Exposure Risk Management from Faecal Pathogens for Workers in Container Based Sanitation Systems

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I, Eve Mackinnon, confirm the work presented in this thesis is my own. Where information is derived from other sources, I confirm that this has been indicated in the thesis.

Abstract

This thesis addresses the need for safely managed container-based sanitation (CBS) systems to contribute to the UN's Sustainable Development Goal 6 and explores occupational exposure risk management to faecal pathogens in CBS systems in three Case Studies. A mixed methods approach undertook qualitative and quantitative risk assessment of exposure and associated risk management strategies. The risk assessment adapted and developed the WHO Sanitation Safety Planning (SSP) framework and identifies critical points where control measures are required to manage exposure.

The risk assessments found tangible evidence of occupational exposure risks from hazardous events, such as spillages and blockages of the urine diverter, and subsequent transmission along the CBS system components. Hand and fomite transmission were identified as key exposure points to operators. Frequent handling of contaminated surfaces during collection increased hand contamination. Modelling of hand contamination during collection activities suggested that the operators might be involved in a chain of infection between households, although effective hand hygiene protocols managed the exposure risk. A Cross Case analysis highlighted four causal mechanisms of occupational exposure, namely (1) technical and equipment failures, (2) behavioural failures, (3) system safety failures and (4) environmental/seasonal failures. A formative analysis of the behavioural determinants of safe sanitation management highlighted emotional and ability factors as behavioural determinants that influenced operators' behaviour.

In conclusion, the Case Studies represent the most in-depth empirical study of occupational exposure risks in CBS systems at a level not detailed in the literature to date. The study highlights work-related activities in CBS systems that bring workers into contact with faecal matter and sets out how exposure risk management frameworks can achieve safely managed sanitation. The use of an adapted SSP and a safety performance management framework is demonstrated as an effective risk management tool of CBS systems in order to achieve SDG 6.

Acknowledgements

First, my thanks to my principal supervisor, friend and colleague Dr Luiza C. Campos with whom I have completed this research. Throughout the last three years Dr Campos has not only guided me through the intricacies of research and requirements for the PhD, but has broadened my perspectives through engagement with Beacon Bursaries, SANCOP, WHO and WSUP. These affiliations and experiences brought depth and meaning to the PhD, beyond being a merely academic exercise. I am grateful for the encouragement and guidance, structure and freedom shown by Dr Campos towards the completion of my PhD.

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Impact Statement

This thesis represents a penetrating investigation into occupational exposure along the CBS system using multiple Case Studies as reference. The study, at the minimum, has contributed to a body of knowledge and momentum in positioning CBS systems as a viable alternative to other onsite sanitation systems, which benefit not only the sanitation entrepreneurs, but also the 4.6 billion people who currently lack access to safely managed sanitation services. The research indicates that CBS is not just a "third world solution", while in London it represents a community response to the pressures of urban living.

The empirical evidence generated from the Case Studies highlights an unfinished agenda in ensuring that sanitation service workers are properly protected from the health risks of exposure to faecal pathogens which is of overall importance to the sector. The findings are expected to focus attention on sanitation service workers, where a previous academic focus has been on quantifying the public health risks associated with inadequate sanitation or the public health improvements associated with sanitation interventions. This thesis rightly refocuses attention on the marginalised and informal sanitation workers in low- and middle-income countries (LMICs).

The findings are relevant to sanitation stakeholders at various institutional levels. At its most ambitious, the findings are directly related and of benefit to policy makers and practitioners aiming for targets associated with Sustainable Development Goal 6.2 in delivering safely managed sanitation services. The thesis sets out a framework and associated exposure risk tools for effective monitoring and delivery of safe and sustainable sanitation management of onsite sanitation systems. At the practitioners' level, the thesis presents the methods and findings of the Case Studies to serve as practical examples for CBS service providers to develop their own SSP for future applications and assessment of risks.

The research results have also provided insights into fundamental human behaviour activity in the sanitation services and the LMICs, for which little human–environment data exists, and are of benefit to academic and commercial actors in the sanitation sector.

In terms of personal achievements, the thesis has led to two peer-reviewed publications[1] in international journals particularly well regarded in the sanitation sector. Relevant findings from the

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[1] Papers: Exploring exposure risk and safe management of container-based sanitation systems: a case study from Kenya. Published: *Waterlines* journal
Practice Paper: Classifying Occupational Exposure Risks and Recommendations for their Control in Container Based Sanitation Systems

thesis were published in the national press in an *Independent* article[2] and also in the *Conversation*,[3] an online academic news journal.

The proposal to "Co designing of faecal waste management options on canal boats" as part of the research of sanitation systems in London through engagement with the local community won a public engagement grant in July 2017 from Beacon Bursaries. The funding enabled a workshop event with key stakeholders to discuss the potential scale-up of CBS in Central London along the canal network. A film was also produced and is available to view online.

The thesis overall was awarded an ISTND research award in September 2017. Dr L Campos also addressed the conference and discussed aspects of the thesis under a broader focus of the potential for CBS to contribute to the goals associated with SDG 6.

The 4th Faecal Sludge Management conference was held in Chennai, India in February 2017. I was invited to attend and presented a poster of my thesis during the poster sessions where I could discuss my research directly with sanitation professionals from academic and commercial backgrounds. Attendance at the conference and its sessions provided an important arena in which to discuss aspects of my research and understand its potential implications in a much broader context.

During the thesis period I co-chaired the 19th meeting of the UK's Sanitation Community of Practice Meeting (SANCOP) in April 2017. The aim of the meeting was to develop a shared understanding of container-based sanitation and the use of SSP to improve health outcomes. The meeting attracted over 50 participants and speakers from prestigious universities, private enterprises, government and nongovernmental institutions. I was also invited to present my findings at the 20th SANCOP meeting held in April 2018.

The results from the thesis studies and application of the SSP for performing exposure risk assessment were integral to developing the teaching resources for the WHO SSP CBS workshop in September 2017. In addition, I supported delivery of training sessions on the implementation of the SSP for CBS systems at this workshop.

[2] www.independent.co.uk/author/eve-mackinnon

[3] http://theconversation.com/eco-friendly-composting-toilets-already-bring-relief-to-big-cities-just-ask-londons-canal-boaters-96066

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Abbreviations and Glossary of Terms

CRT	Canal and River Trust
CBSSP	Container Based Sanitation Service Providers
CAQDAS	Computer Aided Qualitative Data Analysis Software
CBS	Container Based Sanitation
CBSA	Container Based Sanitation Alliance
CCP	Critical Control Point
EcoSan	Ecological Sanitation
E. Coli	Escherichia Coli
FIB	Faecal Indicator Bacteria
FPV	First Person Videography
GEMS	Global Enteric Microbial Study
HACCP	Hazard Analysis and Critical Control Points
HSE	Health and Safety Executive
HFE	Human Faeces Equivalents
HID	Human Infective Dose
ISO	International Standard Organisation
KPI	Key Performance Indicators
KRI	Key Risk Indicator
LMIC	Lower Middle Income Countries
MoU	Memorandum of Understanding
MLATS	Micro Level Activity Time Series
NHS	National Health Service

ODK	Open Data Kit
PRSSRA	Participatory Rapid Sanitation System Risk Assessment
PPE	Personal Protective Equipment
QMRA	Quantitative Microbial Risk Assessments
RANAS	Risk, Attitudes, Norms, Abilities, Self-Regulation’
RoV	Rotaviruses
SPI	Safety Performance Indicators
SS	Sanitary Surveys
SSP	Sanitation Safety Plans
STH	Soil Transmitted Helminth
SOP	Standard Operating Procedure
STOPP	Substitution, Technical, Organisational, Personal Equipment, Personal Behaviour
SDG	Sustainable Development Goals
THOR	The Health And Occupation Reporting
TRA	Theory of Reasoned Action
UDDT	Urine Diversion Dry Toilet
WASH	Water, Sanitation and Hygiene
WTNIS	Wherever The Need India Services
WISE	Work Improvement in Small Enterprises
WHO	World Health Organisation

1. Introduction

1.1. Purpose of the Study

This study examined the potential occupational health risks, in particular to workers, arising from the exposure to faecal pathogens in container-based sanitation (CBS) systems. The study sought to identify the nature of occupational exposure risks and management strategies in the CBS systems studied, and identify patterns and themes; but it was not intended to provide a generalised risk assessment that can be applied to all CBS systems. The examination of exposure and risk was intended to develop a framework for the identification, assessment and management of health risks in CBS systems. The exposure risk framework is expected to be of value to sanitation policy and practice in the implementation of safe and sustainable CBS systems.

1.2. The Sanitation Challenge

A global sanitation crisis exists that refers to 2.4 billion people without access to a basic sanitation facility and a further 4.6 billion people without access to a safely managed sanitation facility (WHO/UNICEF 2015a). The consequence of inadequate sanitation is uncontained and untreated human excreta containing potentially pathogenic microorganisms that escapes untreated into the external environment and leaves individuals vulnerable to exposure. A substantial negative impact on mortality and morbidity is attributed directly to poor sanitation, particularly in low- and middle-income countries (LMICs) in Africa and Southeast Asia (WHO 2014). Exposure to faecal pathogens from the absence of, or poorly managed, sewered sanitation (Cairncross et al. 2013) has important and multiple negative health consequences, including infant mortality, stunting and chronic health diseases, while constraining social and economic development (Garenne 2010; Ngure et al. 2014; Humphrey 2009; Masibo and Makoka 2012). On the other hand, global meta-analyses demonstrate a positive correlation between access to improved sanitation and reduced disease burdens, notably diarrhoeal disease (Davidson et al. 2005; Norman et al. 2010).

The global disease burden caused by inadequate water, sanitation and hygiene (WASH) provision is put at 64.2 million disability-adjusted life years (Cairncross et al. 2013). Yet it is not just diarrhoeal diseases: the global health burden from enteric infection may be underestimated as it fails to account for other health impacts resulting from repeated or low-level exposure to pathogenic agents and asymptomatic infection (Petri 2008). Environmental enteropathy (Ngure et al. 2014) results in symptoms of infection generally milder than other enteric infections but linked to chronic and serious long-term health complications such as growth shortfalls, stunting, malnutrition and poor cognitive development. Today, with emerging understanding of the developmental origins of health and diseases (Bartelt et al. 2013), these may have lasting effects on development and lifelong risk for chronic metabolic noncommunicable diseases (Wells 2016). Finally, sanitation is a human right and is related to important and often overlooked aspects of wellbeing (Greif and Nii-Amoo Dodoo 2015), dignity, gender equality (Montgomery et al. 2012; Corburn and Hildebrand 2015; Olusanya, Alakija and Inem 2010; Stockman et al. 2007; Wilunda, Massawe and Jackson 2013; Peletz et al. 2011) and income generation. There is a known link between the risk of sexual violence to women and access to sanitation (Gonsalves, Kaplan and Paltiel 2015).

This current crisis is coupled with the high population density in urban areas (O'Keefe et al. 2015) and rapid urbanisation and population growth that is projected to add 2.5 billion people to the urban population by 2050 (Alirol et al. 2011). Municipal sanitation systems are already failing to cope with the rapid urbanisation experienced in some countries (Moe 2000). Slum dwellers are particularly vulnerable due to high levels of environmental exposure faced in these conditions (Cairncross et al. 2013). Nearly 90% of the expected population increase is concentrated in Asia and Africa; continents that lack the institutional capacity to deal with the additional pressures of urban planning and provide sanitation infrastructure (Strauss and Montangero 2002). Moreover, the conventional solutions to urban sanitation, such as pit latrines and "open defecation free" campaigns, are failing to stem these issues, which are already profoundly affecting human health. Unconventional solutions to address the need for safe sanitation management, in particular in urban contexts, are urgently required, but, as yet, they remain unexplored beyond a few pilot or small-scale scenarios. This gap in knowledge may play a role in the preclusion of alternative sanitation solutions such as CBS systems within proposals for national urban sanitation planning policies.

1.3. Sustainable Development Goals

Given the negative impacts of future scenarios, there is an urgent need to respond with innovative approaches and technologies to scale up sanitation access (O'Keefe et al. 2015), particularly in urban areas. The Sustainable Development Goals (SDGs) (UN 2015) aim to reduce poverty, contribute to sustainable livelihoods and build healthy and resilient environments and ecosystems by 2030. Safely managed sanitation systems are a key aspect of SGG 6 which integrates these three aims to achieve universal water and sanitation access (Roche, Bain and Cumming 2017). To address the targets set by the SDGs will require an enormous scale-up of safely managed sanitation services (WHO/UNICEF 2015b). Effective monitoring and reporting changes are recommended to address areas of most need (Roche et al. 2017).

1.4. Container-based Sanitation

The sanitation sector is rapidly changing, with private sector organisations developing sanitation services in the underserved communities across the globe. The growth of the private sector offers an alternative approach to sanitation services encouraged by the growth of public–private partnerships (Tremolet, Prat and Monsour 2014). However, the role of the private sector may undermine the municipal commitment to sanitation provision required for sustainable solutions (Osumanu 2008). CBS is an innovative, and primarily private sector led, response to providing sanitation access to (primarily) urban and unserved communities. CBS is described as a modular, unsewered sanitation system, where excreta is collected and transported to offsite treatment facilities (Tilley et al. 2014). CBS systems are not simply a single sanitation technology or facility but represent an approach to urban sanitation provision, where waste is stored, collected, transported, treated and disposed of. However, the institutional frameworks that oversee citywide sanitation planning and associated regulatory frameworks and guidelines have not facilitated the uptake of CBS systems in the recent past. Only in Kenya has CBS gained any official recognition as a safe and cost-effective alternative to sewers or onsite sanitation systems (GoK Ministry of Health 2016).

1.5. Problem Statement and Research Approach

Plausible health risks to workers in CBS systems are due to exposure to the same plethora of pathogenic microorganisms that cause significant public health issues attributed to poor sanitation. Work activities in sanitation systems bring workers into contact with human excreta and faecal sludge products faecal pathogens and potential exposure (HSE 2011). The indicators for SDG 6 also encompass the need to ensure that populations have access not only to adequate sanitation but that these services are safely managed; with safely managed sanitation representing a new and highest rung on the sanitation service ladder.

The study area will be focused on the potential risk of occupational exposure to faecal pathogens and the management of such risks. The study will concentrate on mechanisms of exposure that occur during the work-related activities in three system components, namely collection, conveyance and treatment processes. The study will also investigate the role of influencing factors on exposure risk, such as a variety of biological, physical, institutional and technical factors or risk "drivers" (Defra 2011). These factors vary through time and space and affect change to the hazard (Few, Lake, Hunter et al. 2013) and must be considered during the analysis to make a meaningful assessment of risk (Defra 2011). For instance, the pathogen concentration in excreta is influenced by the prevalence of infectious enteric diseases in a population from which waste is collected and the efficacy of treatment processes. The individual behaviours and activities associated with waste handling and/or transportation and/or processing influence the timing, intensity, extent and duration of hazardous events and human exposure along pathogen-specific transmission routes, such as handwashing or compliance with hygiene protocols. Meanwhile, the vulnerability of the individual following exposure is affected by resistance and/or susceptibility of the host according to age, immunity and other internal factors. Thus, the health risks to operators along the CBS system arising from exposure to faecal pathogens are a function of:

- The type and quantity of pathogenic microorganisms in excreta (incidence/prevalence of infectious disease in the community/treatment efficacy)
- The physical design and infrastructure of equipment/facilities
- Operational practices and individual behaviours, in particular attitudes to risk/compliance
- The local environmental seasonal factors such as flooding, climate and terrain
- The immunity and resilience of human hosts affecting vulnerability and susceptibility to infection following exposure.

CBS systems represent complex sociotechnical systems (Leveson 2012a) and no study of risk could attempt to standardise the exposure risks or variables that exist. The studies described represent "snapshots" in time of the exposure risks responding to specific processes and context. The interpretation and analysis of the results must be viewed with caution, in full recognition of the complexity and its dynamics.

1.6. Exposure Risk Assessment

Exposure risk assessment is a management tool for the measurement of risk, prioritisation of risk and informs decision making in risk management (Haas 1999). Effective risk assessment requires an understanding of how exposure arises. Inspired by the concept of source, pathway, receptor (Broomfield et al. 2010) relationships in environmental risk assessments, a simple model of exposure identifies the components and pathways of exposure expected in a CBS system (Figure 1). In this model, the hazard is the microbiological agent with potential to cause harm (Treby, Clark and Priest 2006; Bartram, Fewtrell and Stenström 2001). The source illustrates where microbial hazards are released during hazardous events and result in receptor (occupational) exposure due to transmission along pathways. Risk assessment involves the assessment of the likelihood and severity of health risks defined as "the likelihood of identified hazards causing harm in exposed populations in a specified timeframe, including the magnitude of that harm and/or the consequences" (Davidson et al. 2005).

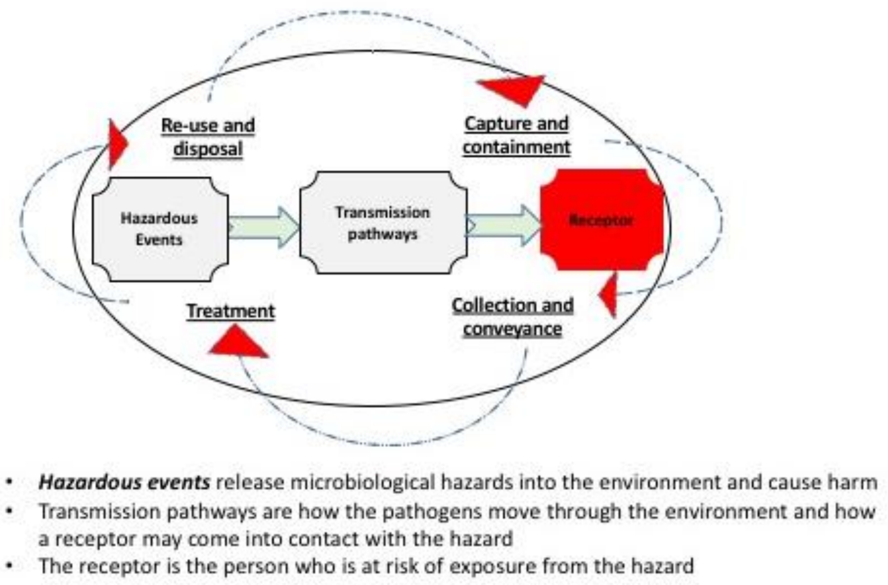

Figure 1 The source, pathway, receptor model of exposure and approach to risk assessment (Broomfield et al. 2010)

The risk assessment process therefore seeks to understand the components in a CBS system:

- The presence of faecal pathogens
- How operators become exposed to the hazard
- The nature of hazardous events and the likelihood of their occurrence
- Given the likelihood of hazardous events and hazards in the environment, what are the potential consequences in terms of health?
- The significance of the risk, given the likelihood and consequences of the event occurring.

The formal use of risk management tools in the CBS sector is growing in significance, notably the application of Sanitation Safety Planning (SSP) (WHO 2016), the development of CBS industry standards (ISO standards) and standard operating procedures (SOPs) (IWA 2016). There is acknowledgement of the need to proactively manage occupational exposure to excreta-related pathogens that arise across sanitation systems. Meanwhile, there is a lack of sector-wide assessment tools and indicators for organisations to assess their performance against in terms of managing such exposure risks.

1.7. Research Gaps

Current evidence of occupational health risks associated with the operation of CBS systems is not extensive, given the infancy of these sanitation solutions. There is only one empirical study considering exposure risks to pathogenic faecal microorganisms associated with the use and operation of CBS (Russel et al. 2015); however, this is concerned with users of the CBS system and not operators.

Occupational exposure studies are either related to the risks associated with emptying pit latrines (Buckley et al. 2008) or comparisons of different sanitation technologies. Quantitative microbial risk assessments (QMRA) estimate the disease burden related to faecal sludge and wastewater used in agriculture, or exposure studies related to the impact of sanitation interventions through different exposure pathways (Drechsel et al. 2008; Katukiza et al. 2014). There is a knowledge gap considering the potential occupational health to workers in the sanitation sector and, in particular, within CBS systems. Given that human excreta contains pathogens, there is an inherent risk to operators who engage in work-related activities that bring them into contact with human excreta. However, the need to scale up sanitation services requires innovative and unconventional solutions to sanitation, such as CBS, while managing the potential risks that occur along the entire CBS value chain. Currently, there is little evidence available from a risk management perspective to inform relevant indicators and thresholds to deliver safely managed sanitation. Ensuring sanitation is safely managed and sustainable will thus require additional tools and frameworks, as well as evidence that points to the correct risk management strategies.

1.8. Research Aims and Objectives

To achieve SDG 6 and related goals will require a scale-up of current sanitation services. As the SDG targets emphasise, it is important that sanitation services are safely managed along the entire value chain to maximise the health benefits associated with access to sanitation (DESA/UN 2016). The overall aim of the research is to identify occupational exposures and develop a health risk management framework relevant for the operation of CBS systems.

To unpack this overarching aim of the research there are two separate research objectives set out below and are explored through associated sub-questions and supporting hypothesis:

The first objective is to describe and explain occupational exposure risks to faecal pathogens that arise during the operation of CBS systems and the second objective is to develop an appropriate risk management framework and risk management tools adapted for CBS systems to support occupational exposure risk management.

Objective One:

Sub-question 1: What are the occupational exposure risks in CBS systems and is it possible to classify causes and controls of occupational exposure risks in the CBS systems studied?

Hypothesis:

There is little evidence of occupational exposure in CBS and the main drivers of exposure risks as current sanitation research has focused extensively on exposure risks to wastewater and wastewater treatment. Understanding the causes of hazardous events and associated control measures is an important aspect for safely managed sanitation.

Sub question 2: To what extent is hand contamination of operators with faecal pathogens a significant transmission pathway of faecal pathogens associated with occupational exposure risks?

Hypothesis: Since sanitation and faecal sludge management are dominated by a reliance on manual handling, with frequent hand contact with contaminated objects, hands play a key role in transmission of faecal pathogens and to the successful management of occupational exposure risks in CBS systems.

Sub Question 3: What are the determinants of operator behaviour and safe sanitation practices linked to occupational exposure?

Hypothesis: Behaviour is linked to processes and assumptions (behavioural determinants) that occur in the mind and drive resulting behaviours. Managing and controlling behaviours first requires an understanding of the determinants that drive desired or undesired behaviours.

Objective Two:

Sub Question 1: What is a suitable risk assessment framework to obtain robust information to inform organisations and managers how to suitability manage risks?

Hypothesis: Workers perceptions of risk reflect real situations and should be included within a measure of occupational risks. Additional information should be derived from more 'objective' understanding of microbial exposure and behavioural surveys.

Sub Question 2: What are the key principles of an occupational exposure risk and management framework for CBS systems?

Hypothesis: Current exposure risk management framework for CBS systems do not reflect the important causal mechanisms for occupational risks. Indicators for the management of worker safety should be linked to causal mechanisms (sub question 1) and be able to cover all aspects of the CBS systems and be easy to adapt to the local context and simple to understand and measure.

Safe sanitation management manages faecal waste safely along all parts of the sanitation value chain and prevents exposure to faecal pathogens to users, operators, workers and community members. The sanitation industry lacks regulatory or institutional support in the form of clear guidelines and supporting documents to carry out safe sanitation management. Since sanitation and faecal sludge management are dominated by a reliance on manual handling, guidelines are required to ensure that manual workers engaged in the operation of CBS systems are not at risk. The research provides a starting point for a risk assessment framework that will identify and mitigate exposure risk in CBS systems and may guide the scale-up and implementation of CBS systems. This research will characterise the occupational exposure risks leading to recommended control measures to mitigate these exposure risks in CBS systems and ensure a safe working environment.

The two objectives and associated research questions characterise the causal mechanisms and pathways that contribute to exposure risk and management frameworks during the operation of CBS systems. The Case Studies provide an opportunity for the observation and assessment of exposure risk management In doing so, new insights may be generated on how to apply and adapt the risk management frameworks for CBS systems.

2. Literature Review

This thesis is principally concerned with the management of occupational exposure to microbial hazards in faecal and urine waste during work activities undertaken in the operation of CBS systems. There is a vast body of literature exploring the links between exposure to faecal pathogens in the environment and subsequent human health effects. While the sanitation sector is actively involved in research regarding public health risks, policy and the implementation of interventions to reduce environmental exposures, occupational exposure in sanitation has only slowly been growing as a focus for policy and research in recent years.

The literature review comprises four parts:

- The first section presents a conceptual model of exposure risk as a basis for the study and literature review.
- The second section describes the principles and current scope of CBS from a global perspective with particular emphasis on operations and safe management. The role of operators in CBS systems is detailed considering the focus on occupational health risks from exposure.
- The third section evaluates the published literature in terms of occupational exposure risks from exposure to faecal pathogens in related industries and establishes the current understanding of microbiological hazards and associated pathologies arising from exposure to faecal pathogens, mechanisms of exposure and relevant risk factors.
- The final section of the review landscapes relevant risk assessment and management frameworks. By expounding on a number of existing risk frameworks and approaches to risk management, integrative thinking is stimulated towards better risk management solutions.

2.1 Conceptual Model of Exposure Risk

Exposure results when people come into contact with something that causes harm (Broomfield et al. 2010). Chapter 1 established a generalised conceptual model of exposure risk – the source, pathway, and receptor model (Figure 1). Without these relationships exposure cannot occur. Exposure is a continuous variable and, as Julian (2016) notes, exposure does not equal infection. Infection, in contrast, is a binary response to exposure, meaning you either become infected or not (Julian 2016). However, reducing opportunities for exposure or severity of exposure will reduce the likelihood of infection.

In this study, exposure risk refers to the likelihood of negative health impacts produced from exposure to faecal pathogens via transmission pathways. The magnitude of exposure along the continuum is thus shaped by a number of social and technical factors arising in the specific context of CBS systems. A sociobehavioural analysis of disease risk considers the role of human agency and the structural contexts in which that behaviour is embedded and how it affects the way people perceive and respond to health risks (Curtis 2011). A comparable recognition of the social and behavioural aspects of exposure is represented by technical and non-technical components of the exposure risk assessment framework developed by Stenström and colleagues (2011) that govern the likelihood and severity of exposure, across the five functional sanitation groups, comparable to the five components in CBS systems. The technical components of the risk assessment refer to pathogen inputs and variability determining exposure risks, while the individual behaviour and perceptions of risk and broader cultural behavioural norms define exposure at particular points in the system components related to hazardous events and transmission pathways (Stenström et al. 2011). The conceptual model of exposure risk in CBS systems must be able to account for the complexities of biological, technical, behavioural and sociocultural factors that influence the likelihood and severity of exposure. The initial conceptual model developed here is a tentative theory of exposure risk to operators in CBS systems. It follows the activities of sanitation service operators along the CBS sanitation chain and considers points of exposure where operators may be exposed to faecal pathogens when hazardous events occur. Figure 2 specifies a number of factors that exert their influence on the nature of the hazard and on the likelihood and severity of exposure (Bartram, Fewtrell and Stenström 2001) and illustrates a range of transmission pathways by which exposure results and goes beyond the guidance in the WHO SSP (WHO 2016). The current CBS models (Russel et al. 2015; Nelson, Mcgillicuddy and Snyder 2014) require operators to enter households to remove full collection containers of excreta with implications of extensive contact with potentially contaminated surfaces for the sanitation workers. Understanding specific exposure pathways is a vital component of exposure risk management and therefore the conceptual model of exposure includes contact fomites (surfaces) as a standalone exposure route to fully manage risks. The conceptual model provided the basis for the literature review, methods and analytical aspects of data collection and was the starting point for the elements of data collection in this study. The conceptual model guided thinking around risk assessment framework and management.

