required for achieving the required quality standard (see table with quality/safety requirements for outputs)): ➢ Septic tank (≥1 log reduction of *E. coli* and ≥2 log reduction in helminth eggs) ➢ Anaerobic baffled reactor (≥1 log reduction of *E. coli* and ≥2 log reduction in helminth eggs) ➢ Anaerobic filter(≥1 log reduction of *E. coli* and ≥2 log reduction in helminth eggs) ➢ Constructed/vertical flow wetland (≥0.5-3 log reduction of *E. coli* and ≥1-3 log reduction in helminth eggs) ➢ Planted gravel Filter ➢ Unplanted gravel Filter ➢ Planted/unplanted drying beds (1-3 log reduction in helminth eggs)						
			Accidental contact with	Hand-to-	PPE	3	3	High	4	2	**Moderate**

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures				Risk assessment		
						TE	Acc	Mitigation potential	IL	LoF	Residual risk
			pathogens while operating the post-treatment components	mouth							**risk (8)**
		Disease vectors	Treatment ponds serve as vector breeding sites	Insect bites	Prevent mosquito breeding in ponds	2	2	Moderate	4	2	**Moderate risk (8)**
Generalities	Various	Various	Input is contaminated with medical waste		In settings where medical waste is disposed of in MSW, this business model is not an option	3	2	Moderate	8	5	**40**
	Various		People from the community access the plant and get hurt, are exposed to pathogens or other hazards	Injury to the body, hand to mouth, inhalation	Restrict access to operations for external individuals	3	3	High	4	1	**Low risk (4)**
	Physical hazard		Workers suffer of musculoskeletal damage due to inappropriate working practices	Injury to the body	Worker education for preventing musculoskeletal damage due to inappropriate working practices	2	2	Medium	4	2	**Moderate risk (8)**

6.1.8 Model 19 – Compost production for sanitation service delivery

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures				Risk assessment		
						TE	**Acc**	**Mitigation potential**	**IL**	**LoF**	**Residual risk**
P1: user interface (urine diversion dry toilets) S1: storage	Biological hazards	Rodents → disease transmissi on	Rodents attracted by organic waste	Hand to mouth, vectors living on rodents	Use of tools	3	3	High	2	2	**Low risk (4)**
		Disease vectors	Flies feeding on organic waste or breed on faecal matter of the urine diversion dry toilets, which can result in disease transmission	Vectors	Screening of storage facility and fly traps on toilets	2	2	Moderate	4	2	**Moderate risk (8)**
	Physical hazards	Sharp objects	**At consumer level:** Exposure of users of the soil conditioner to sharp object (blades, syringes)	Skin contact	Place clearly visible signs on toilets that prohibit disposal of any sharp object and inorganic waste into the toilet	2	2	Moderate	4	3	**Moderate risk (12)**
					Provide trash bins for disposal of sharp objects and inorganic waste components in each toilet	2	2	Moderate			
P2: pre-processing (segregation/ separation)	Biological hazards	Pathogens	Organic waste is contaminated with pathogens deriving from human and animal waste	Hand to mouth	PPE	3	3	High	4	1	**Low risk (4)**
					Use of tools	3	3	High			
					Separation of any components that are contaminated with human and/or animal waste (e.g. diapers, sanitary products). To be discharged into the inorganic fraction and disposed of appropriately.	2	2	Moderate			

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures				Risk assessment		
						TE	Acc	Mitigation potential	IL	LoF	Residual risk
				Inhalation	PPE	3	2	Moderate			
	Chemical hazards	Chemicals	Organic waste is contaminated with toxic matter	Toxic matter	Separation of any waste components that contain (e.g. batteries) or are contaminated with chemicals. To be discharged into the inorganic fraction and disposed of appropriately	3	2	Moderate	2	1	**Low risk (2)**
	Physical hazards	Sharp objects	Skin cuts when handling MSW	Skin contact	PPE	3	3	High	4	1	**Low risk (4)**
					Use of tools	3	3	High			
					Separation of any sharp objects (e.g. razor blades). To be discharged into the inorganic fraction and disposed of appropriately.	3	3	High			
		Malodours	Permanent exposure of workers to malodours	Inhalation	PPE	2	2	Moderate	2	2	**Low risk (4)**
					Rapid processing of MSW after arrival	2	2	Moderate			
P3: pre-processing (settling and drying)	Biological hazards	Pathogens	High loads of pathogens enters the composting process	Hand to mouth and inhalation	Storage treatment at 2-20°C: 1.5-2 years [a]	3	2	Medium	4	3	**Moderate risk (12)**
					Storage treatment at 20-35°C: >1 years [a]	3	2	Medium			
					Storage treatment at pH>9 (alkaline treatment): >35°C; and moisture <25%: >6 months [a]	3	2	Medium			
			Accidental contact while handling the sludge	Hand to mouth	PPE	3	3	High	4	2	**Moderate risk (8)**
					Use of tools	3	3	High			
		Disease vectors	Flies feeding on faecal matter and transmitting	Vectors	Screening of drying beds	3	2	Medium	4	2	**Moderate risk (8)**