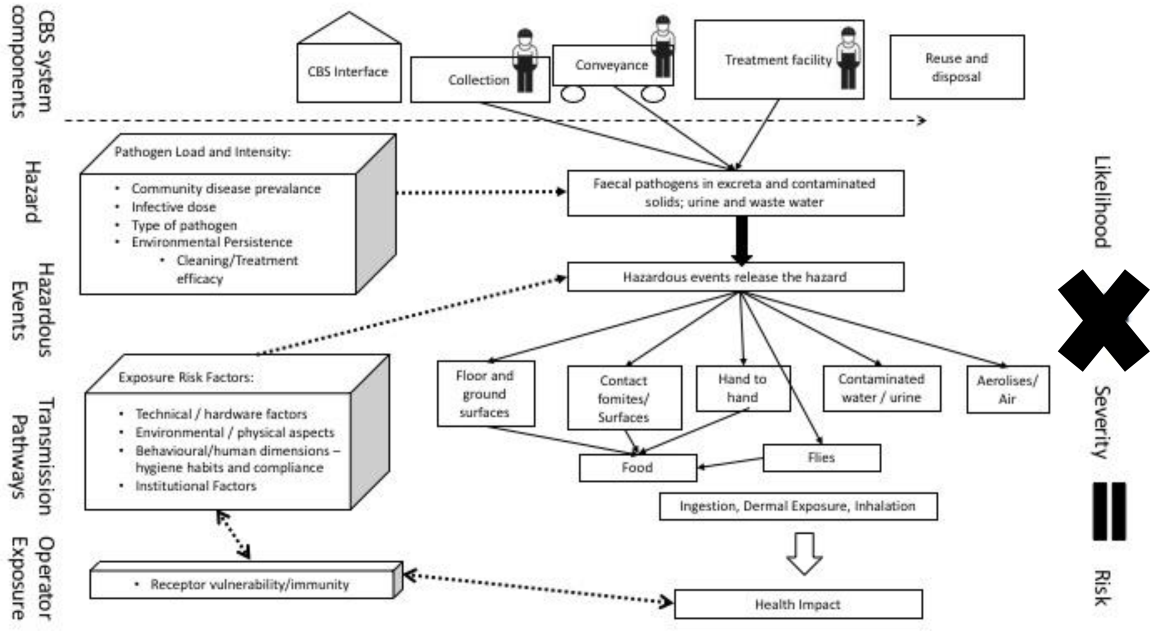

Figure 2 Transmission of pathogens in CBS systems showing key hazard, pathway, receptor relationships and risk factors

The individual CBS system components are expected to be highly heterogeneous in terms of pathogen inputs, exposure groups and activities undertaken, given the geographical and social diversity inherent in any system globally represented. The review encourages an extensive understanding of processes and operations in each system component to properly understand the potential health impacts arising to operators. The review of the literature establishes the current understanding of CBS system components and drives the risk assessment in the Case Studies to focus on operator risks in the collection, conveyance and treatment system components. The relationships between hazard, hazardous events and transmission pathways are highly relevant to explore for exposure risk assessment in CBS. The important risk factors that influence the presence of pathogens in faecal matter related to the microbial hazard are reviewed. The risk factors that affect hazardous events and transmission pathways are gathered together and relevant evidence is reviewed.

2.2. Container-based Sanitation Systems

CBS is an innovative technology that has emerged as a solution for the provision of low-cost sanitation services to populations without safely managed sanitation, in particular those communities presently unserved by sewered connections (WSUP/EY 2017; "Container-Based Sanitation" n.d.). CBS systems are an innovative sanitation solution for managing human waste (excreta and urine) through the safe containment, collection and transportation in portable and sealable containers for treatment in a central facility (Tilley et al. 2014; Russel et al. 2015). A variety of CBS systems exist that offer primary barriers in the prevention of human faecal matter entering the environment principally through the safe containment and safe treatment of excreta. The *Compendium of Sanitation Technologies in Emergencies* cites a variety of technologies under the CBS umbrella ranging from buckets lined with plastic bags to sophisticated designs that separate urine and faeces at the point of use (Gensch et al. n.d.; Tilley et al. 2014). However, some of the fundamental principles shared by CBS systems are:

- A system approach that consists of "modular" components, meaning the system can be adapted to different contexts
- Human waste is temporarily stored in removable and sealed containers which are removed to a treatment facility (Guidelines and Camps, n.d.)
- Waterless operation (except that required for handwashing and anal cleansing)
- Separation of excreta and urine at point of use (but not always)
- Human waste is effectively isolated from the external environment (distinguished from onsite sanitation facilities like pit latrines/EcoSan/septic tanks).

However, the aspect of manual collection of excreta conducted in CBS has drawn negative connotations with models of excreta management such as manual scavenging (Wikipedia n.d.), "bucket latrines" and "pail systems" (Tilmans et al. 2016) and implied a negative image of CBS systems. Bucket latrines were initially considered an improvement on pit latrines, but the promotion of such sanitation technologies was opposed due to severe concerns regarding public health risks. In particular, these manual waste disposal systems were labour intensive, unhygienic and lacked social and moral acceptability (Nilsson 2016). Spillages were often an issue and unregulated disposal led to public health issues. Although CBS shares manual operation and containers to collect, store and transport waste, the distinction of CBS systems from these earlier sanitation models is made in the literature by reference to "procedures that isolate human waste from exposure to humans by measures through the system chain" (Tilmans et al. 2016). However, the *specific procedures* through the system that ensure isolation from human exposure are not referred to by Tilmans et al. (2016). The WHO recently recognised CBS systems as an improved onsite sanitation facility, comparable to ventilated improved pit latrines, pit latrines and pour flush systems (WHO 2017). Figure 3 adapts this WHO classification to include CBS systems within both networked and on-site classifications depending on the location for the final waste treatment. It may be argued that CBS systems where faecal/urine/contaminated products are collected and transported to off-site treatment systems essentially represent a 'network'. The more important point is that 'improved' does not necessarily mean 'safe' and there is a lack of published literature documenting how such procedures isolate humans from exposure. This clear gap in the literature is one of the key objectives this study addresses.

	Sanitation
Improved Facilities	**Networked sanitation** • Flush and pour flush toilets • Container based sanitation with a home-based collection service provided where waste is taken offsite for final treatment **On-site sanitation** • Flush and pour flush toilets or latrines connected to septic tanks or pits • Ventilated improved pit latrines • Pit latrines with slabs • Composting toilets, including twin pit latrines • Container based sanitation with home composting system for waste treatment

Figure 3 Integration of container-based sanitation within the Joint Monitoring Programme classification of improved toilet facilities (adapted from WHO 2017)

2.2.1. Differences with EcoSan

CBS is often compared with ecological sanitation (EcoSan), although there are some important differences. EcoSan refers to the capture of the nutrients contained within human excreta and urine by managing the containment and collection of human waste matter. CBS systems may follow the principles of EcoSan; but the reuse of the faecal sludge or urine by way of composting is not exclusively followed by CBS systems. EcoSan is a very old technology – it was historically termed "night soil collection" and practised across the Middle East/Asia. In Kabul traditional sanitation systems involved double vault above ground latrines and the solid waste was collected by "night soil collectors" for use in agriculture (Patinet 2012). Concerns about the hazards and management of faecal matter in urban environments led to the intensive infrastructure wastewater treatment plants to remove the waste (Piceno et al. 2017).

2.2.2. Organisation, Scope and Growth of CBS Operations

The CBS system is applied in a number of locations by a small group of CBS service providers (CBSSP) across the world (Figure 4), typically in countries with inadequate access to basic sanitation services. The CBS technology was formally developed in 2010 in Nairobi, Kenya in partnership with Oxfam and Sanergy, a private sector organisation (Oxfam 2016). From there, an alliance of six CBS organisations now exists the Container Based Sanitation Alliance (CBSA) to share "best practices" and support the sector (Figure 4). Kildwick is not a member of the CBSA but is a CBS manufacturer based in the UK that supplies CBS hardware for various onsite situations, including canal boats and other off-grid communities in the UK (Kildwick n.d.). Other groups affiliated to the CBSA include Sanitation First, Re:Source, MoSan and Sumaj Huasi (CBSA n.d.). Mostly, these organisations were independently set up to fill service gaps and in most cases with limited interaction with mandated service providers or local authorities (personal communication World Bank).

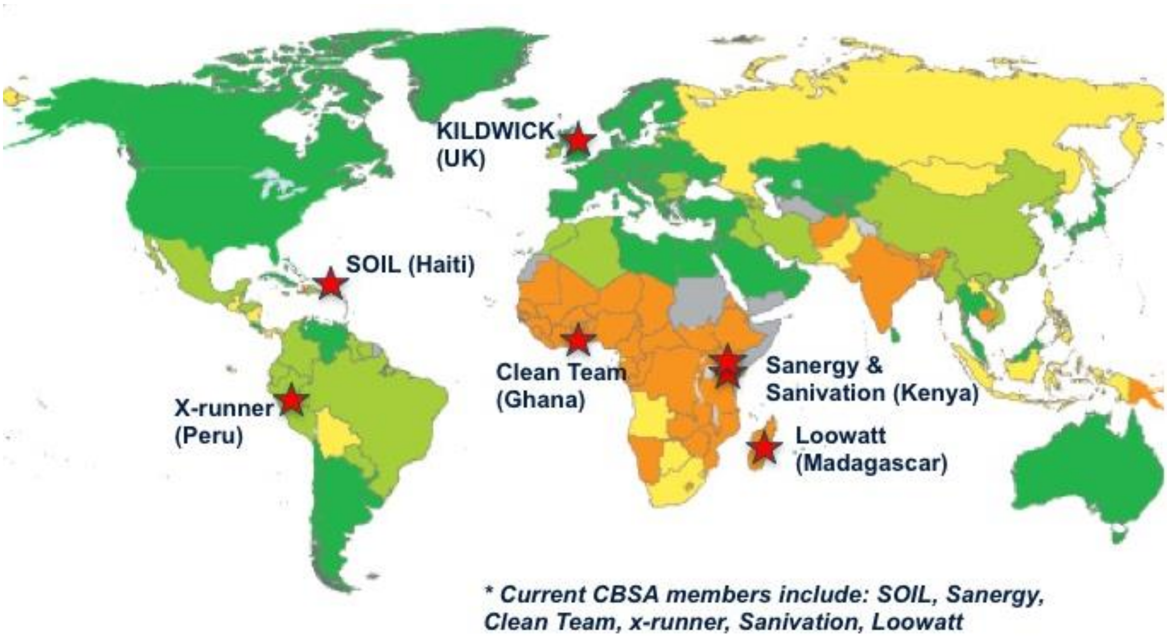

Figure 4 Mapping of CBSSP

Most of the CBSSP are still at a relatively early stage of development in terms of numbers of persons served or waste processed: in fact, there is no published data available on volumes of waste transformed or treated in CBS systems. A 2019 World Bank report evaluated the current scale of CBS as almost 4,000 CBS toilet units installed and over 50,000 people served by CBS systems (World Bank 2019).

There is also similarity to 'port-a-loo' rental companies which provide temporary sanitation solutions for construction sites and music events. LooWatt who are members of the CBSA and provide a CBS service in Madagascar also have a UK based operation providing technically similar sanitation services at music festivals. The provision of sanitation services in the UK is regulated by the Environment Agency (EA), including specific permits and licenses to transport hazardous waste for treatment. Typically, such sanitation/toilet providers in the UK do not perform any treatment of faecal sludge, instead they use a municipal treatment plant for treatment of waste using an anaerobic digester (LooWatt use Thames Water plant pers. comm). The treatment and processing of faecal sludge in the UK is subject to strict, environmental permits, regulations and legislation that are underpinned by statutory instruments (Environmental Permitting 2007) and a number of European Directives (EA 2013). The scope of these regulations does make it difficult for smaller providers to comply with. However, such regulations offer potential benchmarks for CBS systems under development. For instance, composting systems must obtain a PAS 110 certification, whilst, the activities, installation and treatment of faecal sludge must comply strict statutory regulations and environmental permits (Environmental Permitting 2007).

The basic model of CBS is being operated and applied by various CBS organisations, and is typically provided as a commercial service to private households. However, the organisations and service provision are differentiated by 1) type of toilet interface used, 2) commercial service and 3) treatment process and reuse applications. Table 2.1 presents the main attributes of the six principal CBS organisations in the CBSA, where data was available.

Table 2.1 Summary of aspects of CBS system components including location, users, types of technology, service delivery and treatment or reuse options

Service provider	Sanivation	Sanergy	Loowatt	Sanitation First	x-runner	SOIL	Clean Team
Service name	Blue Box	Fresh Life	Loowatt	GroSan	x-runner	Ekolakay	Clean Team
Country	Kenya	Kenya	Madagascar	India	Peru	Haiti	Ghana
City	Naivasha	Nairobi	Antanaviro	Puducherry	Lima	Cap Haitian	Kumasi
				Chennai		Port-au-Prince	
Private/public	Private	Public	Private	Public	Private	Private	Private
Commercial service	Yes	Yes	Yes	No	Yes	Yes	Yes
Total # units	100	>1,000	n/a	41	654	>1,000	>1,000
# of users/unit	5 or less	>40	5 or less	>40	5 or less	5 or less	5 or less
# population served	500	40,000	n/a	1,640	3,270	5,000	5,000
Anal cleansing	Wipe	Wipe	Wipe	Wipe	Wipe	Wipe	Wipe
Source separation	Yes	Yes	No	Yes	Yes	Yes	Yes
Collection model	Operators	Operators	Operators	Operators	Users and operators	Operators	Operators
Treatment process	Pasteurisation	Pasteurisation	Anaerobic digestion	Thermophilic composting (TC)	TC	TC	Municipal treatment plant
Reuse	Fuel briquettes	Soil conditioner/animal feed	Soil conditioner/energy	Soil conditioner	None	Soil conditioner	None
Internet reference	(“Sanivation” 2019)	(“Sanergy” 2019)	(“Loowatt” 2019)	(“Sanitation First” 2019)	(“X-Runner” 2019)	(“SOIL” 2019)	(“Clean Team” 2019)

CBS systems address many of the issues of the global sanitation crisis to increase access to sanitation and provide faecal sludge management. Some of the key advantages are:

- Very low space requirements and well adapted to urban environment.
- Financially attractive, based on life cycle cost-based analysis preferential to alternative systems (United Nations High Commissioner for Refugees 2015).
- CBS systems address the whole service chain from containment to disposal, yet as a modular system additional activities can be bolted on when required.
- Urine and excreta can be extracted as a valuable resource for post processing commodities.

However, some key challenges to the implementation of CBS include:

- Considerable behaviour change required to address issues surrounding users' and households' acceptance; men are often more reluctant to adopt and smell is often cited as an issue.
- Affordability in terms of scale and piloting.
- Ensuring service is safely managed, and little research indicating health risks from CBS, in particular for occupational exposures.
- Lack of standardised approaches or regulatory frameworks is a barrier to scaling up the service.
- Implementation is linked to institutional buy-in, which can be a frustration to scaling up the service. Sanitation First has experienced recent challenges in CBS deployment in Chennai, India due to the perception of it as an "old technology" (personal communication CEO Sanitation First). Similarly, in Ghana, CBS systems had to overcome the idea that they were related to bucket latrines which had previously been banned (Boot and Scott 2009).

2.3. CBS System Components and Operations

The available literature refers to five components that make up a CBS system (CBSA n.d.): (1) containment, (2) collection, (3) transport, (4) treatment and (5) reuse/disposal, as shown in Figure 5 below. This study intends to focus on the first four components, namely containment, collection, transport and treatment.

Figure 5 System components of CBS

Each component in CBS is described referring to the current literature, and where relevant the procedures for safe containment and isolation of waste from human exposure will be referred to. More broadly, the sanitation sector typically includes containment in the second component of collection and refers to the first component, or "functional group", as the "user interface" (Gensch et al. n.d.; Tilley et al. 2014; Stenström et al. 2011). However, to align with the CBS sector and CBSA the thesis will refer to containment as the first component that includes the user interface.

The draft ISO standard ISO/PC 305 for "Non-Sewered Sanitation Systems: General safety and performance requirements for design and testing" (IWA 2016) describes the safety standards defined for non-sewered sanitation systems and is relevant to aspects of the CBS system. However, the ISO standard PC 305 is specific for technologies that treat faecal and urine waste on site and does not refer to collection, transport or treatment of waste off site. Moreover, the ISO is not yet finalised or adopted by CBS service providers.

2.3.1. Containment

The first component, containment, also referred to as the "user interface" or "front end",[4] is the point of use where users interact with the toilet for defecation and urination. It consists of the toilet unit and the collection containers (also known as cartridges) which collect human faecal and urine products. The design of toilet unit installation is either a pedestal or squatting plate. This allows the user to squat (Photo 2.1), sit, or adopt a saddle back position depending on cultural preferences (Photo 2.2). The use of a urine diversion dry toilet (UDDT) (Tilley et al. 2014) is typical in all but one (Loowatt) of the

[4] Front end and back end refer to the IWA definition of container-based sanitation

CBS systems reviewed here. UDDT toilets are “source-separated”, referring to the separation of excreta and urine at the point of use. Loowatt has developed a patented toilet technology that collects both urine and excreta together in the same receptacle. Urine may be diverted into the immediate environment or may be transported at the same time as the faecal matter.

Photo 2.1 Squatting plate

Photo 2.2 Sitting pedestal

The choice of materials depends on a range of factors such as customer preferences, production capability and financial capital and operating costs. The ISO standard defines material requirements including the cleanability of surfaces, hygienic design and watertightness and general safety design to ensure the structural integrity of the toilet units (IWA 2016). Cleanability of surfaces of toilet units is defined by the International Organization for Standardization (ISO) standard as “equal to or exceeding that of a No. 3 (100 – 120 grit) finish on stainless steel” (IWA 2016). Cleanability is an important aspect of equipment design from a safety perspective and is also impeded by common design faults such as poor accessibility, inadequately rounded corners, sharp angles and dead ends (Huss and Ryder 2001). Where CBS toilets are shared, cleaning responsibilities can be hard to assign (Nyoka et al. 2017), which has potential impacts for levels of hygiene at the toilet. In certain contexts, such as healthcare facilities, cleaning is carried out either by users or paid cleaning operatives, where compliance with mandated cleaning routines is more appropriate (WHO 2017).

At present, depending on the particular CBS providers, a massive variety in types of design of CBS units and materials from which they are constructed exists. Some are locally made with local materials such as wood or ferro-cement (SOIL), or are imported pre-moulded plastic units (Sanergy). The containers for waste collection are also variable; the capacity of the solid and liquid waste containers varies from 20–208 litres, and construction materials are generally plastic – but different grades of plastic are used that affect the lifetime of the units (Sanitation First). Waste is either directly deposited into collection containers or into internal liners for solid faecal products made from plastic polymers or biodegradable (Photo 2.3).

Photo 2.3 Biodegradable solid tank bin liners (photo courtesy of Kildwick)

The primary inputs to the CBS system are human excreta and urine, as well as a “cover material”, which is added to the raw excreta to mask odours and prevent flies being attracted to the toilet unit. There will also be menstrual blood, bile, toilet paper or other anal cleansing water. The ISO standard states that mechanisms for disposal of menstrual products should be included in the design of the system (IWA 2016). As a dry toilet system, CBS systems do not require water to operate, which is a distinct advantage for their deployment in water restricted environments. The potential for malodours during containment exists and the ISO standard again refers to requirements to minimise odour emissions. The operation of CBS systems is currently adapted for use at a household level or for use as shared or public “pay-for-use” toilets.

2.3.2. Collection

The removal and collection process in CBS systems involves the removal of the sealed containers with urine or excreta and their replacement with clean, empty containers. This manual process is performed either by service personnel operators as part of a paid for service (Sanivation), or, in some instances, by users who then transfer full containers for transport to treatment sites. Collection activities provide jobs for the local economy and service providers engage in training of operators (Nyoka et al. 2017). Cleaning or general maintenance to toilet units is often performed during the collection process. Cleaning activities are reported to lead to exposure without appropriate safeguards in place, but no evidence of such risks are demonstrated in relation to CBS systems. The ISO standard recommends comprehensive instructions for cleaning, as well as recommended products for cleaning, disinfection and rinsing, as well as those that are not recommended for use (IWA 2016).

The removal and collection of excreta is an integral aspect of the sanitation system from a human exposure perspective (Stenström et al. 2011). If done manually, it is where there is the greatest risk of exposure to humans. Potential exposure risks during the emptying and collection activities in CBS systems, including the collection and transportation of urine in jerry cans from UDDTs and potential malfunctions resulting in exposure and accidental ingestion (Stenström et al. 2011). In general, the potential for exposure during collection depends on the behaviours and hygiene practices of operators, as is important in all parts of the sanitation chain. No comparison of collection activities in CBS systems with other sanitation management systems exists (to the author's knowledge) in terms of exposure risks, although Bischel (2016) also documents risks to operators during collection and emptying of urine from UDDTs. Traditional pit emptying is associated with significant health risks for operators and is often performed clandestinely at night (Strauss and Montangero 2002). Even the mechanised emptying of pit latrines or septic tanks presents significant risks to operators and to the wider community through spillages (SNV 2017).

Other challenges reported in certain environments where CBS systems are deployed include maintaining a consistent quality and frequency of collection (WSUP/EY 2017). There is some use of smart software and QR codes to track and model collection and delivery[5] being developed by members of the CBSA.

2.3.3. Transport

The transport component provides the link between access to sanitation at an individual level and ability for systems to be safely managed with proper treatment of waste. In a waterless system, waste must either be manually or mechanically transported to a treatment facility. The potential exposure risks during mechanised desludging of latrine pits is significant. Studies demonstrate high risks for communities, as well as operators, in urban areas (Campos et al. 2015; Tilmans et al. 2016). In comparison, potential exposure of operators to excreta during transport in CBS systems is minimal, given that the waste from CBS systems is containerised and removed in sealed and watertight containers. As in all components of the CBS system, human behaviour is integral to the efficacy and efficiency of the transport procedures and resulting exposures and depends on basic hygiene and safety precautions being followed (Stenström et al. 2011). Workers should wear protective personal

[5] www.gsma.com/mobilefordevelopment/mgrantee/loowatt-ltd

equipment and employers have a duty to ensure that hygiene instructions and precautions are being followed (Stenström et al. 2011). Full waste containers are sealed and transported to a central waste treatment facility where the faecal matter and urine are processed to remove harmful pathogens for safe reuse or disposal. Transport of excreta and waste products is carried out through specially adapted vehicles, although there are no specifications for CBS vehicles. Moreover, the ISO standardisation does not address the transport of excreta outside the sanitation unit (after containment) for further treatment at another facility or reuse/disposal. SOIL uses modified wheelbarrows and three-wheeled motorcycles for waste transportation (Berner et al. 2015).

2.3.4. Treatment

Treatment processes of human excreta in CBS systems are carried out in offsite centralised treatment facilities. These may either be a part of the CBSSP or are carried out by a partner organisation or municipal service (Clean Team). The treatment processes aim to reduce the pathogen concentration to acceptable levels. The acceptable levels are set out by the WHO and require regular monitoring and verification programmes to achieve this. The performance of treatment systems is determined by the content of a pathogen indicator bacterium, such as *E. coli*, in treated material (WHO 2006). Since CBS systems are dry systems, without the addition of water, the treatment processes vary from those procedures typically used to treat faecal sludge treatment. The most common process used for treatment of excreta and solids in CBS systems is aerobic composting (Piceno et al. 2017), which deactivates pathogens through the interaction of heat, storage time and moisture content (Mehl et al. 2011). Aerobic composting requires oxygen for the survival of thermophilic bacteria which create heat for pathogen reduction, meaning that maintaining correct humidity levels is critical for effective treatment. Sanivation uses pasteurisation in a "continual flow heat treatment system" (Berner, Woods and Foote 2015), while Loowatt uses anaerobic digestion (Galgani, van der Voet and Korevaar 2014; Lohri, Rodic and Zurbrugg 2013) to treat the waste. However, there is little published description of this technology: in part because the private sector protects its intellectual property which includes treatment processes. Thus, there are three main treatment processes for faecal waste in CBS systems: 1) thermophilic, aerobic composting (SOIL, Sanergy), 2) pasteurisation – heat flow (Sanivation) and 3) anaerobic digestion – coupled with pasteurisation/composting (LooWatt).

The size and number of workers employed at treatment facilities in CBS systems depend on the scale of operations and types of treatments involved. Besides the actual processing of the waste to reduce pathogen concentration, operators may be involved in a variety of activities including:

- evacuation of waste (liquid and solid) from primary containers
- washing and disinfection of dirty collection containers

- turning of compost
- monitoring and verification
- processing into reuse/secondary materials.

The potential exposure risks from composting are well documented in numerous risk assessments discussed in more detail in the following section. There is evidence that high concentrations of pathogens on sludge treatment sites (Fuhrimann et al. 2016) and *Ascaris* eggs (Stenström et al. 2011) have been found on face masks of sludge treatment workers, indicating the potential risk of inhalation and exposure.

2.3.5. Reuse and Disposal

The reuse of excreta or safe disposal is the final component of a sanitation system where potentially pathogenic material is completely eliminated from the environment. In CBS, reuse is not a critical component, but, despite this, the majority of the CBSA organisations create a "product" from the processed human excreta collected. The exception is Clean Team (Ghana), which currently operates at a significant scale, but no reuse of the waste is implied in its system and waste is delivered directly to municipal waste treatment plants.

After aerobic composting processes a soil-like substance is produced and is added to soil to improve the nutrient availability and soil structure (Gensch et al. n.d.). The development of briquettes for solid fuel is an application of processed faecal matter (Sanivation) that replaces charcoal or carbon-based products. The final disposal of excreta, if not reused, presents a particular challenge. X-runner, which operates in Peru, is prevented from reusing its treated compost, due to national regulations on the reuse of faecal products, and must send its treated compost to landfill (personal communications x-runner). In the UK, where there is a small CBS system operating on the canal network in Central London, the Canal & River Trust (CRT) directs users of the system to bag waste in nappy bags and dispose of it in the domestic waste bins (CRT 2018).

Various applications for the reuse and disposal of stored urine include infiltration into the soil or use as a plant fertiliser (Stenström et al. 2011; Gensch et al. n.d.; Tilley et al. 2014). In CBS systems, urine is either separated and disposed of at the household level (SOIL, x-runner) or is collected, transported and processed at the treatment facility.

2.4. Evidence of Potential Occupational Health Risks

This section explores health risks and evidence of adverse health impacts faced by the users and workers of sanitation systems, including frontline staff and persons working in industries relevant to CBS systems in both high-income and low-income country contexts. The health risks related to exposure to faecal pathogens in traditional sewered sanitation systems (Feacham et al. 1983) are well described, while both onsite and offsite sanitation systems offer benefits and potential risks in regards to technology, disease prevalence, and health status of families using the toilet (Peasey 2000; Buckley et al. 2008). Many studies demonstrate how poorly managed sanitation systems may lead to exposure to faecal pathogens and subsequent negative health impacts (Prüss-üstün et al. 2004; Katukiza, Ronteltap, van der Steen et al. 2014; Drechsel et al. 2008; Buckley et al. 2008) and descriptions of unimproved forms of sanitation (WHO 2017) are typically associated with significant health risks. There is very limited evidence of exposure risks specific to the use and operation of CBS systems, perhaps given the infancy of these sanitation solutions (Russel et al. 2015). Stenström and colleagues (2011) described health risks arising from the use and operation of urine diversion dry toilets (UDDT), but results were not empirically validated (Stenström et al. 2011) and levels of disease risk assigned is troubling, since it depends on the variability of pathogen inputs and exposure data for specific contexts. There is little focus on occupational exposure risk either; exposure risk assessments regarding the reuse of compost in UDDT systems in Sweden are at a household level (Höglund 2001). The study is timely in relation to recent findings that sanitation workers are often inadequately protected and they face increased exposure risks due to a perception of low status in society (Burgess 2016; SNV 2017).