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures				Risk assessment		
						TE	Acc	Mitigation potential	IL	LoF	Residual risk
			disease								
P4: co-composting	Biological hazards	Thermophilic fungi and actino-mycetes	Inhalation of airborne spores	Inhalation	PPE	3	2	Moderate	4	2	**Moderate risk (8)**
					Moisture (>40%) control for reducing bio-aerosol emission	3	2	Moderate			
		Pathogens	Exposure to pathogens bound in the organic waste	Hand to mouth	PPE	3	3	High	4	1	**Low risk (4)**
					Use of tools	3	3	High			
			Downstream exposure: Those that apply the compost are exposed to pathogens such as *E. coli* and helminth eggs	Hand to mouth and inhalation	≤45°C for ≤5 days (2 log reductions in bacteria and <1 viable helminth eggs per g dried matter)	3	2	Moderate	4	2	**Moderate risk (8)**
					Advice consumers to wear boots and gloves when applying the compost.	3	2	Moderate			
		Malodours	Exposure to malodours	Inhalation	PPE	2	2	Moderate	2	2	**Low risk (4)**
					Good ventilation of working area	2	3	Moderate			
	Physical	Dust	Long-term exposure to dust	Inhalation	PPE	3	2	Moderate	2	2	**Low risk (4)**

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures	TE	Acc	Mitigation potential	IL	LoF	Residual risk
									Risk assessment		
P5: post-treatment	Biological hazards	Pathogens	Downstream exposure: - Accidental intake of contaminated liquid effluent from the plant - Ingestion of produce that is irrigated with unsafe liquid effluent or fertilized with unsafe soil conditioner	Acciden-tal ingestion	Depending on the further use of the outputs of the post-treatment, the following post-treatment options are proposed: Off-site (i.e. discharge): ➢ Drain/transfer effluents/sludge into an existing WWTP for co-treatment ➢ Discharge sludge on landfill On-site (in case of agricultural reuse of the outputs, a combination of the following options will be required for achieving the required quality standard (see table with quality/safety requirements for outputs)): ➢ Septic tank (≥1 log reduction of E. coli and ≥2 log reduction in helminth eggs) ➢ Anaerobic baffled reactor (≥1 log reduction of E. coli and ≥2 log reduction in helminth eggs) ➢ Anaerobic filter(≥1 log reduction of E. coli and ≥2 log reduction in helminth eggs) ➢ Constructed/vertical flow wetland (≥0.5-3 log reduction of E. coli and ≥1-3 log reduction in helminth eggs) ➢ Planted gravel Filter ➢ Unplanted gravel Filter ➢ Planted/unplanted drying beds (1-3 log reduction in helminth eggs)						
			Accidental contact with pathogens while operating the post-treatment components	Hand-to-mouth	PPE	3	3	High	4	2	**Moderate risk (8)**
		Disease vectors	Treatment ponds serve as vector breeding sites	Insect bites	Prevent mosquito breeding in ponds	2	2	Moderate	4	2	**Moderate risk (8)**
P6: storage and handling of urine and P7: dilution	Biological hazards	Pathogens	Workers are exposed to pathogens present in urine	Hand to mouth	PPE	3	3	High	4	1	**Low risk (4)**
					Avoid any contamination of the urine with faecal matter.	2	3	Moderate			
					Discharge urine that is contaminated with faecal	2	2	Moderate			

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures				Risk assessment		
						TE	Acc	Mitigation potential	IL	LoF	Residual risk
					matter or other solid or liquid waste components.						
			Downstream exposure: The ultimate product of the urine, i.e. fertilizer, is contaminated with pathogens (viruses and protozoa of major concern)	Hand to mouth	The following storage times and temperatures are indicated depending on the use of the urine-based fertilizer: 1) Unrestricted, i.e. all crops: ≥6 month at ≥20°C 2) Food and fodder crops that are to be processed: ≥1 month at ≥4°C 3) Food crops that are to be processed, fodder crops (not grass lands): ≥6 month at ≥4°C 4) Food crops that are to be processed, fodder crops (not grass lands): ≥1 month at ≥20°C	3	2	Moderate	4	2	**Moderate risk (8)**
					Urine should be applied close to the ground or worked into the soil.	3	2	Moderate			
					Recommend workers and farmers to wear PPE when applying the urine-based fertilizer	3	2	Moderate			
					The application of the urine-based fertilizer	3	2	Moderate			

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures				Risk assessment		
						TE	Acc	Mitigation potential	IL	LoF	Residual risk
					should be halted one month before harvesting.						
	Physical hazard	Malodours	Exposure of workers and farmers to malodours	Inhalation	PPE	3	2	Moderate	2	2	**Low risk (4)**
Generalities	Various	Various	Unusual contamination of organic waste	Various	Do not introduce the contaminated material into the system. In case the contamination has been observed at a later stage, discharge any material that was potentially contaminated	2	2	Moderate	4	1	**Low risk (4)**
	Various		People from the community access the plant and get hurt, are exposed to pathogens or other hazards	Injury to the body, hand to mouth, inhalation	Restrict access to operations for external individuals	3	3	High	4	1	**Low risk (4)**
	Physical hazard		Workers suffer of musculoskeletal damage due to inappropriate working practices	Injury to the body	Worker education for preventing musculoskeletal damage due to inappropriate working practices	2	2	Medium	4	2	**Moderate risk (8)**