The literature regarding occupational exposure and health risks in the waste and healthcare sector from both developed (Haagsma et al. 2012; Giusti 2009; Avery et al. 2012; Pearson et al. 2015) and developing (Bleck and Wettberg 2012; Rongo et al. 2004) countries is reviewed. The Health and Safety Executive (HSE) in the United Kingdom (UK) compiles annual information on occupational ill-health effects per work sector. Health surveillance data related to occupational exposure in the UK is compiled from the Labour Force Survey – a nationally representative household survey of work-related illness and workplace injury. Additionally, The Health and Occupation Research (THOR) network provides information about self-reported work-related illness and incidence and causation of disease (Turner et al. 2005). The following categories of occupations identified in the literature are consistent with employees or persons engaged in the activities of CBS systems:

- Waste sector workers
- Sewage workers
- Farmworkers and agricultural workers
- Health and social care workers.

Annually, around 6,000 workers in the UK suffer from a work-related illness in the waste sector. The rate of self-reported work-related illness is significantly higher in the waste and health and social work sector compared to workers across other industries: 4.8% and 4.6% to 3.2% respectively (HSE 2016). However, 80% of reported illnesses in the waste sector were musculoskeletal disease or stress effects. Contrary surveillance data from THOR highlighted infectious diseases as a significant cause of occupational ill-health across all work sectors, while diarrhoeal diseases accounted for 75% of infectious diseases outcomes (Turner et al. 2005). A systematic review of work-related infectious diseases also found increased health risks through exposure to biological agents to refuse workers and cleaners (Haagsma et al. 2012). The review also noted that few occupational groups have evidence of exposure to infectious pathogens, which is clearly a limitation in providing accurate statistics. The difficulty of linking disease outcomes and work-related exposure may lead to potential underreporting of work-related infectious diseases (Turner et al. 2005). The HSE identifies specific occupations which place workers at risk from illnesses associated with contact with faecal pathogens in sewage, including sewer inspectors, waste workers, plumbers, agricultural workers and sludge tank drivers among others (HSE 2011). The potential health risks that are identified for these groups include gastroenteritis and more serious health issues such as leptospirosis and hepatitis E, asthma and, rarely, allergic alveolitis (inflammation of the lung) with fever, breathlessness, dry cough and aching muscles and joints (HSE 2011).

Several studies demonstrate that rubbish and wastewater workers in the bioorganic composting sector suffer from respiratory diseases, allergies, infection and general ill-health problems (Maricou, Verstraete and Mesuere 1998; Avery et al. 2012; Pearson et al. 2015; Tschopp et al. 2011). A systematic review linked an elevated risk of respiratory diseases with composting and waste sector occupations, due to inhalation of bioaerosols (airborne particles of biological origin), finding that immunosuppressed persons are particularly vulnerable (Walser et al. 2015). The quantification of potential health risks is precluded by a lack of data or measurements of exposure to bioaerosols in the workplace (Walser et al. 2015). One study found good working conditions accounted for low health risks arising from exposure to bioaerosols but warned about extrapolating the same conclusions to populations with less satisfactory working conditions (Tschopp et al. 2011). Such a warning may be heeded in CBS systems operating in low-income countries where workplace conditions are not comparable.

The European Agency for Safety and Health at Work (2009) report examined occupational health and safety in the cleaning industry. It found that cleaning staff were frequently exposed to dirty toilets and cleaning chemicals, and opportunities to practise hand hygiene were not practical, given the mobile working environment. The report also found that cleaning staff were often not well protected or trained in managing the potential health risks that arose. It identified that the low status of cleaning staff (often women) meant their voices were marginalised in risk assessments (European Agency for

Safety and Health at Work 2009). These types of socially constructed health risks may be of particular pertinence in contexts where CBS systems exist. A lack of institutional government capacity, regulations and guidelines specific to faecal waste management is considered to reduce pressure on sanitation service providers to adequately deal with waste and increases the risk of workers contracting faecal-oral diseases in low-income settings (Medland, Cotton and Scott 2015). Increased vulnerability to health risks is typical in informal small-scale industries where weak regulation exists, linked to workers not wearing suitable personal protective equipment (PPE) (Rongo et al. 2004). Occupational exposure in the informal sector is also related to the fact that: “small enterprises do not see risk prevention as a priority, the statistics show without doubt that the majority of occupational accidents occur in such small businesses in many sectors of activity” (Laine and Malenfer n.d.).

The rarity of individual Case Studies on health risks to CBS operators is not surprising, given the low visibility of waste workers typically in society. However, there is some traction now within the sanitation sector to investigate this area. Case Studies concerning the potential exposure risks from the handling and use of human faeces in Sweden (Schönning et al. 2007), the use and reuse of wastewater and human faecal and urine products in agriculture (Reither et al. 2007), and the reuse of source-separated urine (Höglund 2001), again in Sweden, demonstrated the potential health risks associated with activities and processes involved in the use and operation of UDDTs comparable to those expected in CBS systems.

Health surveillance of work-related issues and supporting mechanisms, such as the THOR network, are important mechanisms to quantify and document health risks and are a vital aspect of institutional risk management. The identification and quantification of potential health risks, for example risks associated with sewage workers emphasised by the HSE are important aspects of risk management that enable the prevention and management of health risks. Even in high-income countries, the evidence presented here highlights the lack of exposure measurements available for quantifying health risk assessments. In low-income countries, where onsite sanitation systems and CBS systems are commonly deployed, health surveillance mechanisms can be expected to be less developed. However, efforts to document and protect workers from unintended health consequences must be prioritised by organisations delivering sanitation services, whilst balanced against the overall public health risks resulting from a total lack of sanitation services and facilities. The current information deficit may present difficulties in estimating the type and nature of ill-health related to the use and operation of CBS systems. This thesis will make preliminary contributions to this knowledge gap and maximise the health benefits of improved sanitation to all.

2.5. Microbial Hazards in Human Excreta and Associated Pathologies

Untreated faecal solids contain a range of pathogenic and non-pathogenic microorganisms. The stool of a healthy person contains commensal bacterial organisms termed "gut microflora". The diversity of gut microflora depends upon the communities and their diet, use of medicine and other lifestyle factors. Commensal gut bacteria present in healthy individuals will not typically lead to an infection (Prüss-üstün et al. 2004) but some opportunistic pathogens are capable of causing an infection in immunocompromised individuals. The presence of strict pathogenic strains of bacteria in the human excreta indicates a health abnormality or a specific illness. The enteropathogens contained in human excreta pose a health risk to individuals, impacting the mortality and morbidity of human hosts (Prüss-üstün et al. 2004). Infection of a human host by a number of enteropathogens is commonly indicated by diarrhoea-like symptoms. The prefix entero- derives from the Greek *enteron* for intestine and is used to distinguish pathogens arising from the gut, and so present in faeces, from other types of disease-causing pathogens found in people. Henceforth, "faecal enteropathogens" will be referred to as "pathogens".

There are four distinct types of pathogens associated with a vast array of pathologies described below and presented in Table 2.2. The first group of pathogens are viruses. There are over 120 enteric viruses which originate in the human gut and may be transmitted by excreta; the most common include rotaviruses (RoV), hepatitis E and A, adenoviruses, enteroviruses and norovirus. In a global study of diarrhoeal diseases (Kotloff et al. 2013), RoV was found to be the most important aetiological agent of diarrhoea. It is highly contagious and infection has been significantly associated with infant mortality (Alirol et al. 2011; Stenström et al. 2011). The second group of pathogens are bacteria. There are two important families of bacteria; Enterobacteriaceae and Enterococci. The Enterobacteriaceae include the family of bacteria known as *Escherichia coli, or E. coli*, which are often used as an indicator organism due to their ubiquitous presence in faeces. The bacteria *Vibrio cholerae* are responsible for outbreaks of cholera. Cholera symptoms include "rice water" diarrhoea, which can lead to severe dehydration and death in vulnerable populations if the symptoms are not treated adequately. The bacteria *Salmonella* spp. cause typhoid and para-typhoid disease, of which there are an estimated 11–21 million cases globally, resulting in approximately 128,000–161,000 deaths annually (WHO 2018). The third group is parasitic protozoans. Prevalent protozoans include *Cryptosporidium parvum*, *Giardia lamblia* and *Entamoeba histolytica*. In infected human hosts, oocysts are released in the faeces and urine which survive outside the human host due to a thickened cell wall. *Cryptosporidium* spp. is a common cause of diarrhoea (Jacob et al. 2015), and has been significantly associated with under-five morbidity (Bartelt et al. 2013; Brown et al. 2015). Infections are also known to adversely influence childhood development via their association with linear growth shortfalls, stunting and wasting (Bartelt et al. 2013). The fourth group are helminths, which include species such as roundworms, *Ascaris*, whipworms, hookworms and *Schistosoma*. *spp*. (Stenström et al. 2011). Helminths species release eggs in infected human hosts which pass through the faeces and urine and become infective in favourable environmental conditions. Helminth infestation is widespread and co-infection of low to moderate worm loads with malnutrition or other enteric diseases is common (Schönning et al. 2007). However, the global prevalence and disease burden associated with these parasites is generally poorly quantified.

The majority of descriptive studies that investigate sanitation and acute diarrhoeal infections typically do not define the specific diarrhoeal disease aetiology. Despite the enormous variety of faecal pathogens, only a few species account for the majority of the global health burden linked to diarrhoeal diseases. The Global Enteric Multicenter Study (Kotloff et al. 2013) identified five pathogens: (1) rotavirus, (2) *Cryptosporidium*, (3) typical EPEC (enteropathogenic *E. coli*), (4) ST-ETEC (enterotoxigenic *E. coli*), and (5) *Shigella*, which accounted for the majority of diarrhoeal diseases in children presenting with diarrhoea over seven study sites across Africa and Asia. Such pathogens are to be expected in raw faecal waste processed by CBS systems, in particular, where there is significant health burden from diarrhoeal diseases in the community or population which the CBS system serves.

Table 2.2 Expected pathogens in human excreta and associated diseases outcomes (Feacham et al. 1983)**;** Schoenning and Stenstroem 2004)

Pathogen group	**Clinical pathology and disease**
Virus	
Hepatitis A and E	Infectious hepatitis
Rotavirus	Enteritis, vomiting and diarrhoea
Adenovirus, enteroviruses	Enteritis, numerous conditions
Bacteria	
Campylobacter jejuni/coli	Campylobacteriosis – diarrhoea, cramping, abdominal pain, fever, nausea, arthritis
Escherichia coli (E. coli)	Diarrhoea
Salmonella typhi/paratyphi	Para/typhoid fever
Salmonella spp.	Salmonellosis – diarrhoea, fever, abdominal cramps. Food poisoning
Shigella spp.	Dysentery (bloody diarrhoea)
Vibrio cholerae	Cholera; watery diarrhoea, lethal if severe and untreated
Parasitic protozoa	
Giardia intestinalis	Giardiasis – diarrhoea, abdominal cramps, malaise, weight loss
Cryptosporidium parvum	Cryptosporidiosis – watery diarrhoea, abdominal cramps and pain
Entamoeba histolytica	Amoebiasis – often asymptomatic, dysentery, abdominal discomfort, fever, chills. Colonic ulceration, amoebic dysentery
Helminths	
Hookworm	Hookworm infection; rash; cough; anaemia; protein deficiency
Schistosoma	Schistosomiasis
Ascaris	Ascariasis; generally no or few symptoms; wheezing; coughing; fever; enteritis; pulmonary eosinophilia

2.6. Infective Parameters of Faecal Solid and Liquid Waste Products

Not all pathogens behave in the same way in the environment and they display unique characteristics in terms of reproduction, transmission and environmental persistence, which affect their ability to infect and transmit disease. The significance, in terms of human health, of exposure to faecal matter depends on the following infective parameters that determine the type and concentration of pathogens present:

- pathogen load/pathogen shedding
- infective dose
- environmental persistence of the pathogen.

The exposure risk must account for these infective parameters during the measurement and assessment of risk. An understanding of these infective parameters is exploited by technical barriers and pathogen reduction in treatment processes. The efficacy of the treatment barriers depends to a large extent on which pathogen species is being assessed as all pathogen species have unique survival capacities.

2.6.1. Pathogen Load

Pathogens possess unique reproductive behaviour, termed "shedding", which gives rise to different numbers of infective cells shed from pathogens in infected human excreta. The "pathogen load" refers to the specific type and concentration of disease agents present in human excreta and is quantified as the pathogenic microbes per gram of faeces. The pathogen load in excreta is a critical factor in determining the health outcome following exposure (Prüss-üstün et al. 2004). The initial pathogen load in faecal sludge is determined by the prevalence and incidence of enteric infection in the community from which the excreta waste is collected (Koné et al. 2007). Pathogens shed infective cells at various intensities and for various lengths of time (see Table 2.3). During the acute infection stage of diarrhoeal diseases, pathogen loading is higher and increases the risk of exposure and transmission of faecal pathogens (Ahmed 2017).

Epidemiological surveillance data may be used to build up a picture of the prevalence of diarrhoeal diseases, although surveillance data is often unreliable or underestimates the number infected because less severe cases do not report to health services (Schönning et al. 2007). Also, discerning pathogen load from diarrhoeal prevalence data can be inaccurate since pathogen shedding may occur in infected individuals showing no clinical symptoms; *asymptomatic* cases of RoV can produce up to 10^{11} RoV particles/gm of faeces (Mattioli, Davis and Boehm 2015) (see Table 2.3). An alternative indicator of the prevalence of diarrhoeal diseases is the coverage and provision of health services and programming. For example, substantial pathogen reduction in faeces was observed following the use of deworming among schoolchildren in South Africa (Buckley et al. 2008). Likewise, coverage of water and sanitation services may be an indicator of the potential incidence of diarrhoeal disease in the community. The World Health Organization (WHO) ranks exposure to environmental pathogen load and subsequent burden of diarrhoeal disease according to community access to water and sanitation scenarios (Prüss-üstün et al. 2004 p. 1334). Although this ranking refers to environmental pathogen loading, since there must a corresponding pathogen loading per gram of faeces to be released to the environment, the two indicators are broadly comparable.

Table 2.1 Disease agents and infective parameters

Pathogen group	Reference	A Pathogen load[6]	B Infective dose (ID_{50})	C Infective period	D Environmental persistence	E Exposure route
1. Viruses						
Rotavirus	(Feacham et al. 1983; Payne and Panashar 2008)	10^{6}–10^{11}/g faeces	< 100 virus particles	24 days	Globally important, not prevented by hygiene	Hands and fomites, water and food
Norovirus	(Feacham et al. 1983; Payne and Panashar 2008)		< 100 virus particles	28 days	Most common cause of infant gastroenteritis	Hands and fomites, water and food
2. Bacteria						
Escherichia coli (E. coli)	(Feacham et al. 1983; Enger, n.d.)	10^{8}–10^{9}/g faeces	High infective dose required 10^{8}–10^{9}	2–10 days	16 months on surfaces depending on strain	Typically, not direct or person to person; food or contaminated water
ETEC	(Feacham et al. 1983; Enger, n.d.)	10^{7}–10^{8}/g faeces	10^{5}–10^{8} cells (0.001–10g faeces)	3–4 days		
EPEC	(Feacham et al. 1983; Enger, n.d.)	10^{5}–10^{9}/g faeces	10^{5}–10^{7} cells (0.01–1g faeces)	>10 days		
Salmonella typhi/paratyphi	(Feacham et al. 1983)	10^{10}–10^{11}/g faeces	High, but lower in susceptible individuals			
Salmonella spp.	(Feacham et al. 1983)					
Shigella spp.	(Feacham et al. 1983)	10^{5}–10^{9}/g faeces in infected person; 10^{2}- 10^{6}/g faeces in asymptomatic carriers	10^{3}–10 cells (0.01-0.1g faeces)		2 months on surfaces, in toilet bowls	
Vibrio cholerae	(Feacham et al. 1983)	10^{6}–10^{9} per ml of rice water stool of faeces in infected individual; 10^{2}- 10^{5}/g faeces in asymptomatic carriers	10^{8}–10^{11}		Can resist desiccation, endemic in water bodies	Contaminated drinking water, food, hands
3. Parasitic protozoa						

[6] Number of cells shed in faeces of infected individuals

Giardia intestinalis	(Feacham et al. 1983)	900 million cysts/day	25–100 cysts for infection to result			Food
Cryptosporidium parvum	(Feacham et al. 1983)	103-107 cells/day	9–160 oocysts (10^{-1}- 10^{-5}g faeces)	2–35 days	High: Not killed by disinfection	Contaminated drinking water, wastewater
Entamoeba histolytica	(Feacham et al. 1983)	1.5x 10^{7} cysts/day in asymptomatic infected individual	10–100 cysts for infection to result			Food
4. Helminths						
Schistosoma spp. (intestinal and urogenital species)	(Feacham et al. 1983; Zhou et al. 2013)	>1000 *S. mansoni* embryos/ day/infected human host	Only two cercariae (blood fluke) can result in human infection if male and female are present		Low: cercariae die within 24-72 hours is they do not find a suitable host	Contaminated water bodies – contact in, swimming
Ascaris	(Feacham et al. 1983)				High: *Ascaris* eggs have been found to survive in dessicated conditions and well over 1 year	Soil

Data on pathogen concentration in raw excreta or faecal solids is rarely collected from sanitation systems (WHO 2004). The evidence describing the likely pathogen inputs in raw faecal waste in CBS systems is limited and is troubled by a lack of precise diarrhoeal disease aetiology at community level. Relatively more research exists concerning faecal sludge characterisation from onsite septic tanks and pit latrines (Nyenje et al. 2013; Koné et al. 2007). A study of a CBSSP in Haiti found nearly 50% of the raw faecal waste samples contained potentially pathogenic bacteria including the bacterial genera *E. coli, Shigella and Salmonella* (Piceno et al. 2017). An earlier study of the same CBS system found 83% of raw faecal waste samples contained viable *Ascaris* eggs and *E. coli* was present in numbers of 10^6-10^7 MPN g^{-1} dry weight (Berendes et al. 2015). In comparison, in mixed faecal sludge from pit latrines, 58% of samples contained viable *Ascaris* eggs with 25–83 total helminth eggs/g of total solids (Koné et al. 2007). In wastewater from sewered systems, initial pathogen concentrations of *Enterococcus* and *E. coli* cells were 2.1×10^5 – 9.2×10^6 NPP g^{-1} d.m (Pourcher et al. 2005). However, specific pathogen concentrations in wastewater and faecal sludge from septic tanks or pit latrines are likely to differ from that expected in CBS systems due to the different operating modalities including source-separation (Pourcher et al. 2005).

Human urine from healthy persons is generally considered a sterile product without pathogens (Höglund 2001), although concentrations of pathogens can be excreted in the urine of individuals infected with schistosomiasis haematobium (Ahmed et al. 2017). However, the presence of viral and bacterial faecal microorganisms in source-separated urine is thought to be due to cross-contamination of urine from faecal chambers and where faecal material enters the urine diverter part of the bowl, which is difficult to prevent (Höglund and Stenström 1999; Höglund et al. 2002; Udert et al. 2003). The notion of cross-contamination is supported by the observation of faecal sterols in source-separated urine (Schönning, Leeming and Stenström 2002). The extent of contamination varies; in one study in Sweden up to 22% of urine samples were contaminated (Höglund 2001), while a study in South Africa found 100% of urine samples were contaminated by the same type of faecal pathogens passed in excreta of infected individuals (Bischel et al. 2015). Given this evidence, source-separated urine cannot be considered sterile and exposure presents a potential risk to human health (Bischel et al. 2015). The WHO (2008) direct storage times for urine to ensure the reduction of pathogens to acceptable levels.

2.6.2 Infective Dose

The human infective dose (HID_{50}) is pathogen specific, and determines the level of exposure required to cause infection in an individual. The HID_{50} is the number of pathogens that must be ingested to cause infection in 50% of the population (Katukiza, Ronteltap, van der Steen et al. 2014). Pathogens with low infectious doses required for infection consequently have the highest risk to cause disease, as the level of exposure required for infection is small. ETEC and EPEC have very high HID, thus certain routes of transmission where large volumes of pathogens may be ingested are more likely to result in infection. It should be noted that the HID_{50} is based on healthy adults, and vulnerable individuals might become infected following exposure to much lower levels. Moreover, the HID_{50} is based on a binary response for infection and does not account for low-level exposure, which may cause longer term chronic health conditions in susceptible individuals. Infectivity (Haas 1999), a related aspect, is the number of days that infective pathogens are shed in the faeces of an infected person (Table 2.3). RoV or norovirus infectious pathogens may be passed in faeces for up to 28 days following infection, compared with persons infected with ETEC who may only be infective for 3–4 days.

2.6.3 Environmental Persistence

Environmental persistence refers to the ability of a pathogen to survive outside a human host. Pathogens' survival varies according to specific environmental conditions and is moderated by the cellular structure of the microorganism. External environmental factors that determine the persistence of pathogens in the environment are those such as exposure to sunlight, humidity, temperature and whether the pathogen is enclosed in solids/aggregate or free-floating (Table 2.3). A important ability of particular pathogens to adhere to surfaces and form biofilms is also an important factor that dictates its environmental persistence - these certain pathogens form protective biofilms under which they receive protection from environmental exposures. *Salmonella* evades destruction from household cleaners in toilet bowls due to such protective biofilm around toilet rims (Barker and Bloomfield 2000). In this way, certain strains of *Shigella* and *E. coli* have been recorded surviving in the environment on hands and surfaces from between 2 to 16 months respectively (Julian 2016). In contrast, *Cryptosporidium* oocysts rapidly desiccate on surfaces but it cellulat structure means it is not killed through disinfection and can survive for long periods in water. The fact that *Cryptosporidium* oocysts and RoV cells are both easily transmitted through certain environments and, when combined with low doses for infection and the release of high numbers of cells in raw excreta from infected individuals, this contributes to their global significance as disease agents. The nature of environmental persistence of particular pathogens is exploited in the design of efficient and effective treatment processes in sanitation systems.

2.7 Treatment Processes and Efficacy in CBS systems

As faecal waste progresses along the sanitation value chain, the microbial characteristics will depend on the efficiency of treatment processes (Stenström et al. 2011). The treatment processes are a barrier to transmission of faecal pathogens in the subsequent reuse and disposal of the waste in the environment. Treatment techniques such as pasteurisation and thermophilic composting reduce the pathogen load by exploiting the specific temperature and time period necessary according to specific pathogen die-off rates (Feacham et al. 1983). Feacham and colleagues (1983) presented temperature and time combinations, called temperature/time death curves, for faecal pathogens including *Shigella, Salmonella, Vibrio cholerae*, in addition to *Ascaris, Taenia* and *Entamoeba*, which depict at what point (temperature/time) die-off of enteric pathogens is achieved (Feacham et al. 1983; Strauch 1991). Table 2.4 below indicates the minimum temperature and times for complete pathogen inactivation.

Table 2.4 Minimum temperature and time combinations required for pathogen inactivation [Feacham et al. 1983]

Pathogen inactivation rates	
Temperatures	Time
above 62 ^{0}C	one hour
above 50 ^{0}C	one day
above 46 ^{0}C	one week

These inactivation rates form the basis for composting parameters used today in the European Commission and Environment Agency guidelines for the reuse of sewage sludge on land (*Safe Sludge Matrix* 2001; Carrington 2001).

Different treatment processes for source-separated urine are used to inactivate the same range of bacteria, viruses, protozoa and helminths. Efficiency of the treatment process appears to be driven by a combination of the length of storage, temperature, dilution and pH value. There is strong evidence that source-separated urine stored for a minimum period of six months at temperatures above 20 ^{0}C (Höglund et al. 2002) or four months at 35 ^{0}C (subtropical temperatures) is sufficient for effective deactivation of all excreta-related pathogens (Ahmed et al. 2017). However, storage of urine at low temperatures, 5 ^{0}C, for six months, did not result in any bacterial or viral die-off. Conversely, at 20 ^{0}C rotavirus and bacteria phage were quickly inactivated after 35 and 71 days, respectively (Höglund et al. 2002). The effect of high pH 9 values in source-separated urine is noted by inactivation of protozoan *Cryptosporidium* oocysts even at 4 ^{0}C after storage for four months; however, a control buffered pH 9 solution did not have the same deactivation impact of oocysts (Höglund et al. 2002). It is therefore posited that the presence of ammonia in urine, due to conversion of urea, may account for the inactivity of oocysts. In some studies bacteria also appear to respond to the higher pH 9 values (Höglund et al. 2002). *E. coli* is seldom found in stored urine, but its short survival time in tests means it is not an appropriate indicator for assessing risks of faecal contamination. *Clostridium* has been found in urine storage tanks, while the high levels of streptococci found were thought to originate from regrowth in the tanks (Hoglund et al. 1998).

The inactivation of faecal pathogens in composting toilet faecal waste is typically by thermophilic aerobic composting (Mehl et al. 2011) or pasteurisation of faecal waste streams (Berner, Woods and Foote 2015). The efficacy of composting in terms of eliminating the faecal pathogens is well documented (Berendes et al. 2015; Koné et al. 2007; Piceno et al. 2017). However, the time and temperatures required to achieve total pathogen die-off in composting appear to vary widely, in part depending on the indicator pathogen under study. Recently, Picone and colleagues (2017) investigated the elimination of pathogens during thermophilic composting at a CBS service in Haiti and concluded that a composting period of one year was effective in reducing the opportunistic pathogen load (Piceno et al. 2017). The *Vibrio* genus was present in a number of the compost samples taken at the end of the treatment process, but it was concluded that recontamination of compost containers may have reintroduced this bacterium from an external environmental source. In an earlier study of the same CBS service, Berendes and colleagues (2015) could not detect *E. coli* in compost samples after three months, representing a 4–5 $\log_{10}$ reduction in viable *E. coli* concentration. They described elimination of viable *Ascaris* eggs after four months in final compost samples and a greater than 1 log reduction was observed over the entire sampling period (Berendes et al. 2015). The eggs of the helminth *Ascaris* possess the longest environmental resistance of all faecal pathogens and are therefore a reliable indicator of the presence of faecal pathogens. Koné and colleagues (2007) described how temperatures above 45 ^{0}C drastically reduced viable helminth count after less than three months co-composting with organic wastes. However, when the composting period was less than two months, *E. coli* was present in compost samples, even with temperatures above 60 ^{0}C (Marin et al. 2014), indicating the important influence of time. A seven-month composting period is reported to reduce pathogens to levels below detection, including *Salmonella* spp., from initial concentrations around 1.7–9.6 MPN g^{-1} and *Listeria* spp. of 44 MPN g^{-1} (Pourcher et al. 2005).

A limitation of some studies is the use of certain indicator species such as *E. coli*, which are more easily inactivated than the more resilient viral and protozoan pathogens in excreta and may therefore underestimate treatment efficacy. In particular, faecal sludge derived from wastewater has far lower (typically tenfold) concentrations of helminth eggs than faecal solids (Strauss and Montangero 2002). More research on CBS systems will be required to evaluate the baseline pathogen inputs and log reduction required to determine the efficacy of helminth inactivation, in particular, in treatment processes for urine and faecal solids.

2.8 Transmission Pathways and Risk Factors

The mechanisms of transmission of pathogens through the environment are a critical element for exposure and subsequent health risks that might arise in CBS systems (Davidson et al. 2005). In this section the transmission pathways and factors that increases the risk in CBS systems are examined. The following seven transmission pathways relevant to operator's exposure in the use and operation of CBS systems are considered, together with potential biological, sociocultural, environmental, institutional and technical risk factors:

1. Hands
2. Fomites (inanimate objects)
3. Soil
4. Water/fluids
5. Flies or vector
6. Food
7. Airborne

Wagner and Lanoix proposed the term "faecal–oral transmission" in 1958 to describe how faecal pathogens travel towards an individual and are ingested via the mouth. It describes five transmission pathways illustrated by the 'F-diagram' (Figure 6); fingers, flies, fields, fluids and foods. It remains as relevant today as it was 60 years ago. The reference to "fields" in the F-diagram reflects the rural emphasis of water and sanitation in the development field (White, Bradley and White 2002) during this period. A more modern interpretation of "field" is soil (Ziegelbauer et al. 2012; Katukiza, Ronteltap, van der Steen et al. 2014), and applies to both urban and rural environments. The transmission of faecal pathogens along principle pathways is occupied with transmission pathways and public health risks associated with open defecation, dirty and overflowing pit latrines and unhygienic carers' practices. Figure 6 notes multiple routes of exposure and is important in demonstrating the complexity and overlapping of exposure routes leading to ingestion and skin penetration. However, it is notable for its failure to capture the significance of fomites as a transmission pathway, or to consider inhalation. Indeed, much of the literature describing transmission pathways is linked to transmission of disease from a particular public health perspective. Such models might not be adequate to capture the specificities of exposure for operators in the CBS sanitation chain. The literature discussed below would suggest a modification to the original F-diagram to include the role of fomites (surfaces of inanimate objects) and the aerolisation of pathogens, which are recognised as important transmission pathways of microorganisms (Stenström et al. 2011; Pickering et al. 2012b). Indeed, exposed materials are recognised in the ISO standard as items that have come into contact with faecal products (IWA 2016). Stenström and colleagues (2011) considered nine transmission pathways in the risk assessment of different sanitation systems, but the scope of transmission pathways included ingestion, inhalation and infection via dermal contact that does not make a distinction between the *transmission* pathways and *exposure* route. The distinction is important since transmission pathways describe the movement of the pathogen through the external/internal environment and exposure route is the manner the pathogen enters the body of the host individual (mouth, skin and inhalation).

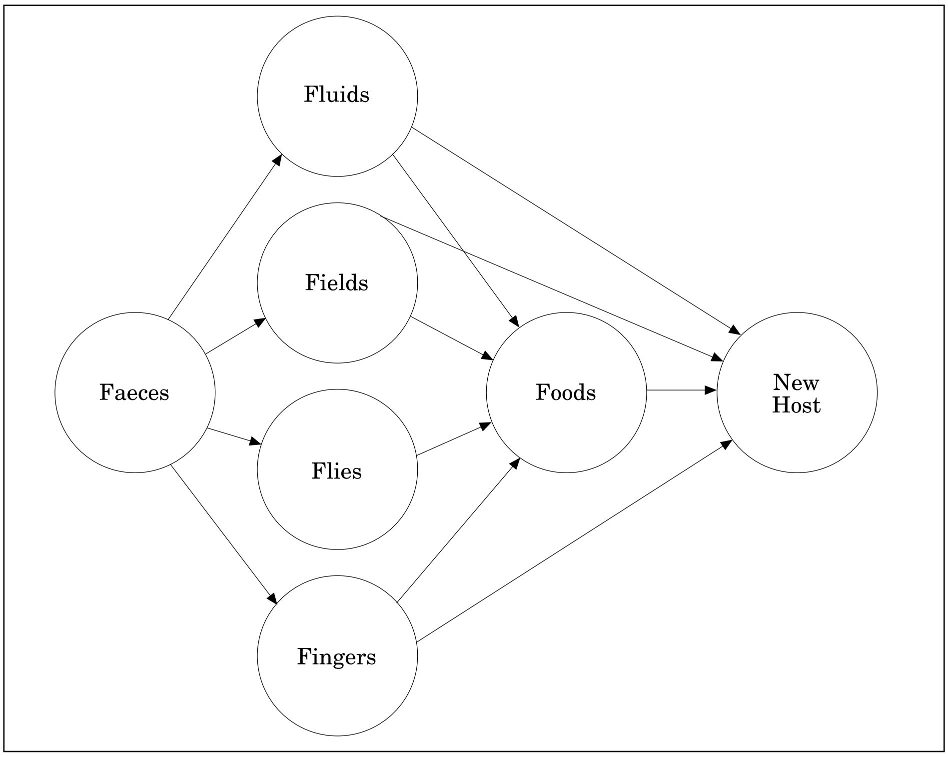

Figure 6 "F-diagram" showing five pathways of faecal–oral transmission (Humphrey 2009)

2.8.2 Hands

Hands are strongly implicated in the primary transmission of faecal pathogens from person to person (Levine and Levine 1991; Wang et al. 2017) and hand to mouth is the dominant pathway immediately after hand contamination (Julian et al. 2009). Toilet use is associated with the positive presence of pathogens on hands (Feacham et al. 1983), which then enables secondary contamination of foods, fomites and water by transporting faecal pathogens into the environment after defecation (Wang et al. 2017; Mattioli, Davis and Boehm 2015). A recent study by Wang (2017) observed temporal and spatial variations in the concentrations of *E. coli* on hands from 2.25 to 1.55 × 10^5 CFU/pair of hands (Wang et al. 2017), although these results were not associated with toilet use. The complete removal of seeded bacteria after handwashing (Prüss-üstün et al. 2004) demonstrated the strong relationship between toilet activities, hand hygiene and hand contamination. Hygiene practices including hand drying and the use of clean towels after handwashing were significantly associated with lower rates of enteric infection in children (PR = 0.58; $p<0.01$) (Worrell et al. 2016).

The role of hand transmission for CBS operators is complicated by findings from Lingaas (2009) who discovered that bacterial transfer from the hands occurred more readily from gloved hands as opposed to bare hands during person to person contact. Conversely, disinfection efficacy appears to be greater for gloved as opposed to bare hands (Scheithauer et al. 2016). These findings are relevant to guide the use of gloves for hand hygiene and have implications for contact transmission (Lingaas and Fagernes 2009) and exposure in CBS systems. Overall, little research has been conducted on the efficacy and role of gloves and other hand hygiene procedures in field trials of sanitation systems.

2.8.3 Surfaces

In low-income, high-density environments, household surfaces may play a significant role in faecal exposure, with one study (Pickering et al. 2012b) reporting that over 75% of household fomites were contaminated with faecal pathogens. However, the difficulty of ascribing a faecal origin to the surface contamination is acknowledged (Julian and Pickering 2015b). Similarly, a UK study found 70% of toilet seats positive for *E. coli* (Scott, Bloomfield and Barlow 1982). The presence of *E. coli* on toilets seats in the UK was associated with toilet use since confounding influences of environmental contamination were minimal.

Dirty toilets are considered a risk factor for exposure to faecal pathogens and diarrhoeal diseases (Baker et al. 2016; Peasey 2000). Flores (2011) describes the extent of microbial contamination in public toilets. He concluded that significant contamination of toilet surfaces, toilet handles and toilet seats with enteric bacteria, as a result of contact with contaminated hands or faeces during toilet use or deposits of airborne microbes, dispersed due to the effect of flushing (Flores et al. 2011). In this manner, surfaces form “a chain of infection” (Gerhardts et al. 2012), and act as both a reservoir and disseminator of transmission to hands and other pathways (Lopez et al. 2013; Devamani, Norman and Schmidt 2014; Julian and Pickering 2015b). Subsequent exposure and infection risks are dependent on the initial surface concentration of pathogens (Julian and Pickering 2015a; Julian et al. 2009). A higher risk of transmission from surfaces is associated with higher pathogen loads during the acute infection stage of diarrhoeal diseases (Barker and Bloomfield 2000). Faecal contamination of surfaces is linked to outbreaks of diarrhoeal diseases (Abad et al. 2001), but the public health implications depend on the survival and persistence of faecal pathogens on surfaces. The transfer of contamination from contact surfaces to people has been noted (Brouwer 1999) as a significant cause of dermal exposure in industrial workplaces.

The potential for transmission correlates with the frequency of contact with contaminated surfaces increases, although infrequent contact events or even single exposure events have been shown to have a disproportionate role in the transmission of infectious disease (Julian and Pickering 2015b). Given the evidence for fomite transmission and surface contamination prevailing from a faecal origin, fomite transmission in CBS systems might be significant. The subsequent infection risk will depend on the frequency of the contact and the type and concentration of pathogens present.

2.8.4 Soil

Contaminated soil has been implicated as a primary transmission pathway and is associated with the prevalence of stunting in exposed individuals (Humphrey 2009). At a household level, studies have not proved conclusive on whether latrine units contributed to high levels of faecal pathogens in soil (Pickering et al. 2012a). Removal of dirt flooring is linked to a significant reduction in the prevalence of helminth infection (Worrell et al. 2016) and a reduction in parasitic infections and diarrhoeal diseases was linked to removal of dirt floors, indicating soil-borne transmission (Cattaneo et al. 2009). However, other studies have failed to identify dirt flooring as a risk factor for soil-transmitted helminth (STH) infection (Echazú et al. 2015). The type of flooring material may impact faecal transmission at a household and facility level in CBS systems due to its effect on the efficacy of cleaning and accumulation of pathogens. Individuals may be exposed to contaminated soil used as a flooring surface in aspects of CBS systems or while handling compost or soil conditioners (Matthys et al. 2007) that are by-products of the treatment processes. The level of soil contamination in end-use products will be related to the efficiency of treatment processes in terms of pathogen log reduction as part of the CBS system (Berendes et al. 2015; Piceno et al. 2017), and the frequency and level of exposure.

2.8.5 Water/fluids

Contaminated drinking water is a primary transmission route for faecal pathogens (du Preez et al. 2011). The interaction of CBS systems with drinking water is not well demonstrated in the literature. In theory, contamination of drinking water at household level can occur due to secondary contamination from airborne pathogens or from unsuitable hygiene behaviours (Prüss-üstün et al. 2004), such as unsafe handling and storage of water. Household water contamination has previously been positively associated with types of “unimproved” sanitation (Mattioli et al. 2013a). However, there is no evidence that the presence of a CBS system in the household is significantly associated with bacteriological quality of household water (Russel et al. 2015).

Wastewater in surface and tertiary drains is an important transmission pathway in slums and low-income countries (Campos et al. 2015b; Katukiza et al. 2010). A strong association exists between proximity and exposure to contaminated wastewater in drainage channels and diarrhoeal incidence (Prüss-üstün et al. 2004; Worrell et al. 2016; Oloruntoba, Folarin and Ayede 2014). However, the role of wastewater transmission in CBS systems depends on the fate of urine and wastewater in CBS systems. CBS systems may collect and dispose of urine at the household level or it is collected and treated separately at a treatment facility.

2.8.6 Flies

Flies are a mechanical vector for the transmission of faecal pathogens (Feacham et al. 1983). Flies are attracted to excreta, which makes them extremely successful agents of transmission (Levine and Levine 1991).

2.8.7 Food

The consumption of contaminated food accounts for 99% of faecal exposure in low-income urban environs (Wang et al. 2017). A number of activities associated with food – preparation, cooking and eating – consolidate contamination from a number of different of pathways (especially the significance of hand transmission). Inadequate hygiene practices hugely contribute to secondary food transmission (Toure et al. 2013; Amoah, Drechsel, Abaidoo et al. 2007), targeted by the inclusion of hygiene in recent SDG targets (Tilley et al. 2014).

Nevertheless, it is vegetable production in urban and peri-urban farms, as opposed to food handling practices, that has been identified as the main point of vegetable contamination (Keraita et al. 2007a; Matthys et al. 2007; Amoah, Drechsel, Henseler et al. 2007; Antwi-Agyei et al. 2015). Ahmed and colleagues (2017) quantified risks from the application of urine fertiliser from UDDT onto salad crops. The study considered appropriate storage times for treatment of urine prior to application to manage risk, but acknowledged that different treatment measures may be appropriate following disease outbreaks (Ahmed et al. 2017). The WHO emphasises safer farming practices and proper treatment procedures as important factors in controlling faecal contamination of crops irrigated with faecal wastewater/sludge (Drechsel et al. 2008). Withholding irrigation prior to harvesting can significantly reduce faecal contamination (Keraita et al. 2007b). In the UK, faecal sludge applications to vegetable crops (in particular crops that might be eaten raw) must adhere to time intervals of 10–30 months between application and harvesting depending on the level of treatment to which the sludge has been subject to (*Safe Sludge Matrix* 2001).

Specific food hygiene practices at the household level or at various stages along the CBS system may encourage the transmission of faecal pathogens. The most significant risk of transmission is from contaminated crops grown with CBS by-products (compost or urine-derived liquid fertilisers). The risk is dependent on the treatment efficiency and the practices of irrigation and manure application onto leafy crops.

2.8.8 Air

In general, the risk of infection from the inhalation of airborne viruses and bacteria is low compared to other transmission routes (Katukiza et al. 2010; Katukiza, Ronteltap, van der Steen et al. 2014). However, it may be more significant in industries where physical or mechanical processes aerolises particulates that can be transmitted by primary and secondary routes, or contributes to secondary contamination of people via food products (Byrne et al. 2008; Buttner and Stetzenbach 1993; Maricou, Verstraete and Mesuere 1998). *Ascaris* ova have been found on the masks of operators emptying pit latrines, indicating that airborne transmission of helminth eggs occurred and may therefore pose a potential transmission risk in certain contexts if barriers to transmission did not exist (Buckley et al. 2008).

2.9 Health Vulnerability

Vulnerability encompasses the idea that adverse health impacts from exposure to faecal pathogens in sanitation services are defined either according to specific situations, or explained by the prevailing economic, social, environmental and cultural contexts within which the sanitation system exists. The role of context is acknowledged, where "the hazardous event is not the sole driver of risk … levels of adverse effects are in good part determined by the vulnerability and exposure of societies and social-ecological systems" (Cardona et al. 2012). The role of behaviour is encompassed in the human dimensions of risk production and certain aspects of health vulnerability. The context of health vulnerability in sanitation systems makes conspicuous the social construction of risk. Health risks are constructed by human activities that transform biological hazards into different intensities and social processes that amplify exposure and vulnerabilities to these hazards. A sociopolitical amplification of risk is produced by elements such as social and environmental vulnerability, system mismanagement and a general lack of control over elements of production (Hurst 1998). According to Hurst (1998), these elements lead to situations where "people working in industrializing countries have a greater risk for a given technology, than for people in first world countries". Similarly, in sanitation chains, Medland and colleagues (2015) highlight specific situations of health vulnerability and increased risk of exposure to faecal pathogens linked to a lack of institutional government capacity, regulations and guidelines that reduce pressure on service providers to adequately deal with waste, leading to inadequate faecal waste management. They also acknowledge risky health and hygiene behaviours and a lack of access to resources or protective equipment for workers (Medland et al. 2015). Similarly, poor hand hygiene compliance and other personal hygiene behaviours are associated with work-related illnesses in the UK waste sector (HSE 2011). A UK study of occupational exposure reported that low compliance with hand hygiene contributed to 30% of time off by waste operators, and hand hygiene compliance is commonly as low as 40% (Haagsma et al. 2012) in some healthcare sectors. In general, health vulnerability is moderated by generic aspects of vulnerability such as age, education and poverty. Age is an important variable, as very young children and the elderly are typically more vulnerable to adverse health impacts from faecal pathogens (Clasen et al. 2010), as well as those who are immunocompromised and people living with HIV (Bouyou-Akotet et al. 2016; WHO 2006). General conditions of poverty and high population densities leading to cramped and unhygienic living conditions reduce people's resilience to microbial colonisation (Weiss 2004).

Education level influences hygiene behaviours and may moderate the level of exposure of individuals to communicable diseases (Jenkins and Curtis 2005), while training that increases levels of knowledge of potential health risks and changes how people perceive and respond to hazards affects vulnerability and personal levels of exposure (Few et al. 2013a; Gallaher, Mwaniki, Njenga, Karanja and Winklerprins 2013). However, evidence also indicates that knowledge and awareness are not the primary factors in determining how people will behave, as other factors such as economic capacity and motivation are important (Few et al. 2010, 2013b). Sociocultural norms and broader economic factors restrict access and choice of materials for performing anal cleansing (McMahon et al. 2011), and handwashing (Alirol et al. 2011), affecting hygiene activities and the transmission of faecal pathogens. Access to handwashing hardware at the household level was significantly associated with the incidence of enteric infections, especially in children.

Cultural contexts are important in terms of toilet use and hand contamination, since anal cleansing rituals, together with a lack of toilet paper, soap and hand towels, were linked to elevated hand contamination and subsequent outbreaks of faecal–oral diseases (Rajaratnam et al. 1992; McMahon et al. 2011) (Green cited in McMahon et al. 2011). Contaminated wastewater in CBS systems is generated according to anal cleansing rituals, hygiene and cleaning practices at the household level, and cleaning and treatment processes at the facility level. Therefore, procedures used for infiltration of contaminated wastewater and urine in CBS systems may present an exposure risk to local communities downstream, which would also depend on environmental factors, such as geomorphology, seasonality, population density and proximity of drinking water systems at site level.

2.10 Summary of Transmission and Exposure Risk Factors

Multiple risk factors exert their influence over the three important variables that determine the pathogenic microbial composition and subsequent health risks from exposure along the entire CBS chain: 1) the initial pathogen inputs and barrier efficiency, 2) transmission pathways and barriers, and 3) health vulnerability. The discussion above demonstrates a number of biological, socioeconomic, behavioural and environmental risk factors that influence the level of exposure variables along the CBS system chain.

(1) The initial pathogen inputs of raw faecal waste are determined by the spatial and temporal variance of diarrhoeal diseases in the population. The specific infective parameters of pathogens in raw waste in turn determine the potential environmental transmission and severity of exposure to faecal pathogens in terms of health risks. The literature describes a limited number of studies describing initial pathogen inputs in CBS systems in both urine and faecal waste streams. Given the global health burden associated with infectious diarrhoeal diseases and enteric diseases, especially in low-income countries with inadequate water and sanitation coverage, the presence of important disease agents in human excreta and urine waste streams can be expected to be significant. However, a key gap in the literature is studies characterising pathogen inputs into CBS systems, which reflects the lack of data concerning the diarrhoeal disease aetiology, specifically in low-income contexts. The treatment processes eliminate faecal pathogens along the CBS system chain. The environmental persistence of different faecal pathogens is exploited in the specific treatment parameters (time and temperature) designed to eliminate harmful pathogens in excreta theoretically to zero. These treatment parameters affect the concentration of pathogens according to the application, efficacy and efficiency of treatment processes along the entire CBS system.

(2) The significance and relevance of transmission pathways for disease transmission in CBS systems depend on multiple risk factors. Certain pathogens are more adaptable to certain transmission pathways than others. Transmission pathways exist in a complex causal web, related to a number of behavioural, cultural, environmental and institutional risk factors. This interconnectivity is demonstrated where cutting one major transmission pathway may well show no effect on the exposure outcomes (Prüss-üstün et al. 2004).

(3) The health vulnerability of operators is affected by the specific context of the CBS system which in turn is affected by multiple risk factors. It relates to the likelihood of hazardous events and transmission pathways, but more specifically refers to the level of immunity to certain infectious diseases. Individual behaviours of operators will affect vulnerability to exposure along certain transmission pathways, in particular, hand hygiene and hand transmission.

2.11 Health Risk Assessment and Management Frameworks

The study aims to draw together tools in a framework to enable the characterisation of hazards, hazardous events or "exposure points" and employ qualitative measures or quantitative assessment methods such as QMRA in a CBS system context. The discussion of frameworks presents a landscape of relevant risk frameworks, but does not purport to be a definitive list of health risk frameworks or approaches. The frameworks were included in the review as they aligned with and add to the conceptual framework of the study.

At its most basic, risk refers to a negative future impact resulting from a future event defined as: "risk is in relation to a future activity, which has a negative consequence resulting from an external source, with respect to something humans value" (Aven 2016). Health risk assessment is the measurement of adverse health impacts from exposure of persons to (microbial) hazards (Haas, Rose and Charles 2015). It is part of a broader process called "risk analysis", which includes assessment, management and risk communication, applied to manage risks from external hazards (Haas, Rose and Charles 2015). In this review, ten risk assessment and management frameworks (Table 2.5) are evaluated that present different conceptualisations of risk ranging from simple and precise interpretations to more complex and intricate definitions that account for health vulnerabilities and the external socioecological environment. The level of risk is measured by either a quantitative or qualitative risk assessment approach; the former which views as objective and measurable. For example, the WHO safe water framework views risk as "the likelihood of identified hazards causing harm in exposed populations in a specified timeframe, including the magnitude of that harm and/or the consequences" (Davidson et al. 2005). The latter include more intricate explanations of risk production that emphasise the role of the socioecological dimensions in risk production, whereby "risk does not have an objective relationship with the hazardous event or hazard from which it arises, but is determined by variables in the environment in which it is produced" (Cardona et al. 2012). One example of this is in the climate change literature, which explicitly includes the "vulnerability of an exposed population" (Cardona et al. 2012) as an equal determinant of hazardous events in risk production.

Table 2.4 Health risk frameworks

#	Framework	Risk assessment approach	Risk assessment tools							Risk management		
			system mapping	hazard identification -quantitative	hazard identification -qualitative	key risk Indicators	risk assessment	critical control points	control measures	critical limits	monitoring	verification
1	Hazard Analysis and Critical Control Points (HACCP)	Qualitative	x		x		x	x	x	x	x	x
2	Sanitation Safety Planning (SSP) (WHO)	Qualitative	x		x		x		x	x	x	x
3	Participatory Rapid Sanitation System Risk Assessment (PRSSRA)	Qualitative				x	x					
4	Microbial Exposure and Health Assessment in Sanitation Technologies and Systems (SEI)	Quantitative/qualitative	x	x	x		x	x	x			
5	Safe water framework (WHO)	Quantitative	x	x			x		x	x	x	x
6	SaniPath tool	Quantitative		x			x					
7	Human faecal equivalents (HFE)	Quantitative		x			x					
8	SPI framework	Qualitative			x	x			x	x	x	x
9	Health and Safety Executive (HSE) framework 254	Qualitative			x	x			x	x	x	x
10	HSE 48	Qualitative			x	x			x	x	x	x

2.11.2 Quantitative Microbial Risk Assessment

A quantitative microbial risk assessment (QMRA) predicts the potential health risks arising from exposure to pathogens, and can be included as an aspect of risk assessment in a framework for the management of those risks. For instance, the WHO safe water framework (Table 2.6), which manages municipal drinking water supplies (Medema and Ashbolt 2006), uses QMRA to assess health risks and evaluate potential public health risks from environmental exposure to key pathogens (*E. coli* 0157H7, *Campylobacter* and rotavirus) from wastewater reuse and irrigation (Haas 1999; Ferrer, Nguyen-Viet and Zinsstag 2012; Westrell 2004). There is a standardised four-step method for conducting a QMRA health risk assessment from the National Academy of Sciences (Haas, Rose and Charles 2015):

Table 2.6 WHO safe water framework QMRA approach to managing risk of municipal drinking water supplies

Step one	Hazard identification	Describes/identifies index organism of enteric pathogens in the environment and associated illnesses
Step two	Exposure assessment	Measures the presence and distribution of index organisms, environmental persistence and behavioural exposure data
Step three	Dose response	Quantifies the probable health risks
Step four	Characterisation of health risks	Integrates steps 2 and 3 – in terms of potential frequency of exposure and numbers of people exposed to inform model parameters and the probability of infection (Ferrer, Nguyen-Viet and Zinsstag 2012; Nicas and Jones 2009)

These steps guide the overall risk assessment and data collection. The first step identifies the pathogen species, and in the WHO water safety plans also includes a description of the systems, hazards and hazardous events. The exposure assessment describes pathogen occurrence and variability, including the effect of treatment. This step requires a significant volume of robust microbial data to overcome temporal and spatial variations in environmental contamination, or uses secondary data on the presence of index organisms. Behavioural exposure data characterises exposures, which may be gathered through site visits, structured observations or household interviews to develop a profile of individuals within a certain population. In step three, the dose-response relationships quantify the probable health risks in exposed persons are calculated using pathogen specific dose-response curves and mathematical models based on the experimental data (Haas 2015). The final step integrates steps two and three to give a point estimate of infection risk.

Although QMRA is the gold standard in quantitative health risk assessment, as an operational management tool, costly and complex data collection may prohibit uptake of this methodology for risk assessment in small and medium-sized enterprises. However, QMRA may be more feasible if used to identify singular and dominant exposure routes (Wang et al. 2017; Robb et al. 2017) or as a follow-up procedure to quantify exposure risks where high risks are noted. Also, it can support the interpretation of monitoring data showing contamination, despite the number of assumptions required in model parameters (Haas, Rose and Charles 2015). Alternative quantitative risk assessments include the SaniPath assessment tool (Robb 2015) and human faeces equivalents (HFE) (Julian 2016). Both tools quantify health risks from exposure to faecal pathogens in the public domain, but compared with QMRA, which identifies index pathogenic organisms, the SaniPath tool and the HFE methodology determine the environmental exposure and probability of infection using a faecal indicator bacteria (FIB) (Julian 2016). The SaniPath tool combines FIB with behavioural exposure data collected from survey data related to frequency of exposure events to calculate probabilistic risks of exposure of different transmission pathways. The model output provides a useful analysis of the relative importance of transmission routes in an urban context (Robb et al. 2017; Wang et al. 2017), and although it has not been applied to municipal level service chains, presumably it could be adapted to do so. The use of FIB in SaniPath overcomes the requirement of robust data for quantification of specific pathogens and precise epidemiological data on infectious doses for susceptible populations, which is a limitation of using QMRA methods, especially in developing country contexts with an absence of quantitative data (Mattioli, Davis and Boehm 2015). However, it requires assumptions to be made regarding the relationship between the concentration of FIB and the concentration of a specific pathogen for exposure modelling. Second, the presence of FIB is assumed to be due to specific diarrhoeal diseases, although they may be related to a broader spectrum of health-related issues. HFE uses the level of environmental exposure to determine the potential risk posed by other pathogens, typically transferring exposure to *E. coli* to infection risk. Since *E. coli* is a bacteria, the HFE is only relevant for infection risks from bacterial infections that could be expected to have comparable environmental persistence. Moreover, community infection rates at a pathogen-specific level and dose-response information must be up to date and available to accurately assess risks from other pathogens, information which can be restricted in many resource-poor contexts.

2.11.3 Qualitative Risk Assessment and Management

Hazard Analysis and Critical Control Points (HACCP) is a largely qualitative preventive risk management approach. It is an almost universal approach in the food safety industry that was originally developed by NASA to prevent the contamination of space food (WHO 2000). It aims to eliminate exposure by the implementation of appropriate controls at hazardous events and is defined as "the identification of hazards with potential to cause harm, and preventative measures for control" (WHO 2003). The *Codex Alimentarius* guidelines (WHO 2003) set out the principles of risk management in HACCP, which identifies hazards and assesses the potential likelihood of hazardous events occurring along the system. One of the most important principles of HACCP is the identification of critical control points (CCPs) where "it is possible to reduce, eliminate or mitigate exposure to hazards" (WHO 2003). At CCPs control measures are set up to prevent or minimise the hazardous event and prevent contamination. If preventive measures do not exist at a CCP, the process or step must be changed (WHO 2003). The remaining principles of HACCP establish critical limits for the controls and set up a system for the monitoring and observation of critical limits and corrective actions if the control fails. Verification and documentation of the control procedures are required, although verification is normally not microbial due to the time involved and physical measurements are more valid for monitoring. The uptake of HACCP principles is evident in the risk management approach outlined in the SSP (WHO 2004, 2016). It has also been adapted to control the risks associated with the disposal of contaminated human waste (Edmunds, Elrahman et al. 2016). A limitation of the HACCP approach for CBS risk assessment might be that the concept of CCPs works well in a defined factory setting but transferability into a fluid/private domain household where use and behaviour cannot be controlled has not yet been proven. CCPs, referred to as "exposure points", are employed by Stenström and colleagues (2011) and reflect sociocultural and technical barriers to control transmission of exposure in sanitation systems. Handwashing, personal and hand hygiene or food hygiene practices conform to sociocultural barriers (Freeman et al. 2013), while technical barriers include treatment procedures, hardware and equipment features. A similar "multi-barrier" approach to reduce reliance on individual measures of control (Antwi-Agyei et al. 2016) or simplistic models of transmission was suggested by Bleck and Wettburg (2012) for tackling occupational exposure risks. This approach encourages the use of technical and organisational control measures which lead to substitution or elimination of the hazard and is preferred to personal or behavioural barriers since behaviour change is unreliable (Bleck and Wettberg 2012).

The Sanitation Safety Planning (SSP) risk assessment and management framework is a semi-quantitative, modular risk assessment designed to manage potential health risks from exposure to harmful microorganisms along a sanitation system (WHO 2016). Originally, it was developed to manage health risks arising from the reuse of the wastewater and faecal sludge from municipal wastewater treatment systems, but is intended for integration into any type of sanitary management system. The SSP approach comprises six main modules, comparable to HACCP principles, described and set out below in Table 2.7.

Table 2.7 Key modules of Sanitation Safety Planning for risk assessment and risk management

Step one	SSP team development	Preparation and assembling of a team to perform the risk assessment. A participatory approach and stakeholder engagement with an "extended peer community" (WHO 2016) is encouraged
Step two	System mapping	Describes the sanitation system, sets the boundary of the risk assessment, waste flows and exposure groups
Step three	Risk identification	Identification of hazardous events and control measures. Ranking of health risks
Step four	Improvement plans	Develop improvement plans for high-risk events
Step five	Operational monitoring	Establish operational and verification monitoring of control measures
Step six	Supporting programmes	Ensure development of supporting programmes and review plans

Essentially, the SSP guidance sets out a system and exposure risk assessment. This is typically a qualitative description, but, as in the HACCP, FIB may be quantified and used as a proxy for verification of the effectiveness of the control process (WHO 2000, 2003). Multiple transmission pathways and exposure routes are identified and, in particular, vulnerable exposure groups, to adequately estimate risks. The risks are ranked according to the likelihood and severity of the health risk. The system assessment provides the basis for the implementation of monitoring and management, making up the SSP. Operational monitoring sets up control measures at CCPs. The controls are monitored to ensure they adequately prevent or minimise the hazard.

SSP is being adopted by the CBSA to practise safely managed sanitation in CBS systems (Annex 1). However, at present there is no clear policy or regulatory framework or entity responsible for the implementation of SSP. There is also a lack of practical guidelines or tools specific for CBS systems, and bias may occur if SSP is viewed as a regulatory tool rather than as a part of an internal safety system culture. Institutional and organisational barriers such as a weak regulatory environment mean that critical levels may not be enforced at a national or even international level. However, SSP is an accessible, simple and quick to use tool relevant for small companies/organisations to use autonomously, which is a sensible approach for the sector (EU OSHA n.d.). SSP can be implemented independently at the community level or complex municipal level sanitation systems; and is designed to be conducted by system operators at site level.

A feature of qualitative approaches shared by the frameworks is the use of local stakeholder knowledge to assess exposure risks. Participatory approaches are used to assess health risks from household and community sanitation chains in Participatory Rapid Sanitation System Risk Assessment (PRSSRA) (Campos et al. 2015a), as well as in HACCP and SSP. It results in the participation of diverse groups of stakeholders in risk assessments, which encourages a mutual respect for different perspectives *and legitimises* the inclusion of new participants in policy dialogue (Funtowicz and Ravetz 1993). It also means that no one group is dominant in its concerns or specific perspectives, and trust becomes an essential aspect of the assessment (de Marchi and Ravetz 1999). However, a potential objection to such diverse participation is that users' and operators' perceptions of risk may not objectively measure hazards within the environment, which can present the wrong risk outcome and lead to a situation where risk is over- or underestimated. To illustrate this point, an assessment of exposure risks related to farmers engaged in urban agriculture highlighted exposure to heavy metals as a significant occupational exposure risk. However, the farmers perceived the considered biological microbial risks as far higher than the actual risks from heavy metals evidenced from the microbial samples taken (Gallaher, Mwaniki, Njenga et al. 2013).

The PRSSRA method spatially maps health risks but does not map system processes or identify hazardous events and control measures, precluding its direct application as a risk management tool for CBS systems. However, Acker et al. (2016) adapted the PRSSRA framework for municipal sanitation infrastructure and services, and developed a risk assessment process that identified hazardous events and used sanitary surveys to qualitatively assess the likelihood of exposure via these risk indicators in municipal systems using informed expert stakeholders. But the risk assessment format developed may not be replicated easily by small organisations and poses a problem for replication. Therefore, although a promising methodology, the approach needs refinement for adoption at a commercial or industry level.

2.11.4 Risk Metrics

The risk assessments mentioned use risk metrics to make a judgement about the level of risk (Aven 2016) and inform subsequent management plans. Risk ranking is a conventional risk metric that provides an overall view of system hazards in order to manage, determine and prioritise control measures used in a number of public health risk assessments, such as the Environment Agency, National Health Service (NHS) and the WHO (Broomfield et al. 2010; National Patient Safety Agency 2008; Edmunds, Abd Elrahman et al. 2016). A risk matrix assigns a qualitative descriptor (Table 2.8) or a numerical scale (Table 2.9) to the two dimensions of risk – the probability and magnitude/severity of the consequence. The matrix combines the probability and consequences as a product into a single risk score.

Table 2.8 Qualitative risk matrix for screening exposure risk (Environment Agency 2010)

Significance of risk	**Consequence**			
	severe	moderate	mild	negligible
Likelihood	**Risk screening classification**			
high	high	high	medium/low	near zero
medium	high	medium	low	near zero
low	high/medium	medium/low	low	near zero
negligible	high/medium/low	medium/low	low	near zero

Table 2.9 Semi-quantitative risk matrix (National Patient Safety Agency 2008)

Significance of risk	**Consequence**				
	5 catastrophic	4 major	3 moderate	2 minor	1 negligible
Likelihood	**Risk screening classification**				
5 almost certain	25	20	15	10	5
4 likely	20	16	12	8	4
3 possible	15	12	9	6	3
2 unlikely	10	8	6	4	2
1 rare	5	4	3	2	1

The consequence assesses the health outcome or potential health outcome of a hazardous event and may determine severity of the exposure (National Patient Safety Agency 2008; WHO 2016; Alberta Environment and Sustainable Resource Development 2012). Consequence scores are defined as objectively as possible through clinical symptoms or diagnosis and use agreed definitions that must be applied consistently across the risk assessment (Table 2.10). However, some measure of subjectivity occurs and requires that practical training on risk assessment and the use of relevant examples form part of the risk assessment implementation (National Patient Safety Agency 2008).

Table 2.10 Consequence description and scoring (WHO 2016; National Patient Safety Agency 2008)

Negligible/minor	1 Health effects typically requiring no medical intervention/no time off work
Mild	2 Only temporary symptoms, such as nausea or headache, minimal medical intervention/<3 days off work
Moderate	3 Moderate health impacts, such as acute diarrhoea, minor trauma, cough, self-limiting illness, some days of work off but no long-term impacts
Major	4 Very obvious health impact with significant medical intervention, long-term incapacity, chronic diarrhoeal diseases, helminth infection

The likelihood scoring reflects either the *probability* or the *frequency* of the hazardous event occurring, and refers to the chance of an event occurring at some point in the future (probability) and how many times the hazardous event will occur (frequency) (National Patient Safety Agency 2008). Both are often used interchangeably to describe the frequency with which a hazardous event or infection will occur. Both probability and frequency may be timebound, that is, the frequency/probability with which the hazardous event will occur in the next six months, one year or two years. The combined risk scores produced (high, moderate and low) accord to different actions required, the aim being to identify and eliminate high risks. But risk matrixes are not able to distinguish between high consequence and low frequency events with high frequency and low consequences events. However, events occurring at a high frequency but lower consequences are typically more acceptable to decision makers than events which occur at a very low frequency but have a comparatively higher consequence in terms of health impacts (Faber, Schubert and Baker 2007). For this reason, the numbers assigned in quantitative risk matrixes cannot be interpreted in the mathematical sense; as Hurst (1998) states, “metrics are not a measure of risk itself and the appropriateness of the metric should and may always be questioned”. However useful risk scoring is to reflect general risk level, it is important to interpret the ranking with care, considering the scales are arbitrary and controversial (Hurst 1998).

A second risk metric is the risk triplet (Figure 7) (Aven 2015), which articulates three dimensions of risk on each side of a triangle, where increasing or decreasing any element of this component will affect the overall amount of risk (Treby, Clark and Priest 2006).

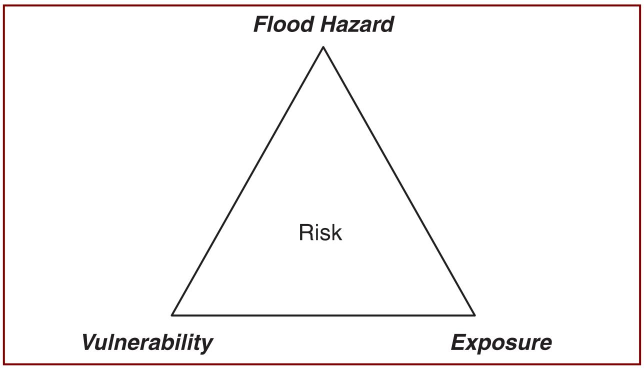

Figure 7 Risk triangle (Aven 2016)

The risk triplet produces an overall risk level (e.g. health risk level from sanitation per spatial area) (Campos et al. 2015).

2.11.5 Key Risk Indicator Assessment Tools

The PRSSRA framework uses key risk indicators (KRIs), set out in Table 2.11 below, to measure three components of risk: 1) hazardous events, 2) transmission routes and 3) vulnerability. This metric was also adapted by Acker et al. (2016) to measure risk in their risk assessment of municipal sanitation infrastructures.

Table 2.11 Indicator for exposure risk from PRSSRA

Risk component	Indicator
Hazardous events	Level of emission of pathogens and final pathogen concentration in the environment
Transmission routes	Type and duration of contact
Vulnerability	Education, age and housing conditions

Indicators as tools may observe changes in likelihood and consequence of potential risks and can indicate existing problems and guide further actions (Hwang 2010). The WHO measures the potential risk of bacteriological contamination of water sources using a set of qualitative KRIs in the form of a sanitary survey (SS) tool to predict microbiological contamination risks associated with potential exposure pathways (WHO 2004). Despite a lack of evidence of correlation between (SS) indicators and faecal contamination of water sources (Snoad et al. 2017), the WHO considers SS more valuable than bacteriological testing as predictors of FIB contamination due to the spatial and temporal variability of microbiological water testing (Adams and Wisner 2002). The lack of correlation renders them less useful in terms of use as a diagnostic tool, although they still impart value as a risk tool. The way in which indicators are chosen and values are assigned are critical to the success of the metric (Campos et al. 2015b), and it must be acknowledged that the assigning of risk scores as numerical estimates for risk is subjective and subject to bias.

Key performance indicators (KPIs) are used to monitor the overall safety of the operations and assist with risk management (HSE 2006) in the oil and gas, rail and nuclear industries. Although risk and performance indicators may measure the same thing, KPIs measure progress towards a specific goal and focus on performance targets, while KRIs focus on defining and monitoring critical thresholds (Hwang 2010). Safety performance indicators (SPIs) measure safety performance at different operational levels. Like KRIs, they give a sense of how well the entire system is operating in terms of overall safety performance.

The HSE 254 is a risk management framework developed for chemical hazards (HSE 2006). It identifies major hazards and hazardous events at risk control sites (RCS), approximate to a CCP in HACCP, and identifies appropriate control measures in place (or should be). The approach is similar but goes beyond HACCP and SSP by developing *leading and lagging indicators* for each RCS to monitor control measures (Figure 8). The metrics used as indicators may be consistent with day-to-day operational monitoring – that is, similar to critical limits from HACCP or operational monitoring in SSP; however, multiple control measures may exist for one potential exposure risk.

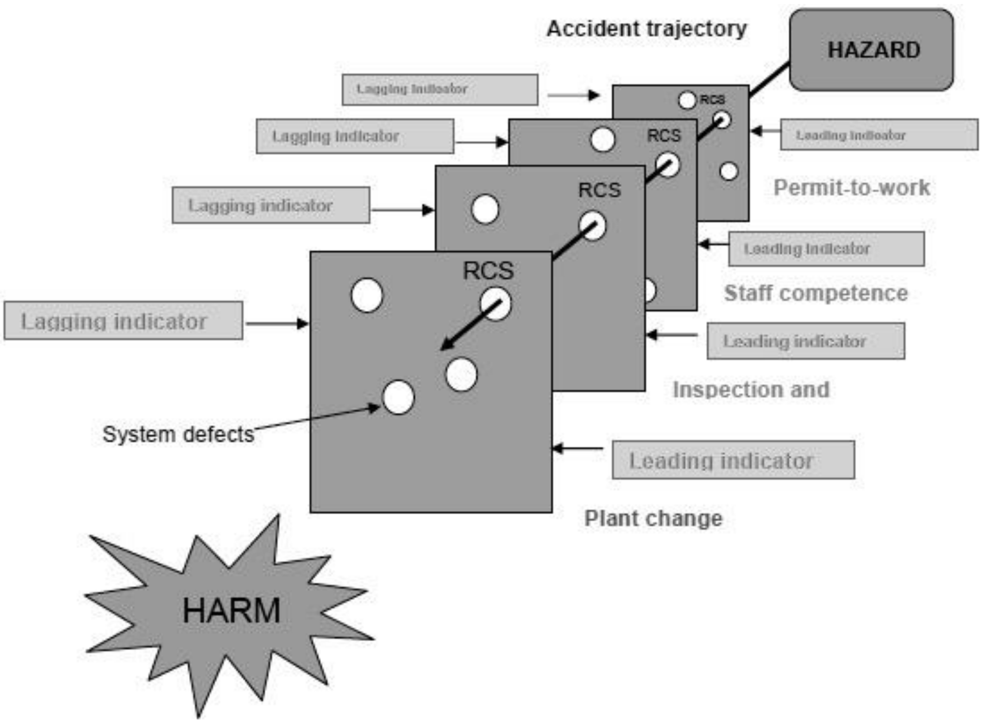

Figure 8 HSE 254 framework (HSE 2006)

The International Atomic Energy Agency safety performance framework is used for the generic safety management of hazardous industries (Figure 9). It has been adapted for the safe containment of microbiological hazards in the SPI framework (Atkins and Park 2011). The hierarchical framework consists of the upper level, which is the overall safety goal (e.g. the safe containment of biological hazards). The framework then set outs clearly and logically the requirements for the delivery of the overall safety goal down through the framework. It is a top-down approach to safety that ensures conditions necessary to achieve this overall safety goal. The hierarchical structure allows measurements to be taken at different operational levels within the organisation, and also means the overall goal is not reliant on a few or random measures.

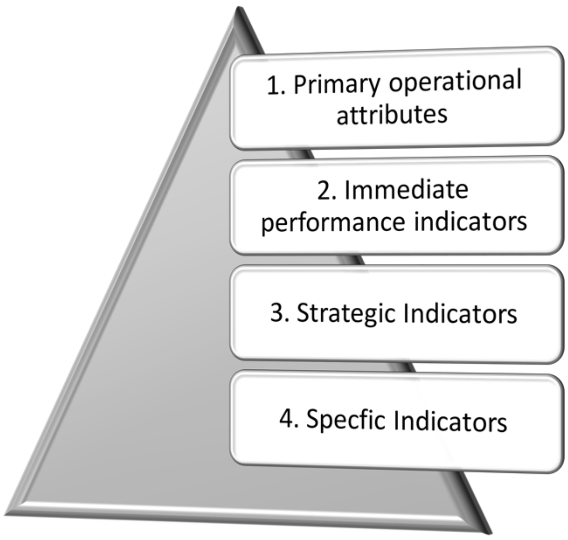

Figure 9 Safety Performance framework for generic safety management

The concept of an overall performance goal (such as safety) reflects a systems theory perspective (Leveson 2011) and provides an alternative theoretical foundation to conceptualise health risk and management in CBS systems. A fundamental aspect of systems theory is that "emergent" properties of a system (such as safety) cannot be observed from examining the property of one component of the system (Leveson 2011). Safety is determined in the context of its relationships with other components in the system; attempting to address safety issues by addressing only one part of the system would not lead to adequate safety results. For example, a safely sealed container used for transport cannot be used to determine the safety of exposure to hazardous waste. Also, single indicators may distort information; for example, an exemplary staff health record does not prevent severe consequences resulting from spillage or other losses of containment.

2.12 Behavioural Frameworks

Recognition of a human dimension in risk enables effective risk management. The human dimension in risk assessment is elevated by Hurst (1998), who considers accident causation in technical Case Studies under three perspectives of human error, failures of systems and safety culture and hardware failures. He described risk assessment as the "pursuit of completeness" to obtain a detailed and complete understanding of relevant perspectives in accident causation (Hurst 1998). In fact, recognising the human contribution to risk as a distinct and separate area is important. The HSE (1999) estimates that 80% of accidents may be attributed to a human cause or omission and points out that it is often insufficient to assign human error to frontline staff, as the root cause of the behaviour may lie deeper in organisational design, management and decision making.

The HSE 48 framework characterises two principal causes of human error as either due to 1) conscious decision to violate procedures, which is quite rare, or 2) errors that are unintentional causes of human failure (Figure 10). Errors stemming from genuine mistakes occur when a person has insufficient knowledge or awareness of rules to perform correctly, or skills-based slips or lapses of attention, which can occur however well trained, compliant or motivated a person is. Distinguishing between the two causes is important for risk management as corrective and control measures would be separate.

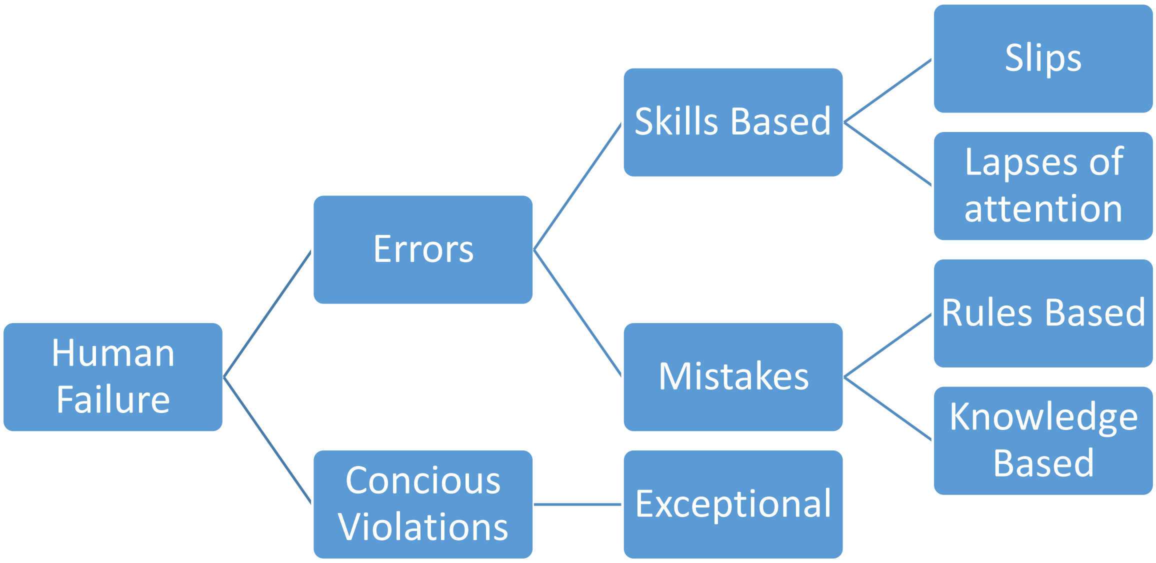

Figure 10 Causal model of human failure from HSE 48 (HSE 1999)

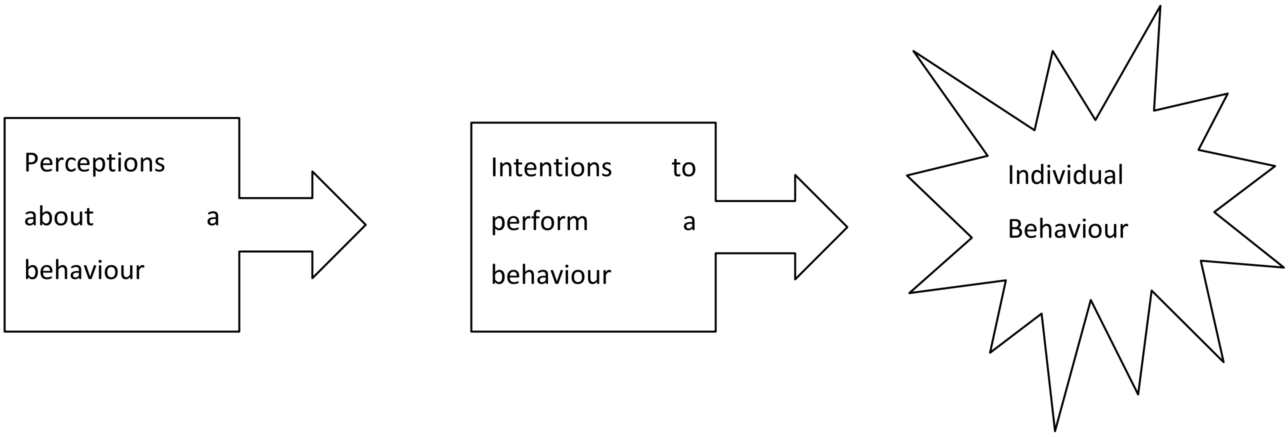

Figure 11 Barrier Analysis

Another way of understanding human behaviour is through a theory termed "barrier analysis" (Figure 11). It is based on the assumption that individual *perceptions form the basis of intentions* which, in turn, determine individual behaviour. Two models underpin the barrier analysis approach; the health belief model (Rosenstock et al. 1998) and the theory of reasoned action (Ajzen 1985), which proposed that perceptions included:

- perceived susceptibility to illness (*can I get sick*?) and threat of an illness (*how sick would I get*?)
- perceived benefits of taking an action to reduce threats
- perceived barriers to action or expectations about perceived self-efficacy

- perceived social acceptability, known as “social norms”, which describes behaviour driven by a person’s “perception that most people who are important to him [or her] think he [or she]should or should not perform the behaviour in question” (Ajzen 1985).

These perceptions about a behaviour then trace causal links from beliefs, through attitudes and intentions, to actual behaviour. The role of external factors in determining the uptake of specific behaviours, absent in the models above, is included in the motivation-opportunity-ability model (Ölander and Thogersen 1995), where opportunity to perform a behaviour is dependent on “objective conditions”, and therefore external to the person’s control when making decisions.

Mosler (2012) applied important insights from these behavioural models to identify determinants related to water, sanitation and hygiene (WASH) behaviours in the RANAS (risk, attitudes, norms, abilities, self-regulation) framework (Mosler 2012). RANAS is a structured approach for assessing and evaluating a particular behaviour (Tumwebaze and Mosler 2014) of a specific population in order to design targeted behaviour change strategies (Contzen and Mosler 2012). It has been developed specifically as a behaviour change tool for the WASH sector. Table 2.12 lists the five behavioural blocks in the RANAS framework, which manages to achieve success in sanitation interventions (Tumwebaze and Mosler 2015).

Table 2.12 RANAS framework and behavioural determinants

Behavioural determinants	Description
Risk factors	Awareness and understanding of health risks, primarily a sense of vulnerability to diarrhoeal disease, and how likely people felt they would contract diseases
Ability factors	Analyse people’s confidence to perform behaviours
Social norms	Perceived social pressure to carry out a behaviour associated with the safe sanitation management
Attitude factors	Measured satisfaction with the system and its effectiveness compared to other systems
Self-regulation	Evaluating and correcting behaviours. Habit and remembering to do behaviours

The inclusion of such behavioural frameworks and tools (Devine and Devine 2009; Mosler 2012; Michie et al. 2014) under a risk management lens in sanitation service provision may be an important aspect of health risk management and delivery of safety outcomes.

2.13 Concluding Remarks

The literature reviewed presented the linkages and described various factors that shape the transmission and exposure to faecal pathogens with subsequent infection with diarrhoeal diseases. A striking feature of the literature review was a conspicuous gap in occupational exposure risks to sanitation workers, in particular for CBS technologies. This literature review provides relevant details to guide the subsequent data collection, analysis and interpretation of exposure in CBS systems. The literature review analysed the contemporary risk analysis frameworks and methodological approaches to risk assessment that informed the methodological approach and framework development for CBS systems, including the benefits of using participatory approaches. The review revealed the use of SSP and HACCP approaches for risk management, which may be adapted for CBS and are specifically developed in the subsequent methodology. The adaptation of QMRA approaches for risk evaluation from environmental exposure in CBS may help deliver objective and verifiable results, but from a risk management perspective the methodology is potentially too complex for use as a regular monitoring tool. The literature also discussed the use of KRIs and associated benefits, as it avoids the reliance on a few or random indicators that might be difficult to measure, or lead to a distorted view of how well the organisation is fairing in terms of safety (Hwang 2010). The use of indicators also provides a high level of assurance of risk management to the organisation and external regulators (HSE 2006). Their use in the WASH sector is being encouraged by the UN (WHO/UNICEF 2015b) to monitor progress towards specific goals such as safe sanitation management and other relevant targets, especially in relation to SDG 6 (Schwemlein, Cronk and Bartram 2016).

The risk assessment framework applied in the undertaking of the research study is based on the SSP and integrates from the elements of the different frameworks, according to the explicit benefits they deliver as revealed by the literature review. The main components or steps to the exposure risk assessment framework are:

1. System mapping of the activities and waste flows produced in the CBS systems – using transect walks, observation and key informant interviews to validate the map or can be performed as part of step 4,
2. Microbiological sampling for E. Coil FIB on key contact surfaces in the CBS system for verification of level of contamination,
3. Conducting a sanitary survey across the key system components based on indicators of exposure to inform likelihood,
4. Participatory risk assessment with key stakeholders to identifying hazardous events and relevant control measures across the different system components and risk ranking.

The exposure risk framework is anticipated to be used beyond occupational exposure risk management, and it may be used to manage risk to diverse exposure groups – and it is adaptable to identify exposure risks to different exposure groups such as users and communities. The exposure risk framework may be used as part of a tool box that can support CBS service providers to identify exposure risks and validate control measures with microbiological testing. The use of exposure risk management frameworks could also be used at an institutional level to benchmark service providers and encourages the institutional acceptance of CBS systems as a sanitation service.

3 Methodology

3.1. Introduction and Overview

3.1.1. Study Purpose and Research Aims

This chapter introduces the rationale for the methodological approach, in particular the use of multiple Case Studies and mixed methods, to investigate the research aims. An outline of the overall research design is presented, to illustrate the various steps of research involved. Attention is drawn to the contribution of the literature review, the steps of field work, from data collection through to data analysis. The sections that follow elaborate on the specific methods of data collection and analysis. Issues of trustworthiness, bias and limitations of the study are addressed at the end.

The research addresses two principal research objectives and sub questions to address these objectives, outlined in section 1.8. The first objective was addressed by the evaluation of potential exposure risks to operators in the CBS systems studied, and supported a conceptual model of occupational exposure to faecal pathogens in CBS systems. The research design allows a holistic picture of exposure risk in three different CBS contexts to be developed, the foundations of which are the findings from exposure risk assessment workshops, and these are then explored in more depth with additional data strands. The second objective developed sequentially was an exposure risk management framework for CBS. The framework was theory driven by the outcomes and conditions identified as part of the first objective.

The timebound progression of research activities and outputs of the PhD is presented in Table 3.1.

Table 3.1 Research activities and outputs

Overview of the timebound progression of research phases conducted as part of the PhD research activities		
Description of research phase	Time Span	Outputs
Preliminary Work	MAR 2016 - JUN 2016	Development of methodology and methods
Initial literature review		Literature review of CBS systems, exposure risk and management
Exposure Risk assessment and data collection tools		Conceptual model development
Case Study 1 - Kenya (2016)		
Field work and primary data collection	JUL 2016 - AUG 2016	Exposure Risk Assessment
Write up initial findings	SEP 2016 - APR 2017	Exposure Risk Assessment Analysis
Data entry and analysis		Quantitative exposure modelling
Development of methods		Submission of upgrade report
Case Study 2 - London (2017)		
Field work and primary data collection	MAY 2017 - JUL 2017	Exposure Risk Assessment Environmental Sampling Quantitative exposure modelling Behaviour survey
Write up initial findings	AUG 2017 - DEC 2018	Exposure Risk Assessment Analysis
Development of safety performance framework and indicators		Identification and preparation for CS 3
Case Study 3 - India (2018)		
Field work and primary data collection	JAN 2018- MAR 2018	Participatory exposure risk assessment workshop Sanitary survey Validation and assessment of safety performance indicators (SPIs)
Write up initial findings	APR 2018 - JAN 2019	
Secondary Literature review		Literature review update
Data Analysis and Synthesis		
Final PhD edits and Thesis write up	JAN 2019 - MAR 2019	Incorporation of expert comments and corrections into thesis Final thesis submission

3.1.2. Multiple Case Study Research Approach

Three Case Studies (Table 3.2) were selected to conduct field work through a purposeful research design. The research partnerships formed with the institutions and communities that make up the Case Studies were developed over the course of the research period, which led to certain evolutions and limitations in the research design which is discussed in section 3.5.1 and 3.9. In principal, each Case Study formed an independent research step and generated theory driven analysis of exposure risks and causal mechanisms. Each Case Study was evaluated sequentially, which drove the iterative development of the data collection and analytical procedures (Wilmot 2005). The Case Study method was appropriate to evaluate, describe and explain occupational exposure in CBS. As Yin (2003) explains, Case Study research is appropriate when it is necessary to investigate *"complex multivariate conditions and not isolate variables, and … to rely on multiple, not singular sources of evidence"*. The research aim warranted a broader and more holistic understanding of occupational exposure risks than might be obtained by a more survey based or experimental design to the Case Study. Moreover, given the expected audience, practitioners reviewing findings from risk assessment consider the use of Case Studies more relevant as opposed to research conducted in fictional settings (Defra 2011). The Case Studies performed an instrumental role for the development of a risk management framework objective (Baxter and Jack 2008). The investigation of exposure risks in and of itself provided useful contextual data in the application and management of risk management for CBS.

Table 3.1 Summary of Case Studies and description of activities and operation

Case Study reference	1	2	3
Description	Sanivation	Canal boats	Whatever the Need India Services (WTNIS)
Location	Naivasha, Kenya	London, UK	Pondicherry, India
Date of study	July 2016	March 2017	January 2018
Number of users	100 households	Est. 300 houseboats	50 shared toilets
Type of organisation	Sanitation social enterprise	Private households	Local NGO
Modality of CBS unit	Urine diversion dry toilet (pedestal)	Urine diversion dry toilet (pedestal)	Urine diversion dry toilet (squatting)

Cultural practices	Wiping	Wiping	Water/washing
Collection	Serviced (weekly)	Self-managed	Serviced (weekly)
Treatment	Pasteurisation	Composting	Composting
Reuse and disposal	Fuel (briquettes)	Compost or direct disposal	Compost/soil conditioner
Case Study method	Literal replication	Theoretical replication	Literal replication

Unit of Analysis

An important aspect of the Case Study method is the specific "unit of analysis" being studied (Yin 2003). The individual cases are the boundary of the study, within which the unit of analysis was the hazardous events and eventual occupational exposure risks in system components. This was defined during the initial stages of exploration. Initially, the study attempted to cover exposure risks to all exposed individuals, but it became apparent that this was too ambitious for the field of one enquiry and, therefore, from the outset, it was decided to focus only on the exposure risks to operators.

Replication Logic

The use of Case Study research is sometimes perceived as a weakness, unable to deliver robust and rigorous research, since it does not conform to typical examples of the "scientific method", which produces statistical generalisations through sampling logic. Sampling logic typically uses large sample sizes to reduce the influence of confounding factors and bias and allows the generalisability of results to represent a larger population and different contexts in a statistical sense (Watkins 2012). In contrast, the sampling method in Case Study research relies on a replication logic not a sampling logic. This replication logic allows analytical generalisations of the findings, which may test theoretical concepts and models of exposure (Yin 2014), but these are not representations of a larger universe and are not strictly generalisable in the statistical sense (Yin 2003). Given the need to describe and explain the cause and effects of exposure risks in CBS, a survey based logic of sampling was not appropriate for this study (Yin 2003). The use of replication logic through multiple Case Studies, as opposed to singular, enabled the researcher to build stronger analytical conclusions (Yin 2018) and a more compelling study overall (Yin 2014). This replication logic informed the Case Study selection, whereby it was predicted that Case Studies would show similar exposure risks and causal mechanisms in a conceptual sense.

Cross Case Analysis

While the individual Case Studies described and explained the hazardous events and pathways that give rise to occupational exposure risks, the comparisons of findings between the Case Studies allowed the possibility of direct replication of exposure risks across cases. The Cross Case analysis brought together the findings from the "independent" studies of exposure risk outcomes and is an important aspect of Case Study research (Yin 2003).

The main purposes of the Cross Case analysis were 1) to summarise the hazardous events and exposure risks and management, given the comparison of findings across the Case Studies, and 2) to evaluate the characteristics and emerging patterns between the cases arrayed in the form of immediate and primary causal mechanisms of occupational exposure risk in CBS systems.

The Cross Case analysis did not directly compare occupational exposure risks across the cases, as this would destroy the integrity of the cases. Instead, the Case Studies attempted to replicate the conceptual theories around occupational exposure risks and risk factors in CBS systems outlined in Chapter 2. Findings replicated across the Case Studies therefore strengthened the evidence (Yin 2003) in support of the conceptual model of exposure and evaluation of exposure risks to operators. The qualitative tools used in the Cross Case analysis focused on patterns between the cases, and displaying data from individual cases. Cross Case synthesis may be quantitative, if sufficient numbers of cases exists, but in this study, three cases did not allow for meta-analysis between cases.

The analytical process identified patterns evident across the cases considering causal mechanisms of exposure loosely based on a framework of disease risk analysis that aligned the concept of exposure across a range of technical, environmental, regulatory and behavioural factors in each category and compared risk across systems (Mayer 1986).

The Cross Case analysis process guides towards developing analytical generalisations or "lessons learned" (Yin, 2014 p. 40) that aim to go beyond the specific cases explored here, but were not intended to represent a larger population nor did they propose that the findings are representative of the CBS systems as a whole. The distinction between statistical and analytical generalisations described how a Case Study approach derives generalisations through the use of theory earlier in this chapter. The Cross Case analysis produced generalisable findings and concepts that may be applicable to a variety of contexts that go beyond only those "like cases" represented by the original Case Studies, and also defined new areas of research and contributed to working hypothesis emerged from the Case Studies (Yin 2014 p. 41).

3.1.3. Mixed Methods Approach

A description of the research approach as mixed methods is appropriate, given that each individual Case Study (Table 3.4) included the collection and analysis of both qualitative and quantitative data, and integration of that data, to inform the overall exposure risk assessment. Integration of the different data strands during the research enquiry critically distinguishes mixed methods from a study that merely collects and reports quantitative and qualitative data without an attempt to integrate the two research strands, as identified in a review of mixed methods studies by Brown et al. (2015).

First, the terms "qualitative" and "quantitative" reflect different ways to address a research enquiry. Historically, these definitions have been quite divisive, with qualitative approaches seen as "soft" as opposed to "hard" and truly scientific quantitative approaches (Yin 2003). However, as Yin (2003) points out, Case Studies may be both quantitative and qualitative. When research is described as "qualitative", it typically fits under an interpretivist paradigm which understands reality as a social construct, shaped by personal narratives and perspectives (Ulin 2005 p. 17), in contrast to a quantitative approach that aligns with a positivist paradigm where reality comprises measureable, observable and objective data (Scammell 2010). Both of which really miss the point, since these descriptions are attributes of the data itself rather than an approach itself. An appropriate definition of qualitative methods used in this study is "analysis to account for construction of socially and culturally derived meanings and the human interpretations of meaning" (Scammell 2010). The use of qualitative data in risk assessment and management was essential to consider the human drivers of behaviour, in a context where human agency is seen as an important risk factor in the transmission of diarrhoeal diseases (Antwi-Agyei et al. 2016; Darout, Astrom and Skaug 2005; Graf et al. 2008). Human dimensions are an important factor in risk assessment and management (Hurst 1998) and require in-depth analysis. Describing the contextual and structural elements of the individual Case Studies in which human behaviour is embedded (Curtis 2000) is also achieved through qualitative data. The qualitative data generated may be semi-quantitative as in the risk assessment outcomes, or may be used to explore and explain patterns in the causal mechanisms. The use of qualitative methods in public health research is increasing, a hitherto underused approach by environmental health researchers (Lodell et al. 2005).

Quantitative methods used in health risk assessment typically generate numerical data used to assign and quantify the level of exposure and health risks (Barker, Amoah and Drechsel 2014; Wilmot 2005). The large sample sizes required for statistical generalisations mean that data generated from quantitative methods is resource intensive (time, money and expertise). Crucially, quantitative approaches are unable to provide insights into the contexts, the "why" and "how" of certain phenomena (Tariq and Woodman 2013; Brown et al. 2015), which are relevant in public health and risk management.

A hybrid/mixed method approach to combine the strengths of both approaches in the research outputs has therefore been used. It reflects a pragmatic worldview popular in public health research, given the interest in interactions between the human and physical worlds (Brown et al. 2015), and it allows an exploration of the social and cultural construction of risks, while not fully rejecting the notion of objective risk (Baxter and Jack 2008).

The qualitative and quantitative data collection was carried out concurrently and the integration of the two research strands was at the interpretative stage. With some exceptions, a partial explanatory sequencing occurred, whereby the qualitative studies were used to explore and explain reasons for results of high and/or low exposure risks from preceding quantitative research. This process of integration to verify findings and develop credible evidence bases (SFD Promotion Initiative 2015; WHO/UNICEF 2015b) is a principal advantage of the mixed methods approach (Yin 2003). The use of multiple data sources is routinely employed. As shall be presented shortly, a number of different data sources were used in the study, to increase the credibility of the findings; in particular, it negated to some extent the small sample sizes from which data was generated in the individual Case Studies. Triangulation of different data strands was used to examine digressions between the findings and generate new insights. For example, the data from in-depth interviews was compared alongside participatory risk assessment findings to expose differences between the interpretations and thus demand explanation and further enquiry in the discussion. Likewise, the qualitative data was used to explain trends in quantitative exposure models (Rice et al. 2013). In doing so, the perceptions of health risks from operators were considered as worthy as the evidence of "hard" biological contamination (Few et al. 2013a).

3.2. Case Study Selection

The selection of Case Studies expected to replicate findings of occupational exposure risks. The Case Studies included in the study were selected in order to "serve as a profile for understanding the principal features of a group" (Ulin 2005 p. 57). The common features typifying the CBS systems and aspects of exposure were that (1) the faecal products were collected and contained in sealed containers, (2) the containers were collected and transported to an offsite location for subsequent treatment and disposal, and (3) the management and separation of urine and solids. The Case Studies were distinctive in that they were either "paid for services" or "owner managed". Additional criteria for the selection of the Case Studies was the opportunity to yield descriptive, information-rich insights, and the willingness of CBS organisations to participate and engage in the research.

3.2.1. Case Study 1: Sanivation

The initial Case Study with Sanivation was an opportunity for the researcher to become familiar with a CBS system study. The research was conducted over five weeks of field study from 10 July to 2 August 2016.

Sanivation is a Kenya-based sanitation social enterprise that produces biofuel from collected faecal sludge waste. The organisation was founded in 2014. The CBS service used for this study is Karigita, a peri-urban town in Nakuru county, central Kenya. Kenya is considered a middle-income country, in the medium human development category and ranked 142 on the UN's Human Development (HDI), which accounts for levels of education, health and life expectancy (UNDP 2018a). The ILO (2017) reports that around 26% of the population live on less than $3.10 (in purchasing power parity) per day. The population at the study site has exploded in recent years due to economic migrants attracted to the area by the vegetable growing and flower farm industry, which exports high-value products to the global market. The flower farms located in Nakuru county employ an estimated 70,000 local residents (Naivasha, n.d.). The majority of the workers are women and they rent single rooms, which make up plots consisting of 8–10 rooms. These plots tend to have a single pit latrine but no sewered connections and no water supply. Sanivation removes both urine and faeces and uses urine-diversion toilet and collection buckets for urine and excreta (Photo 3.1). The portable toilet is provided free to householders who then pay a small monthly subscription fee to use the service. The waste is collected and transformed into fuel briquettes.

Photo 3.1 Sanivation collection vehicle for the collection of containers from households and transportation to the offsite centralised treatment facility

At the time of the field study, Sanivation provided this CBS service to almost 100 households. There were two frontline staff members who interacted with the householders receiving the service, one of whom (female) liaised directly with the clients and the Sanivation office-based staff. The servicing operator (male) was responsible for the (1) collection and replacement of the containers and cleaning duties and (2) the transportation of the contents of the containers back to the treatment facility. At the treatment facility, there were two treatment operators (male) who were responsible for performing activities associated with (1) the unloading and processing of containers and (2) the treatment of faeces and urine for post-processing.

3.2.2. Case Study 2: London Canal Boats

The second Case Study explored the operation of CBS on houseboats in the UK, in Central London canals. Data collection and analysis was over three months, March–May 2017, and a second study took place in July 2018. The socioeconomic context of the UK is reflected by its rank of 14 on the HDI, with life expectancy of 81 years and 17 expected years of schooling. Thus, Case Study 2 was situated in a more developed context in terms of the national economic size and strength, when compared with either Case Study 1 or 3. The London CBS system Case Study was selected due to its distinct context but was also convenient to access; with minimal investment in terms of time and resources and required no interaction with an external private service provider.

The London canal network is home to an estimated 3,000 live-aboard canal boat dwellers and in recent years there have been significant increases in the number of boats being used for habitation (Symonds 2016). The canal boats provide a permanent urban living space and the canal networks are juxtaposed with the more traditional urban environments (Photo 3.2). These canal networks share similarities with urban contexts in the developing world. Vehicular access is limited, space and tenure is informal and amenities such as electricity and water are communal and sourced. Canal boats are unsewered and excreta[7] must be stored temporarily on board. Direct defecation or urination into the canal is not culturally acceptable. Two techniques for managing sanitation on board a boat exist: (1) excreta together with the black water used for flushing is stored in a tank and evacuated using a pump-out "pay for" service at points connected to the sewered system on land; (2) excreta is stored in small portable containers and manually disposed of in disposal points along the canal network, which are free to use. A growing number of boaters are switching to a urine diversion dry toilet and composting treatments that share several technical similarities to the CBS systems, the principal difference being

[7] Urine and faeces (Tilley et al. 2014)

that the CBS systems used on canal boats are self-managed units. There is no entrepreneur or service provider contracted to collect and/or treat the waste. The participants are thus considered both "users" and "operators" of CBS systems, since they self-manage the collection and conveyance and/or treatment and/or reuse and/or disposal of the waste.

Photo 3.2 Canal houseboat mooring up on the Lee Navigation Canal in London, UK

3.2.3. Case Study 3: Wherever the Need India Services

The third Case Study was a CBS system provided by Wherever the Need India Services (WTNIS) in Puducherry, India. WTINS is a local partner of the charitable institution Sanitation First, based in the UK. WTNIS operates in the Cuddalore district of Tamil Nadu and the union territory of Puducherry (Figure 12). The field work was conducted over three weeks in February–March 2018. India is also described as being in the medium human development category, ranked 130 out of 189 countries on the HDI. Almost half the population, 42%, live on less than $3.10 per person per day (UNDP 2018b), and a high inequality of income distribution also exists in India.

WTNIS provides a communal urine separation squat toilet (named a "GroSan") free of charge to local communities. The community toilets are located in urban areas, where communities live without any other sanitation options, meaning open defecation is the normal sanitation practice. The toilet service is focused in urban slums, which are characteristically juxtaposed with higher level income residents, typical of Indian urban development and income inequality. The GroSan units are supervised to ensure correct usage and maintenance through their community organisers.

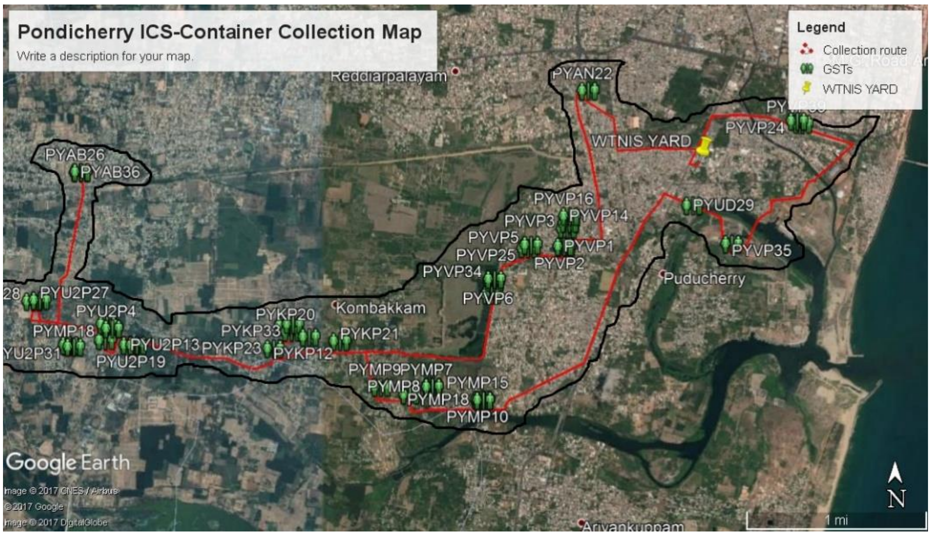

Figure 12 Location of GroSan toilets and the WTINS composting facility in Puducherry, India

At the time of the field study, there were 41 operational GroSan units being managed by WTINS. In terms of frontline operational staff, there were two cleaning staff (female), two collection and transportation staff (male) and one treatment facility staff (male). WTNIS provided weekly collection and maintenance services for the community toilets (Photo 3.3). There are four solid containers placed under each GroSan toilet unit. Once each container is filled (in about a week), the containers are rotated. By the time the fourth container is in use, the first container has stood for about three weeks and is in a position to be removed. WTNIS staff transport the container to the processing compound. Treatment of faecal waste is by aerobic thermophilic composting, using windrows with the addition of farm manure to enrich and support the composting process. Once it is certified pathogen free, the compost is packed and supplied to local farmers. The farmers use the compost to grow food and cash crops for domestic and commercial consumption.

Photo 3.3 GroSan unit showing operators removing full containers and replacing the container from the rear of the unit

3.3. Research Design

Figure 13 illustrates the research steps and embedded data collection and analytical components aligned with different units of analysis across the three Case Studies. The variety of research methods which were applied were used to unpack the different aspects of the research objectives and hypothesises. The findings from each case study were used to as evidence against hypothesis developed at the outset. Although, it was not always possible given practical resource limitations to replicate these findings across the case studies, the results feed into a bigger picture of triangulation across multiple methodologies.

The first step in the research was the literature review of the current scope and scale of CBS systems and relevant exposure studies associated with the transmission of faecal pathogens. The review was ongoing and constantly updated to account for novel findings of exposure and transmission of diarrhoeal disease (Wang et al. 2017). The second step was data collection and analysis that occurred in all three Case Studies. Figure 13 highlights the different quantitative and qualitative data collection techniques used to investigate variations in the level of environmental faecal contamination at critical points, behavioural analysis and other risk factors that affect the relationship between hazardous events and exposure risk outcomes. The interpretation and analytical components integrated these different elements to develop a comprehensive understanding of CBS systems and analytical generalisations of the exposure risk assessment and exposure risk factors. The final output was the safety performance indicators (SPIs), which were piloted in Case Study 3. The SPIs are indicators developed from the theories of exposure risks emerging as findings from the Case Studies.

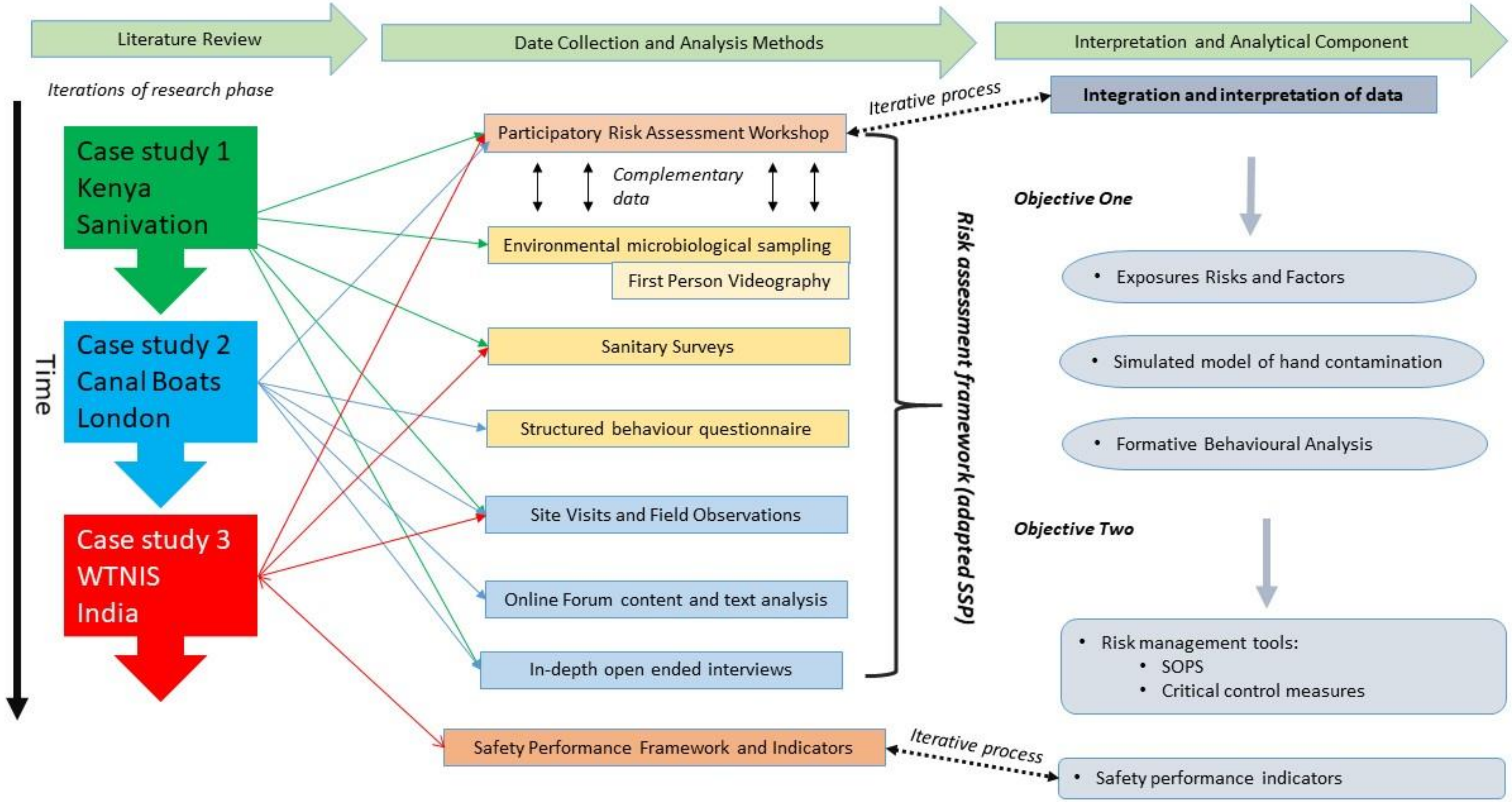

Figure 13 Integration and sequencing of Case Studies, data collection and analysis

Table 3.3 summarises the four main data collection components (and analytical component) utilised in the Case Studies for the exposure risk assessment: 1) the participatory exposure risk assessment workshop (exposure risk outcomes) including key informant interviews (risk factors and transmission pathways); 2) field visits and participant observation; 3) behavioural and sanitary survey (risk factors and transmission pathways); and 4) environmental microbiological sampling (hazard and transmission pathways). Additionally, the text analysis in Case Study two informed risk factors and transmission pathways. The findings from individual qualitative and quantitative strands are compared and triangulated and integrated during the interpretation and discussion of exposure risk. The micro-level activity time series data (Table 3.3, row 7) contributed to the QMRA exposure estimate of fomite transmission. The quantitative exposure assessment and modelling conducted here was not intended to emulate gold standard microbial exposure science studies, but captured exposure information specific for CBS systems and contributed to the development of a multidimensional risk management approach that combined microbial and behavioural data. The following sections will elaborate on the specific methods for data collection, analysis and synthesis applied for each Case Study.

Table 3.3 Primary data collection elements

Data collection element		**Quantitative/ qualitative**	**Case study**			**Analytical component**
			1	2	3	
1	**Risk assessment workshop**	Mixed	Yes	Yes	Yes	Exposure risk (outcomes)
2	**Key informant interviews**	Qualitative	n=6	n=4	No	Hazardous events, transmission, (pathways), outcomes
3	**Online forum – text analysis**	Qualitative	No	Forum threads Dec 2016–Mar 2017	No	Hazardous events, transmission (pathways)
4	**Field visits and participant observation**	Qualitative	>20 HH 2 x c/c 1 x treatment	> 20 HH	> 20 HH 2 x c/c 1 x treatment	Hazardous events, transmission (pathways)

5	**Structured survey (behavioural and visual)**	Quantitative	Sanitary survey (n=20 toilet interfaces)	Behaviour survey (n= 40 pp)	Sanitary survey (n=12 toilet interfaces)	Transmission and risk factors
6	**Environmental microbial sampling**	Quantitative	Yes	Yes	No	(hazard and transmission pathways)
7	**Micro-level activity time series data through videography**	Quantitative	20 HH servicing events, two hours following operator			QMRA

3.4. Ethical Approval and Informed Consent

The relationship between the researcher and the gatekeepers of the Case Study sites posed potential ethical dilemmas. Access to CBS sites was based on cordial relations and the trust established between the researcher and gatekeepers of the CBS sites during informal meetings and international conferences settings. However, the informal basis of the relationship presented potential ethical dilemmas. There was an unspoken acknowledgement from gatekeepers that any research findings presented externally would not present the organisation in a bad light or damage their reputation as a CBS service provider. In fact, there was the expectation that the research would yield positive findings (such as low occupational exposure risks) that would support the entire CBS sector to scale up activities. Indeed, the researcher's own bias sought to demonstrate CBS as a positive alternative to other onsite sanitation infrastructure and technology choices from a public health perspective. There was therefore a dilemma in truthfully presenting the findings (accounting for the researcher's subjective bias), while not placing the CBS service provider in an unfair position. The second ethical dilemma resulted from direct interactions with frontline staff targeted for primary data collection. Frontline staff occupy a lower position hierarchically within the organisation, which results in a strong power dynamic that can make staff feel vulnerable and exposed to repercussions from disclosing or sharing concerns with the researcher. During data analysis, the researcher took into account the potential that statements made by key staff and stakeholders might be subject to this power dynamic. Other ethical issues considered were if the day-to-day CBS operations would be disturbed by the research activities in the Case Study sites. The potential for the observation of staff performing routine activities to lead to mental stress on staff was taken into account in designing the research protocols. Ethically, it was required that the benefits of the research be shared with the participants as well as the researcher. Making sure the results benefited the participants of the enquiry was a key aspect addressed in the study protocol.

To address these potential ethical issues, memorandums of understanding (MOUs) were drawn up between the CBS organisations, the researcher, the university and Unilever, the primary funding source. The MOUs outlined the expectations related to permit research activities, including interviews and observation for data collection purposes (Appendices 1–2). The MOUs also discussed the protocols for sharing research findings resulting from an in-depth analysis of occupational exposure risks within their organisation, including expected benefits, with CBS providers and other stakeholders. The MOUs required that findings be approved by the CBS service providers prior to publication. In the case of PhD write-up, the findings could be reported freely. Sanivation granted approval to carry out research work on 12 May 2016, according to the research protocol, and worked closely with the researcher to ensure the research was carried out in a rigorous and methodical manner. Sanitation First and Wherever the Need India Services (WTINS) granted approval to carry out collaborative research work with the signing of an MOU between Sanitation First, WTNIS and the researcher and research supervisor on 16 February 2018.

The identity of participants was not disclosed and names were dissociated from responses during the coding and recording of qualitative data. The live data was stored on an encrypted hard drive and backed up on the UCL networked drive. The paper records were stored at the researcher's immediate office space and will be destroyed at the end of the PhD study. All data was recorded and licensed in accordance with the UCL data laws. The data was ultimately owned by Unilever, according to the contract with which the researcher fulfilled the research.

All data collection activities performed as part of the research complied with ethical procedures approved by the independent UCL Research Ethics Committee. Ethical applications were sought and approved for each of the field work activities.

In relation to Case Study 1: Ethics approval was granted by the Chair of the UCL Research Ethics Committee at University College London (9097/001, approved 7 June 2016).

In relation to Case Study 2: Ethics approval was granted by the Chair of the UCL Research Ethics Committee at University College London (9097/002: Human safety and risk reduction of microbial exposure in container based sanitation system, approved 21 April 2017).

In relation to Case Study 3: Ethics approval was granted by the Chair of the UCL Research Ethics Committee at University College London (Project ID/Title: 9097/004: Exposure risk management in container based sanitation, approved 9 January 2018).

As an aspect of the ethical approval, the specific study objectives were shared with potential participants in order for them to give informed consent. The form also acknowledged their right to data protection, which included disclosing specific information to the organisation.

Regarding the use of online web content, the guidelines and legal advice were followed according to Facebook principles. This stated that, to use forum content, a privacy policy statement had to be pinned to the Facebook page, informing forum group members that information posted might be used for the research objectives described here.

3.5. Exposure Risk Assessment

The exposure risk assessment workshop was the starting point for data collection in all three Case Studies. It adapted the relevant modules of the SSP manual that refer to a comprehensive framework for exposure risk management (WHO 2016) and HACCP guidelines. However, since implementation of control measures or improvement plans fell outside the scope of the research study, only the first three modules from the SSP framework were adapted to inform the following steps:

1) construct a system map
2) list potential hazardous events, transmission pathways and specify exposure groups and identify CCP and control measures
3) rank the specific exposure risks.

The first step of system mapping developed a level of familiarisation and knowledge of processes and activities in CBS system. It consisted of a situational analysis of the site through field visits that produced initial diagrams of the CBS system (Drechsel et al. 2008), which also defined the boundary of the CBS system. For the Case Studies, the assessment system boundary was limited to the first four CBS components: containment during toilet use, emptying and collection, transport, and waste processing and treatment of the excreta and urine. For simplicity, reuse of the final product in the system mapping and subsequent exposure assessment was not considered. The system map was a simple flow diagram annotated to describe the steps and processes undertaken in the operations and encouraged the identification of CCPs (WHO 2003). The system maps also characterised the nature, transformation and storage of waste materials, specified exposure groups, and sequencing of activities and processes. Waste characterisation identified different waste fractions, including variability of each waste type and the physical path taken through the system. Along the system components, the following information was recorded:

- Waste source and type, volume and expected pathogen load of the waste (helminth, viral, bacterial, oocysts).
- Secondary data sources or qualitative data sources informed the level of incidence and prevalence of diarrhoeal disease in population.

The second step was the identification of hazardous events and transmission pathways to operators. The definition of a hazardous event is "an event which might lead to human contact (users, operators or communities) with faecal waste and provide an opportunity for transmission and infection" (WHO 2016). Transmission pathways (WHO 2016) were adapted from the SSP guidance to specifically account for the role of fomites and urine as a potential transmission pathway in CBS systems. Identification of the hazardous event was initialised in a previous step of system mapping but furthered by (1) the participatory workshop and (2) during participant and transect walks of system components (described in section 3.6.1).

Participatory Workshops

The participatory workshop brought together stakeholders to identify and make decisions on occupational exposure risks. The participants were employees of the CBSSP; including cleaners, service operators and management personnel. In case study two the primary participants were users/self-operators and some representatives from the industry. The participants were chosen to reflect a mix of age and gender – however no children were present as the workshop considered occupational exposures. The education levels of the participants varied within and between the Case Studies. The education level was not recorded; although it can be assumed that given the context and setting of the workshops all participants in Case Study two are likely to have completed secondary education, and all participants where literate. In contrast, in Case Studies 1 and 3, not all the participants were literate, and did not speak English as a primary language – although all participants were able to speak English at a basic level. In all case studies the workshop participants volunteered and were recruited through direct engagement as employees of the organisation or responded to advertisements for the workshop publicly located (Case Study 2). The location of workshop was chosen to be convenient to the participants and was therefore held either in the place of the organisations head office. In Case Study 1 the workshop session was held in Sanivation offices, Sanctuary Farm, Naivasha, Kenya. In Case Study 2 the workshop was held in a local café that also encouraged participation with snacks and refreshments offered to participants. In Case Study 3 the workshop was held at the WTNIS service office in Puducherry, India. or centrally located public venue that was convenient to the targeted population. All the workshops were held over one day – which was enough time to cover the agenda and fitted in with time commitments. In Case Study 2 a trade-off was between a daytime workshop which restricted participation to those in part-time or self-employment; but was preferred to an evening event as some people worked nights/shifts/had other plans. More importantly, an evening event would have been far shorter.

Appendices 4–6 demonstrate the risk assessment materials adapted from SSP shared with stakeholders, which defined the relevant biological hazards, hazardous events, exposure pathways and receptor groups. The forms developed for the participatory workshops assisted the participants in the identification of hazardous event and exposure pathways and control measures where the information was recorded on a relevant data entry format. This produced a table of hazardous events, transmission pathways and exposure group for each system component and relevant process step.

The inclusion of stakeholders in the participatory workshop disrupts what Winterfeldt (1992) refers to as "the normal paradigm of expert control and provides public inputs where none traditionally exist and is an opportunity for dialogue creation and option invention to inform decision making and debate". The inclusion of operators' voices in the research (Scammell 2010) was an important factor, given the potential marginalisation of operators performing manual or cleaning roles (HSE 2016), compared to colleagues performing more managerial roles within the same organisation. The workshop format followed a discussion of system inputs, process activities and potential exposure risks in detail for each system component. The workshops were an opportunity for the different stakeholders to share experiences and so provided qualitative content and anecdotal evidence that could be drawn upon later in the subsequent analysis of the risk assessment.

The presence and efficacy of control measures was recorded, including the presence of single or multiple controls, and participants determined whether they felt these controls were effective or ineffective at controlling the hazardous events or exposure risk. If there were no control measures in place for a particular exposure risk, this was also noted. The identification of CCPs where hazardous events exist in the system is a key part of the HACCP exposure risk management approach (WHO 2003). At CCPs, control measures represent an opportunity to reduce or eliminate transmission occurring.

Although described sequentially here, the identification of control measures at CCPs and relevant mechanisms were recorded concurrently as part of a risk assessment and taken into account during the risk ranking exercises.

The third step was risk ranking: where the participants "scored" individual hazardous event and exposure pathway (together termed an "exposure event") according to the likelihood (L) of hazardous events and exposure and consequences (C) of the exposure in terms of adverse human health impacts. The level of risk was assigned using a numerical scale to rank the likelihood and consequence of each specific exposure event and combined the numerical values in a risk matrix to determine the risk level (Tables 3.4 and 3.5 respectively) according to a traffic light system, with a low-, medium- and high-risk status adapted from the SSP (WHO 2016). When assigning the risk level, the infectious potential of the exposure event and health consequences were taken into account. It was assumed that infective pathogenic organisms were present in raw human excreta. Although it is acknowledged that the initial pathogen load in raw excreta depends on the incidence of enteric infectious diseases in the local population, since prevalence was unknown for many scenarios and typology so varied, a reasonable correlation between human excreta and pathogen presence may be assumed. Urine was also considered a microbial hazard, since studies in a similar sanitation service chain concluded that stored urine was highly contaminated (Bischel et al. 2015).

Table 3.4 Likelihood and severity semi-quantitative (timebound) classifications

Likelihood of exposure event (L)	
High 5	Several exposure events per day
Routine 4	Routine (daily) exposure events per day
Incidental 3	Less than one exposure events per day
Negligible 1	Less than one exposure events per week
Consequences (C)	
Significant 5	Hazard or hazardous event resulting in illness – chronic diarrhoea, wasting, helminth infections
Moderate 4	Hazard or hazardous event resulting in self-limiting health effects; acute diarrhoea
Mild 3	Hazard or hazardous event resulting in minor health effect – nausea, irritation
Negligible 1	None or negligible health effects compared to background levels

Table 3.5 Risk scoring based on semi-quantitative risk matrix

Exposure risks (L x C)	Description
High 20 and above	Possible that the event results in acute and/or chronic illness. Urgent action required to minimise risks
Medium 4–20	Possible the event results in moderate health effects – fever, headache, diarrhoea and unease from malodour
Low <3	No health effects anticipated. No action required now. The risk should be monitored for changes

3.5.1. Key Differences across the Case Studies in the Exposure Risk Assessment Methodology

The research collaboration with CBS organisations to carry out and participate in the research were developed over the research period. The research activities therefore had to comply with restrictions enforced by the organisation; that reflected their capacity and openness and ease of an independent researcher looking at 'health risks' to their employees – which was potentially a sensitive issue. The following sections provides a rationale to some of the key differences in the methods applied and particular limitations.

Case Study 1

The participatory exposure assessment was severely time limited in the field (due to public holidays and staff pressure), meaning that the risk ranking exercise was performed by the researcher – but considering the views and perceptions of key stakeholders and was validated by the management team. This may have affected the risk ranking and scoring comparative to other Case Studies which were scored by participants. However, the use of the same risk matrix and descriptive classifications limits this effect. Nonetheless, direct comparisons between Case Studies must take into account variable subjective interpretations of risk scores. Direct observation and transect walks at both a household and facility level were performed to inform system maps. Specifically, the collection operator during collection cycles was shadowed to observe activities and exposure events occurring at both the user interface and during collection and conveyance. Similarly, activities over a two-day period in the treatment and processing site were observed.

Case Study 2

A one-day exposure risk assessment workshop was held, with eleven key stakeholders, principally made up of toilet users, since no service provider is responsible for the operation of the units. Kildwick and Simploo, two CBS manufacturers, were approached and participated with their insights and information during the workshop and risk assessment. The Canal & River Trust, the regulatory authority that oversees all activities and monitors boat use in the UK, was approached to contribute to the overall perception of the use of CBS systems and overall risks but did not participate. The workshop was held in locations convenient to the stakeholders. Recruitment was face to face, via social media in the UK using a closed Facebook group, or distributing information online and physically in the community.

Case Study 3

The third Case Study was limited in performing certain elements that were represented in the other Case Studies- however – the main activity of the participatory exposure risk assessment, sanitary surveys and system mapping was well engaged with by the country team and therefore it was felt that the other limitations were acceptable. Principally, it was not possible to perform any microbiological sampling and collect FIB due to a lack of access to laboratory facilities in India. This component of the exposure risk assessment was considered less crucial, and the microbiological data from the Case Studies 1 and 2 was adequate to start to develop and quantify findings in relation to the role of contact surfaces in transmission risks. One of the more critical elements that was lacking was key informant interviews, which was directly blocked by the national program director. Although, unsatisfactory the research did collect informal conversations with the relevant workers as a substitute in the data analysis. The first risk assessment was independent of the PhD research and the results were shared with the researcher.

3.6. Qualitative Data Collection and Analysis

To supplement the exposure risk workshops, further data was obtained on the contextual and behaviour factors associated with exposure risk through the qualitative data collection elements and qualitative analysis.

3.6.1. Participant Observations and Site Visits

Site visits were a key source of gathering primary data and information related to the work activities of CBS system operations. Site visits were conducted at all three Case Studies, although in Case Study 3 it was not possible to observe the conveyance or activities associated with the reuse and/or final disposal of the waste. Field observations were made overtly without intended interruption to the programme activities. The "Hawthorne effect" describes a phenomenon where the act of observation itself affects the performance of activities - through alterations to and/or avoidance of doing particular behaviours due to being observed (Gould 2017). The potential effect of this was acknowledged during the interpretation of observations of hand hygiene. To limit the Hawthorne effect on the workers during observation – the observation was made as unobtrusive as possible, for example, not carrying any checklists/boards and not standing and staring whilst workers performed activities. An estimated minimum period of two days were spent by the researcher conducting "onsite" field visits at each of the Case Study settings – which also allowed workers to become somewhat customised to the researcher being present during operations. First-hand CBS work activities were observed while accompanying frontline operators at different service levels: the service operator and/or user was accompanied on collection visits, including cleaning and emptying the toilet units, and the transport of urine and excreta back to the site for treatment (Case Studies 1 and 3), or its removal to a storage/onsite treatment site (Case Study 2) was observed. A minimum of 20 CBS toilet units located at household or community level were visited in each Case Study. In Case Studies 1 and 3, the treatment facilities and waste handling and processing activities were observed. In Case Study 2, the handling and treatment, storage processes and/or the direct disposal of urine and faeces were observed.

Details of the site visits and observations gathered were written up, including notes on procedures that deviated from normal or potential hazardous events and potential risks to operators. The information yielded from site visits enabled a new perspective and added depth and context to exposure risk assessments and quantitative data components, and supported the analysis of quantitative and qualitative data at interpretation. During the site visits, time was spent talking with users and operators. Although informal and unrecorded, these onsite discussions allowed the individuals and workers to describe and explain their use and working practices, variations from the norm and supplemented information from qualitative in-depth interviews. Fundamentally, site visits enhanced an understanding of the overall CBS system processes for the principal researcher, which improved the subsequent interpretation and perspectives yielded from other data collection methods. These field notes are located in Appendices 7–8.

3.6.2. Semi-structured Interviews

Individual narratives of exposure were investigated based on semi-structured key informant interviews. A purposeful sampling methodology is consistent with health research studies, where participants were chosen for their particular insights into exposure (Borghi et al. 2002; Pickering et al. 2013), but is less desirable than random selection as it is not a representative sample of the total population cohort. Ten operators were selected from Case Studies 1 and 2 (n=6, n=4 respectively). It was not possible to recruit interviewees from Case Study 3, due to problems beyond the researcher's control. Questions were open ended and constructed to avoid "leading" questions. The role of the researcher and the subjective bias in the interview process are discussed later. The interview was loosely guided by questions related to:

- demographic background information
- length and experience using/operating CBS
- knowledge and perception of health risks associated with faecal pathogens
- experience of accidents and exposure events arising during CBS work activities
- perceptions of the system management
- other people's perceptions about the CBS system.

The interviews were conducted in English and administered face to face. The interviews were recorded on Recorder software, a simple android audio device. Immediately after each interview, the audio recording was transcribed into a Word document and included any information and contextual information that had been spoken but not recorded during the interview. Where translation was required, a translator was present. On average, interviews lasted 25–50 minutes. However, the objectivity and quality of in-depth interviewing improved naturally over time as the interviewing technique was adapted and evaluated while transcribing interviews.

3.6.3. Document Data

In Case Study 2 an online Facebook forum with nearly 2,500 members called "Compost toilets for boats and off-grid living" was a rich source of content for text analysis (Figure 14). The forum provides a space where members contribute regularly to threads about personal experiences, technical advice, questions and opinions on subjects related to the use and operation of CBS systems. A random period for analysis, December 2016–April 2017, was selected. The selection of relevant threads was guided by reference to any component of the CBS system: use, emptying, collection, composting, waste and disposal. Threads were transcribed in Word software with a reference number and any identifying personal data was deleted. The qualitative data and subsequent analysis (section 3.6.4) was expected to provide insights into exposure risks and CBS system processes and behavioural determinants of exposure risks.

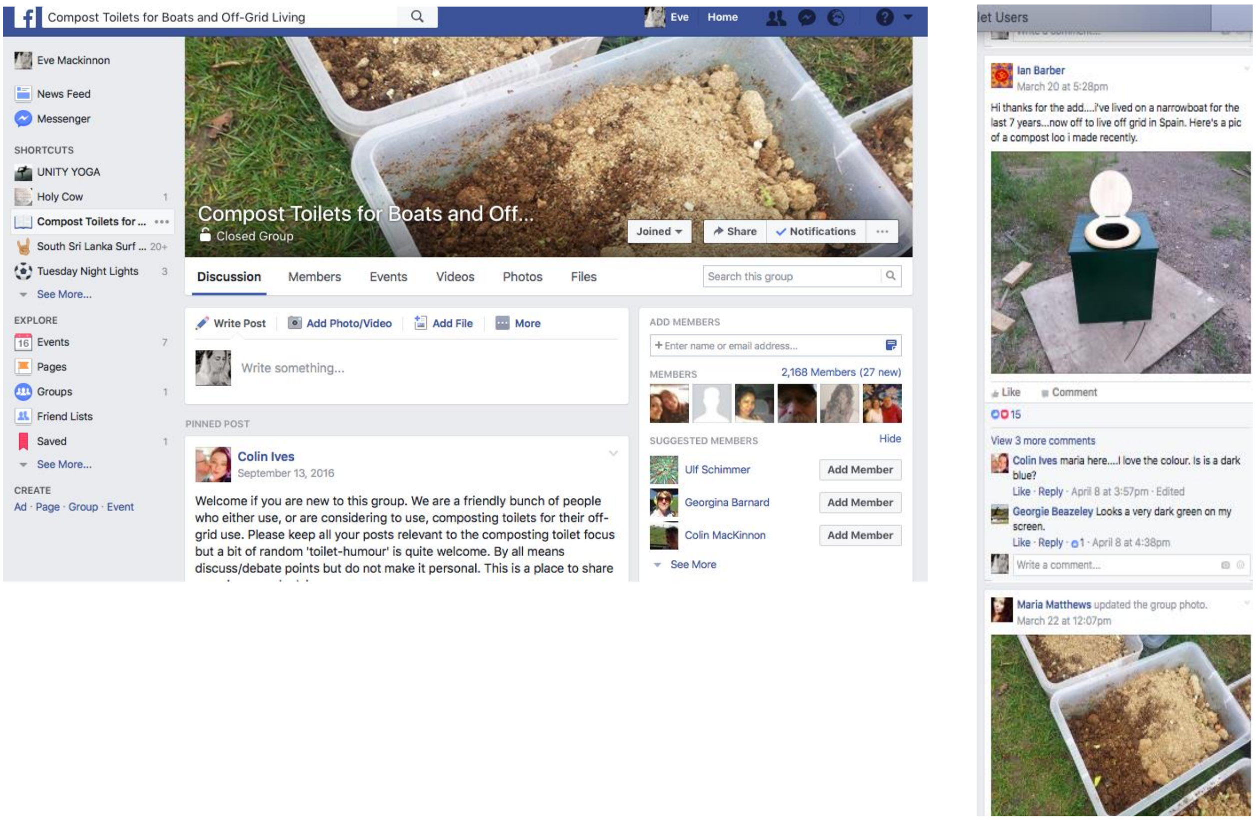

Figure 14 Facebook forum 'Compost toilets for boats and off-grid living' landing page used for qualitative data collection

3.6.4. Qualitative Data Analysis

The qualitative data analysis comprised the analysis of interviews transcripts, field observations and text analysis. Transcripts and field notes were uploaded to NVivo 11, a computer-aided qualitative data analysis software, which enabled the researcher to identify trends and patterns within the qualitative data through coding. In the analysis, segments of the text were classified and organised using deductive and inductive codes (applied in NVivo 11) and aligned to the theoretical domains of the RANAS behavioural framework (see section 2.12). These behavioural domains guided the deductive coding using a qualitative codebook, as described by Creswell (2009). Text was classified by marking segments of codes that corresponded to a code or multiple codes. The structural coding categorised textual data under the conceptual domains, which were then collated and compared for more detailed analysis. Further analysis inductively coded and added subcodes and searched for relations and patterns in the data.

Once the text was coded, NVivo 11 used search procedures to collate different segments of text under the same codes. In this way emerging patterns in the responses to these codes and explanations of causal mechanisms and risk factors emerging from the narratives were derived. Analysis of the simple frequencies in how frequently codes were referred to helped identify major themes expressed by participants. In the results and discussion chapter, the qualitative data analysis explores these behavioural factors driving the management of the CBS systems and looks at relationships that exist between these themes. A number of statements are presented directly as quotes as it allows the voice of the operators to be heard. The findings from the qualitative analysis are also used to support and explain the findings of the risk assessment workshops. In the Cross Case analysis and discussion, the findings from qualitative data strands are compared with relevant findings in the literature.

3.7. Quantitative Data Collection and Analysis

3.7.1. Sanitary Survey

The sanitary survey component collected quantitative data and measured the extent of risk according to indicators, or proxy indicators linked to components of hazardous events, transmission pathways and vulnerability of the operator to exposure to faecal oral pathogens; the surveys are located in Appendix 9–11. The choice of indicators was based on the fact that they are reliable and linked (correlate) to exposure and measurable and verifiable (Schwemlein et al. 2016). The indicators and rationale for selecting them are defined in Table 3.6. Excel software was used for sanitary survey creation and analysis in Case Study 1 using paper survey formats. In Case Study 3 the survey was created using Open Data Kit (ODK), which supports survey creation, data collection and analysis. Since the data collected was not exported to the ODK server, the collection complies with the General Data Protection Regulation (GDPR) and did not require encryption. The results from the surveys were downloaded onto Excel software. The analysis of the survey identified averages, means and percentages of exposure risk and triangulated those results with data collected during the hazard analysis. However, the small samples sizes precluded a meaningful cross-sectional regression analysis of indicators with subsequent microbial contamination. The quantified results were compared with the exposure risk assessment results and qualitative data findings in a process of triangulation.

Table 3.2 Indicators used to quantify and assess the exposure risk at toilet facilities posed to operators during collection activities using key risk indicators

Exposure Risk component	indicators	Definition	Rationale	Reference
Hazardous events	Leading/lagging			
Lagging	Spillages observed			
	Blockages of urine diverter observed	Visual observation of urine diverters for blockages	Blockages of urine diverters may lead to contact with hazardous waste during removal or cause overflow onto surfaces and the ground surfaces	(Schönning, Leeming, and Stenström 2002; Stenström et al. 2011)
Leading	Proportion of users <5	Proportion of users under 5 years old as a % of the whole	Children and elderly are more likely to misuse the toilet and lead to spillage or blockages and subsequent risks of transmission	(Nyoka et al. 2017)
	Proportion of users >60	Proportion of users over 60		
	Adapted hardware	Where elderly or under five children are present is hardware adapted to the user	Hardware that is not adapted to the user presents difficulties in use and can lead to subsequent hazardous events leading to exposure of faecal pathogens	(Nyoka et al. 2017)

	Physical integrity of toilets and containers	Visual checks for damage to toilet units and containers, including presence of well-fitting lids	The physical integrity of the toilet and the hardware ensure that faecal matter is isolated from contact with people. Cracks in the hardware, poor seals or other damage may lead to hazardous events	
	Malodour	Presence of strong or offensive odours linked to the site	Presence of strong malodour may indicate poor isolation of waste and is unpleasant for individuals to be exposed to	
	Regular servicing	Indication that units are regularly scheduled and is according to the need of the users	Regular servicing is a proxy for overflow and containment	
Transmission pathways				
Hand hygiene	Anal cleansing materials	Observation or visual checks of the presence of toilet paper or water depending on context	Presence of anal cleansing materials is a proxy for hand contamination and subsequent transmission of contamination to contact surfaces	(McMahon et al. 2011)
	Access to water at HH level	Observation or visual checks of the presence of water at the HH level	Access to water at HH level is a proxy for hand contamination and subsequent transmission of contamination to contact surfaces	(Sandy Cairncross et al. 2010)
	Access to soap at HH level	Observation or visual checks of the presence of soap at the HH level	Access to soap at HH level is a proxy for hand contamination and subsequent transmission of contamination to contact surfaces	(Cairncross et al. 2010)

	Access to functional handwashing facilities at HH level	Observation or visual checks of the presence of functional h/w facilities	Access to functional handwashing facilities at HH level is a proxy for hand contamination and subsequent transmission of contamination to contact surfaces	(Baker et al. 2016)
Surfaces	Cleanliness	Observation of extent of faecal smudges or spillage on toilet contact surfaces	Dirty toilets are a proxy indicator of contamination of toilet surfaces and subsequent transmission in CBS systems	(Moore and Griffith 2007; Pickering et al. 2012a; Flores et al. 2011; Brouwer 1999)
Vector	Presence of flies	Observation for presence and number of flies present	Presence of flies is linked to the transmission of contamination via mechanical vectors	(Feacham et al. 1983)
Environmental sanitation	Surrounding environment	Observation for presence and volume of rubbish or unsanitary conditions around the facility	The environmental sanitation surrounding the facility was a proxy indicator for transmission via soil and external pathways	(Schertenleib 2005)
Wastewater	Condition of soakaways	Observation for functional soakaways, noting blockages, disconnected pipes, or absent infrastructure	The condition and presence of soakaway pits where used for the disposal of urine and wastewater was used as a proxy for level of transmission possible via this pathway	(Tilley et al. 2014)
Flooring	Type of flooring	Observation of type of floor surfaces in facility	The floor surfaces – mud, bare earth, concrete or plastic – are linked to different rates of transmission of faecal oral pathogens and subsequent health impacts	(Pickering et al. 2012a; Worrell et al. 2016; Robb et al. 2017)

Airborne	Cover material	Presence of cover material	The presence of cover material (where an integral part of the functioning) implies that faecal waste is covered after defecation and therefore exposed during containment	(Barker and Bloomfield 2000)
Vulnerability				
	Training	Obtaining information on the most recent training or awareness raising sessions related to risks or health and safety issues with exposed staff	Frequency of training was a proxy for the vulnerability of exposed individuals and subsequent health impacts	(Gonese et al. 2006; Agunwamba 2001)

3.7.2. Closed-ended Behaviour Survey

A structured questionnaire was formulated based on the five behavioural blocks of risks, attitudes, norms, abilities and self-regulation to identify behavioural determinants associated with the self-management and operation of the CBS systems on houseboats in London (Case Study 2). The questionnaire format is located in Appendix 12 and comprised three components. The questionnaire first gathered information on the demographic data, location and type of toilet infrastructure. Second, it measured direct or indirect proxy indicators aligned to the target behaviours of safe handling of excreta, including the (1) self-reported frequency of emptying and cleaning of toilet units, (2) self-reported frequency of spillages and (3) the self-reported hand hygiene practices while emptying and processing toilet contents. The third component measured the behavioural factors based on the RANAS model of behaviour change (Contzen and Mosler 2013). Each section of the survey was aligned to a specific behavioural factor and posed a series of statements as indicators for corresponding behavioural factors. Section 1 measured perception of risk; the perceived vulnerability to (how possible it is to get sick) and severity of (how serious getting sick is) diarrhoeal diseases. Section 2 measured ability factors; ease of use of the CBS and how people dealt with setbacks. Section 3 measured the attitudes including satisfaction with the toilet compared to other systems. Section 4 considered social norms about other people's perceptions of the use and management of the CBS system.

EpiCollect software for survey creation was used. Data was downloaded onto Excel software for analysis and data cleaning. Data cleaning involved creating pivot tables to count the frequencies of the given answers for each question. The analysis measured the responses of indicators using means and modes in Excel software. The results were expected to highlight trends and incidences of behavioural determinants that may be used to provide insights into findings from the exposure risk workshop.

3.7.3. Environmental Sampling

The final element performed in Case Studies 1 and 2 was microbial environmental sampling of important contact surfaces in CBS operations. It was not possible to carry out environmental sampling analysis in Case Study 3 due to laboratory restrictions beyond the control of the researcher[8]. The

[8] In India external, public laboratories do not handle human faecal waste for analysis. Sanitation First did not have their own analytical capabilities at the time of research, therefore, it was not possible to collect microbial data.

environmental sampling captured information on the presence of faecal contamination of household toilet fomites (inanimate contact surfaces), identified as a key transmission pathway for operators who frequently have contact with toilet fomites. The contamination level of different contexts was compared to the findings from sanitary surveys and behavioural dimensions of data. In addition to its role in understanding these environmental contexts that influence exposure risks, the in-situ enumeration of the faecal indicators was used to estimate risks to operators from fomite transmission based on the QMRA approach.

In Case Study 1, households (n=11) were selected using random number sampling methodology from a total of 52 households involved in the study. In each household, there were 4 categories of contact surfaces were sampled (loo seat, contact surface, urine container and faecal container). A total of 73 unique samples were collected from the households. It should be noted that the original number of microbial samples planned was far higher, however, the facilities in the field laboratory in Kenya were limited due to the late arrival of the IDEXX incubator necessary for the incubation of the IDEXX trays. The incubator was delayed at customs in Kenya due to import restrictions and was not available for the research study. An incubator was improvised in the field using an 'egg incubator' – used for animal husbandry that was available locally. This was a major limitation to the microbiological study since the 'egg incubator' could only hold a maximum of 12 samples per day – meaning the total sample size was reduced from 300 planned to 70 (dictated by the number of field days available to the researcher). Technically, the egg incubator performed well and was calibrated with a digital thermometer. However, it was a major blow to the overall research capacity from Case Study 1.

In Case Study 2, houseboats (n=7) were selected by purposive sampling, which selected houseboats with CBS systems. A total of 33 unique samples were collected from contact surfaces (loo seat, contact surface, door handle, urine containers and faecal containers). Initially, 20 houseboats were planned for sample collection, however, random sampling of houseboats failed to successfully identify houseboats using CBS systems or it was found that householders were absent. It was concluded that randomly approaching houseboats during daytime hours was not appropriate in London as most residents were at work during the daytime hours. Therefore, the researcher contacted canal boats owners in advance and scheduled meetings at houseboats using CBS systems. Contact was made using social media posts and word of mouth from previous participatory workshop events. Consequently, only seven houseboat owners were available to participate during the research period, which was limited due to the time and financial resources of the PhD thesis.

In total of 106 unique fomite samples were collected from the toilet unit and bathroom surfaces, faecal collection container surfaces and urine collection container surfaces (Case Studies 1 and 2).

Swabs were collected from surfaces to test for the presence of *Escherichia coli* (abbreviated as *E. coli*), which are bacteria found in the environment, foods and intestines of people and animals. *E. coli* is used as a faecal indicator bacteria (FIB) organism for faecal contamination despite the limitations of using *E. coli* as an FIB. Each fomite was swabbed using a representative 10 cm^2 area, with the swab stored in a 15 ml vial with 7 ml of PBS solution, and quickly transported back to the laboratory in a cool box (Appendix 13). To ensure quality control of the sampling process one field blank was collected per batch of new swabs to ensure the sterility of swabs and sampling process. The swab was wetted in the field in Ringers solution and processed with the rest of the samples (Pickering et al. 2012). The samples were processed using IDEXX Colilert-18 and Quanti-Tray 2000 to provide a most probable number (MPN) of faecal coliforms, which provided lower and upper detection limits of 1 and 2,400 MPN/100 millilitres, respectively (Russel et al. 2015). The samples were incubated for 35 hours according to the reagent instructions. After this time a UV light was used to identify the presence of *E.Coli.* If no fluorescence was visible in the tray, then a zero value was assigned. The value of the upper detection limit was assumed if all the cells in the tray were fluorescent (Russel et al. 2015). The CFU *E. coli*/100 cm^2 was calculated using a formula that accounts for sampling efficiency of the swab and dilution factor. The sampling efficiency was also tested independently under laboratory conditions investigating the sampling efficiency from wood and plastic surfaces. The results of these tests indicated identical sampling efficiencies to what was taken from the literature. Statistical analysis of the colony counts was performed to obtain average, median and standard deviation. The *E. coli* data was log transformed (log 10), whereby zero colony counts were exchanged with a value of 1.0 (Devamani, Normanand Schmidt 2014) so zero value could be analysed representing < 1 colony forming unit (du Preez et al. 2011). The HFE methodology developed by Julian (2016) links the level of *E. coli* found on fomites to determine the potential risk posed by other pathogens when combined with community infection rates and dose-response information (Julian 2016). The first step of this methodology was followed and approximated the level environmental faecal contamination by dividing the *E. coli* concentrations on reservoirs by the average reported *E. coli* concentration in faeces, which was estimated conservatively as 10^6 CFU g^{-1} (Forsythe 2010; Mara and Oragui 1985).

It bears noting that the swabbing technique for microbiological analysis has limitations affecting sampling, namely, swabbing does not necessarily recover all the bacteria from a surface and recovered bacteria may not be released from the swab (Moore and Griffith 2007). Despite these constraints, we employed the swabbing technique because alternative methods for microbiological analysis were cost-prohibitive. To obtain data as robust as possible, a triplicate sampling procedure was conducted on both wood and plastic surfaces to explore any significant differences in the sample efficiency. This was included in the interpretation of results as a factor of swabbing efficiency based on laboratory experiments. The test protocol followed established protocols (Moore and Griffith 2007; PHE 2013).

3.7.4. Micro-level activity time series activity mapping

A technique called "first person videography" (FPV) collected micro-level activity times series (MLATS) data of the operators using a head camera to record the operator's hand movements during the servicing routine (Julian and Pickering 2015a). The video recorded the operator from a first person perspective as the camera was mounted on a headband around his head while he conducted his normal routine. Further details on the protocol followed for video data capture are provided in Appendix 14. The use of the camera was ethically approved and did not pose an inconvenience to the operator. The permission of the householders was sought before filming, and the purpose of the study was explained to them. All householders accepted the head camera being switched on during servicing. An entire servicing round in Sanivation is six to eight hours including driving and servicing an average of 20 households. The filming started when the operator approached a house for servicing but filming stopped while driving. To gain a representative sample, 22 servicing events were captured at household level over a two-day period. Unfortunately, during data transfer 12 servicing events were deleted erroneously from the hard drive.

Analysis of the video data to produce second-by-second data of the operator's hand contacts was conducted using a software program called the "virtual timing device for the personal computer" (VTDPC) created by Dr R Canales at the University of Arizona (Julian et al. 2018b). The software allowed second-by-second categorisations of hand contacts using an exposure template which recorded object contact and location of contact, as shown in Table 3.7. The output file of the data in Table 3.7 was then inputted into Excel software to count the frequency (all the occurrences of a particular contact within a timeframe) and duration (the total time in contact with a particular object) of the contact.

Table 3.7 Template to record micro-level activity data of contact events

Location			**Object contacted**				
Inside house	Outside house	Roadside	Dirty collection container	Clean collection container	Door	Face	Nothing
Toilet cubicle		Tuk-tuk	Toilet surface (exterior pedestal)	Toilet seat (interior, e.g. UD)	Keys (HH)	Red gloves	Nothing
Waste treatment site		Motorbike	PPE (not red gloves)	Labels	Phone	Hair	Nothing

	Tuk-tuk (handles)	Water/bev	Reporting sheets	Not in view	Nothing

3.7.5. Exposure Assessment Model

A Monte Carlo model (Mattioli, Davis and Boehm 2015) was used to model the concentration of *E. coli* on the hand, C_H, through time, taking into account intermittent contacts with surfaces and continuous inactivation of *E. coli* on the hand, as consistent with previous publications (Julian 2009, 2016). The Monte Carlo simulations were generated by a Masters student aligned to Davis University in the USA. The modelling was performed as part of a broader research study looking at fomite transmission in sanitation systems. For this reason, it was decided to use the results of the modelling already determined, as opposed to running the model again.

The inputs and interpretation of the model results were uniquely performed by the researcher responsible for the thesis and not the Masters student at Davis University. The transfer efficiency of pathogens according to the surface material was estimated (Table 3.8 below) and the objects identified in the MLATS were assigned a value of *E. Coli* surface concentration. The MLATS data indicated whether EC was transferred according the sequential contacts. It was assumed that wetness did not affect the transfer efficiency (although this is probably not realistic, as there was no indication of humidity on each fomite surface).

The inputs to the exposure model were the concentration of *E. coli* on the hand prior to contact with a surface (at time t-Δt), the concentration of *E. coli* on the object contacted, the transfer efficiency *E. coli* between the object contacted and the hand, the surface area of contact between the hand and the object, and the inactivation rate of *E. coli* on the hand. CH was thus modelled as follows:

$$C_H(t) = C_H(t - \Delta t) + T_{\mathrm{O,i\to H}} S_{\mathrm{O,i\to H}} (C_{O,i}\, k) \qquad (1)$$

Where:

$C_H(t)$ is the concentration of *E. coli* on the hand at time t (CFU/100 cm^2)

$C_H(t - \Delta t)$ is the concentration before the contact with object i (CFU/100 cm^2)

Δt is the time step between two subsequent object contacts (s)

$T_{O\text{-}H}$ is the transfer efficiency of *E. coli* from object i to the hand (%)

$S_{O\text{-}H}$ is the fractional surface area of contact between object i and the hand (area of contact/area of whole hand)

$C_{O,i}$ is the original concentration of the *E. coli* on object i (CFU/100 cm^2)

k is the inactivation rate constant of *E. coli* on the hand (0.003/s)

The transfer efficiency was assumed bidirectional (equal transfer from hand-to-object or from object-to-hand) and independent of the duration of the contact based on previous modelling work (Table 3.8). According to the model, if object i has a higher *E. coli* concentration than the hand at time t, there will be a net transfer of *E. coli* from the object to the hand. However, if the concentration on the hand is greater than that on the surface, the surface will receive a net transfer of *E. coli* from the hand.

Both left and right hands were assumed clean before contacting any surfaces (assumed concentration log (CH,0) = -10). Surface concentrations were assumed to follow log-normal distributions. The transfer efficiencies of contacts were assumed to follow normal distributions, truncated at zero. The fractional contact areas between the hands and the surfaces were assumed to follow uniform distributions. During the calculation, the values used for each input were evaluated based on the mean, standard deviation and different distribution types.

The model also evaluated the potential for net transfer of faecal bacteria from study participants' hands towards the loo seat, as a potential route of transfer of faecal contamination between households. The transfer of *E. coli* to or from the loo seat at time t thus depends on the concentration of *E. coli* on the hand at the time of contact, the surface area of contact of the loo seat and the transfer efficiency between the hand and the loo seat. Net transfer of *E. coli* in the direction of the loo seat requires that the concentration of bacteria on the hands is greater than that at the time of contact on the loo seat. Thus, the net bacteria transferred to or from the loo seat (L) at time t was calculated as:

$$L(t) = [C_{loo\ seat}(t) - C(t)_H] S_{\mathrm{H \to L}} A_{\mathrm{H}} T_{\mathrm{H \to L}} \qquad (2)$$

Where:

SH-L is the fractional surface area of contact between the hand and the loo seat (area of contact/area of whole hand)

AH is the total area of the hand (using a value of the 50th percentile, 0.107 m^2, for men's hand surface area from the US EPA *Exposure Factors Handbook*)

TH-L is the transfer efficiency between the hand and the loo seat (%).

The exposure model performed 10,000 Monte Carlo simulations for the right and left hands for each of the ten collection activities observed. The output was a time series of *E. coli* concentrations on the surfaces of the each hand determined by both sequential contact events and bacterial inactivation.

All graphs are in the form of log concentration of *E. coli* on the hand versus time. A negative value of L(t) indicates net transfer towards the loo seat.

Surface Concentration

The fomites selected for sampling were the loo seat, urine and faecal collection containers and toilet surfaces. These microbial results from Case Study 1 were used to estimate surface concentration of fomite categories in the model. The *E. coli* measured was adjusted for sampling efficiency to obtain actual *E. coli* measurements, due to the errors associated with swab sampling of surfaces. The *E. coli* concentrations were used to populate the minimum and maximum surface values attributed to each surface category in the exposure model.

All other categories assigned in the exposure model for which values were not available were assumed to be clean. The concentrations of *E. coli* were set to –10 for the initial concentration of surfaces. All the exposure model parameters, values and references are set out in Table 3.8.

Table 3.3 Fractional transfer efficiency values used in exposure model

Surfaces category	Surface from reference	Transfer efficiency	Reference
Faecal collection handles	Metal (stainless steel, high humidity)	0.541	(Lopez et al. 2013)
Faecal collection containers	Plastic (laminate, high humidity)	0.274	(Lopez et al. 2013)
Urine collection containers	Plastic (laminate, high humidity)	0.274	(Lopez et al. 2013)
Interior toilet surfaces	Plastic (acrylic, high humidity)	0.533	(Lopez et al. 2013)
Exterior toilet surfaces	Wood (painted)	0.274	(Lopez et al. 2013)
Urine diverter	Metal (stainless steel, high humidity)	0.541	(Lopez et al. 2013)
Face mask	Finger to face	0.339	(Rusin, Maxwell, and Gerba 2002)
Mouth	Finger to face	0.339	(Rusin, Maxwell, and Gerba 2002)
PPE (not red gloves)	Polyester	0.0037	(Rusin, Maxwell, and Gerba 2002)
Labels	Plastic (laminate, high humidity)	0.274	(Lopez et al. 2013)
Tissue paper	Paper (high humidity)	0.001	(Lopez et al. 2013)
Air freshener	Metal (stainless steel, high humidity)	0.541	(Lopez et al. 2013)
Tuk-tuk	Metal (stainless steel, high humidity)	0.541	(Lopez et al. 2013)
Reporting sheets	Plastic (laminate, high humidity)	0.274	(Lopez et al. 2013)
Plastic bag	Plastic (laminate, high humidity)	0.274	(Lopez et al. 2013)
Red gloves	Plastic (acrylic, high humidity)	0.533	(Lopez et al. 2013)
Mobile phone	Phone	0.418	(Lopez et al. 2013)
Storage compartment	Metal (stainless steel, high humidity)	0.541	(Lopez et al. 2013)
Household/door/keys	Metal (stainless steel, high humidity)	0.541	(Lopez et al. 2013)

3.8. Issue of Trustworthiness

The relationships with gatekeepers to access CBS sites was based on expectations that the CBS organisation would benefit from the research. However, in presenting the results of the exposure risks, the failings and potential health threats faced by the staff working in the sector would be potentially exposed. In conducting the research, the researcher was aware of their position as advocate of CBS as an innovative sanitation system and acknowledged the potential impact this may have on the interpretation of findings and sharing of the data to reflect certain realities.

If the research produced from this study is to be considered useful and trustworthy, the academic rigour of the research must be intact. The key issues addressed during the research phases were aspects of credibility, dependability, conformability and transferability of the qualitative research, compared to the validity, reliability, objectivity and generalisability of quantitative research (Watkins 2012). The credibility of the qualitative data, in particular the participant observation and key informant interview data, was strengthened by triangulation with structured survey and environmental sampling. Likewise, concerns about potential information bias, which would damage the credibility of the results from the exposure risk assessment, were allayed by comparison and triangulation of the exposure risk assessment results with the results of other data strands. The credibility of interview data is also strengthened by direct use of participant quotes, in the results and discussion.

The use of methodological conventions for qualitative analysis, such as coding of transcripts, ensured the dependability of the qualitative data. The use of parallel approaches for site visits and observation used across data sources and between Case Studies enhanced the dependability of the research findings. The role of observer bias and the reactions to data which may have influenced data collection have been acknowledged and justified the confirmability of the qualitative data collected. A criterion comparable to generalisability in quantitative datasets is irrelevant in qualitative analysis since results are the product of a specific context. Instead, qualitative data is considered transferable. The thick description of the Case Studies enables some transferability of the research findings, whereby under similar *contexts* and *conditions*, it is likely that the research findings could be transferred to another situation if contexts were similar. The Case Studies and the results are justified by rich descriptions of context, which should enable practitioners to judge the wisdom of the results and the transferability to another context.

The validity of the quantitative data was critical to the research rigour and acceptance of the findings to a wider audience. To ensure valid data and enable strong conclusions to be drawn, the microbial data was used to support the qualitative exposure risk assessments.

In summary, the research methods have considered several important aspects in the design and analysis of the research process concerning academic rigour. The challenge of ensuring academic rigour was even greater in a mixed methods approach, because the multiple data collection methods were directed by divergent paradigms. The most important aspect was to ensure that the overall mixed approach was relevant and the research was integrated (Brown et al. 2015). The mixed methods approach was highly relevant in this study as the quantitative data clearly enhanced the interpretation of qualitative data, and, in contrast the qualitative data, *"*puts words behind the numbers" and was an opportunity to go into more depth (Watkins 2012). The integration of the data strands at analysis was final confirmation of the relevance of the use of mixed methods supporting the exposure risk assessment.

3.9 Limitations to the Case Study Methodology

The first limitation was the small base of CBS private service providers to draw from, as finding collaborative partners for the research was challenging, given the lack of incentives for service providers to participate in the study. Initially, Clean Team in Ghana were planned to collaborate with Unilever and UCL in the overall research objectives. However, due to changes in external context, the collaboration with Clean Team did not materialise. Therefore, it was down to the researcher to find CBSSP research partners.

This practical limitation to observe and document CBS systems to assess exposure risks was overcome by purposeful sampling techniques. The researcher initiated a research collaboration with Sanivation at an event in Oxfam head office, Oxford, March 2016 and led to Case Study 1. However, this research collaboration did not extend past the first year, due a shift in operational focus (beyond CBS) of Sanivation. The lack of continuity with the Case Study partner necessitated the need to identify new research case studies and limited the extent to which effective control measures could be tested. The research collaboration with Sanitation First was established during a conference in India in February 2017 with acting CEO in the UK. However, the collaboration lacked formalisation and ownership with the national country director which resulted in limitations to conduct the necessary field research, which was beyond the researcher control.

In addition, working in countries such as India and Kenya meant that the access to laboratory materials was extremely limited. The small sample sizes from which the microbial contamination data and sanitary survey data were collected (qualitative and quantitative strands) were a limitation to robust interpretation of the data. It precluded statistically relevant analysis that would have identified trends and relationships between the variables and dependent variables, meaning individual p-values for each indicator (question) could not be assigned (Russel et al. 2015; Tilmans et al. 2016).

Extrapolating the findings to other CBS systems is hampered by the lack of confidence with which we can be sure these results are representative of this CBS system, let alone others. However, by exploring theoretical principles of exposure and risk factors, the study is protected from claims that results cannot be compared alongside alternative sanitation or other CBS systems; instead, our objective was to describe the conditions of exposure and inform effective risk management approaches relevant in the context of a particular Case Study and maintain the integrity of the Case Study.

Section 4.3 has acknowledged potential biases arising during the participatory exposure risk assessments that affect the basis of empirical data collection and analysis of occupational exposure risks along the CBS system within the Case Studies.

In Case Studies 1 and 3, the research was restricted by service providers preventing the recording of interviews with householders and staff. This therefore limited the triangulation of the data with the exposure risk assessment. There was no easy way to overcome this, but informal conversations were noted in field diaries and field notes. A limitation was also gaining access to talk to householders and operators (staff) to discuss exposure risks in the form of in-depth interviews. The quantitative statistical analytical power was limited due to small sample sizes.

The triangulation of data derived from different strands highlighted discrepancies in the main unit of analysis data, that is, between the sanitary survey, interviews and exposure risk assessment. Such differences encouraged further investigation, but the discrepancies in exposure risk outcomes drawn from participatory risk assessments based on a small stakeholder group challenged the validity of the evidence. For instance, the conflicting risk ratings from sanitary survey indicators and participatory groups posed a problem for establishing actual exposure risks. It is suggested that these differences may reflect a selection or information bias

4. Results of the Independent Case Studies

The results of the system mapping, exposure risks assessments including CCPs and control measures of the independent Case Studies are presented in subsections 4.1–4.3. The discussion of the exposure risks identified and the implications for the risk management occurs in Chapter 5 as a Cross Case analysis. The results of the environmental contamination are briefly presented within the independent Case Studies. A fuller discussion of the implications of environmental contamination and infection risk to operators is presented in Chapter 5. Chapter 6 presents the results of the exposure modelling and discusses the implications of this from a risk management perspective.

4.1. Case Study 1

Case Study 1 explored exposure risks to operators working for Sanivation, the sanitation social enterprise, based in Kenya. The occupational exposure risk assessment was obtained directly from the participant observation of operators. Exposure risk was indirectly measured through the sanitary survey, which measured indicators of exposure risk factors, and the interview data from key informants, which provided a rich narrative of exposure risk factors. Information on the hazard (the presence of faecal pathogens on key transmission pathways) was obtained by environmental sampling of fomites using *E. coli* as a FIB. The findings are presented under the following headings of system mapping, environmental contamination, exposure risks, control measures and critical control points.

4.1.1. System Mapping

The illustrated system map was developed from observations and validated by the key staff in charge of CBS operations in the service organisation. The system map outlined the process steps and activities performed by the operators according to five system components (Figure 15). It sets out the activities and the interrelationships between the links in the CBS chain – the production of waste at toilet use, collection and emptying of waste, transport in collection vehicles, treatment and reuse of treated waste products.

The narrative description set out in Table 4.1 describes the activities, waste fractions and exposure groups in more detail.

Table 4.1 Description of activities, waste characterisation and volumes of waste generated along the system chain

System component	Waste source	Waste type	Volume		Intensity of repetitions			Activities associated with system component	Exposure Group (pp)		
			l(l)	(kg)	U	O	C		U	O	C
Containment	HH	Urine	10		1–3/day		0	defection and urination (user)	62	1	0
		Paper		2	1–3/day		0	temporary storage of waste	30		
		Faecal matter and cover		5	1–3/day		0	cleaning of toilet			
Collection and conveyance	HH				0	> 20 /day	0	lifting up lid to service boxes	0	1	1000
					0	> 20 /day	0	screwing lid onto full urine containers			
					0	> 20 /day	0	removing urine containers			
					0	> 20 /day	0	replacing with empty containers			
					0	> 20 /day	0	fixing lid onto faecal containers			
					0	> 20 /day	0	removing faeces containers			
					0	> 20 /day	0	replacing with empty containers			
					0	> 20 /day	0	removing tissue bag and tying to faecal container			
					0	> 20 /day	0	replacing black bag for tissue waste			
					0	> 20 /day	0	ID labelling of faecal containers			
					0	> 20 /day	5	loading/stacking onto tuk-tuk			
					0	> 20 /day		travelling on tuk-tuk with waste containers			
Waste transfer and treatment	HH	Wastewater from washing process				> 20 /day		offloading of urine/faecal waste	0	5	500
		Plastic bags contaminated with faecal matter				> 20 /day		weighing of waste streams			
						> 20 /day		transfer of urine to 1000m2 storage			
						> 20 /day		transfer of faeces to 100l metal drums			
						> 20 /day		waste plastic bags in 100l metal drum			
						> 20 /day		drying of plastic bags before incineration			
						> 20 /day		washing of urine containers			

> 20 /day	washing of faecal containers
> 20 /day	disinfection of urine containers
> 20 /day	disinfection of faecal containers
> 20 /day	drying of urine containers
> 20 /day	drying of faecal containers
> 2 /day	treatment of waste
> 20 /day	final disposal of waste
> 20 /day	incineration

Note: U = users, O = operators, C = community

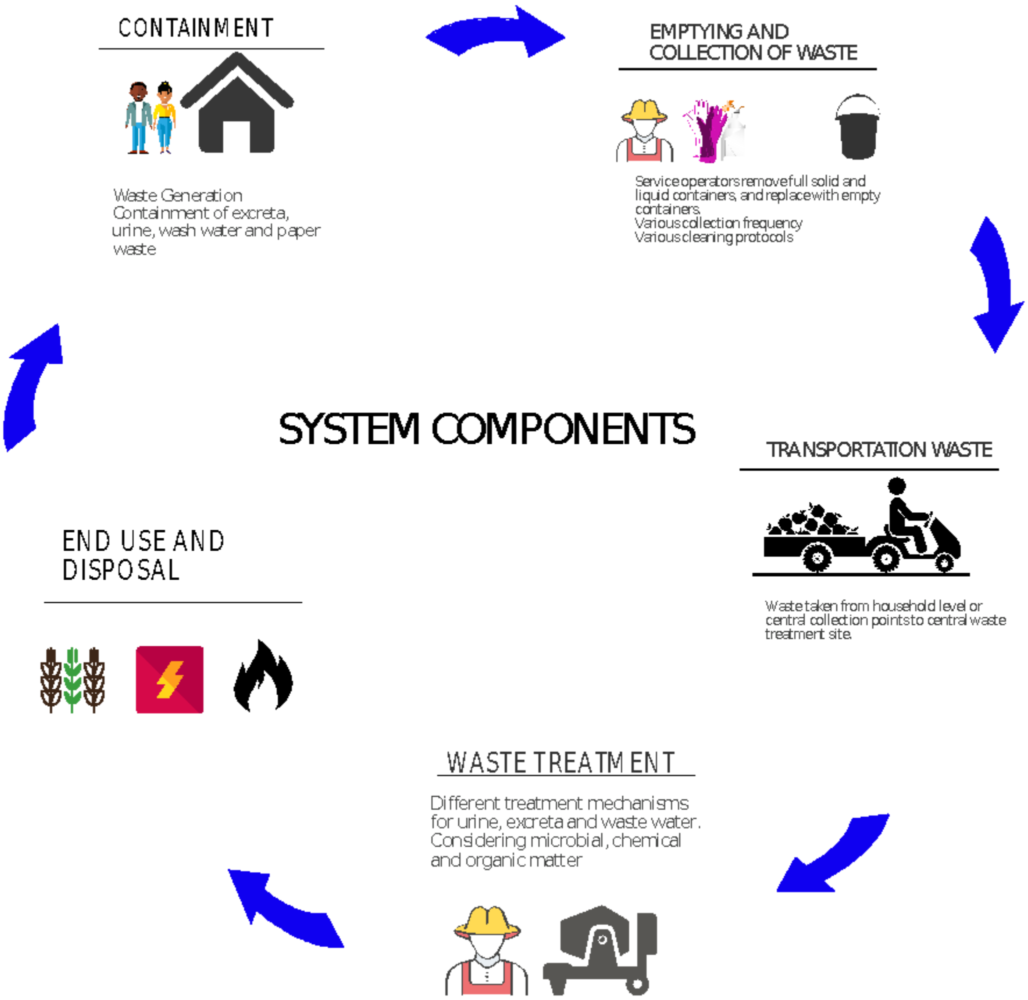

Figure 15 System map of Case Study 1

The operators collected faecal waste products generated at household level from approximately 20 households on a collection schedule each day (Table 4.1). The steps associated with the containment of waste were toilet use and temporary storage of the waste in collection containers. The solid waste containers (faecal and paper waste) were lined with black plastic bags to facilitate the removal of the faecal waste from the containers. To collect the solid waste, the operator first opened the top section of the toilet housing, sealed the bag and covered the full collection container with a lid located inside the toilet housing. Similarly, a lid for urine, located inside the toilet housing, was placed on top of the full urine container. Once both containers were sealed, the operator lifted them out of the toilet housing and they were replaced with empty containers, and followed the procedure in reverse.

The bags containing paper waste used for anal cleansing were sealed with a tie-knot performed by the operator and affixed to the full collection containers. At this point, the operator cleaned and disinfected the toilet surfaces comprising the toilet seat and sides of the “blue box” and assessed the toilet for cleanliness – noting the score ranked 1–3 for internal monitoring purposes. Once the toilet had been cleaned satisfactorily, the operator sprayed some perfumed scent as an odour neutraliser. The full containers were then taken back to the collection vehicle and loaded onto the vehicle, taking care not to mix the full containers with the clean empty ones. This process continued from house to house until the collection schedule had been completed. Once the containers were returned to the treatment depot, a second treatment officer assisted with unloading of the full containers. The collection containers were weighed, again for internal monitoring purposes. A number of different procedures for urine and faecal matter are involved in the treatment and processing of the waste. The first step in this treatment process required that urine from collection containers was decanted by operators into a large volume container with a capacity of $1m^3$, prior to infiltration of the liquid in a soakaway pit on site.

Pasteurisation was used to deactivate the faecal pathogens in human excreta. The first step in the treatment of the faecal waste was that it was removed from the plastic bags by a procedure that turned the bags inside out and allowed waste to fall out and into the temporary collection containers on site. If the faecal waste did not fall out, it was manipulated and encouraged to do so by the treatment operators since plastic bags could not be included in the pasteurisation process and thus needed to be separate. Once the faecal waste was collected together it was put onto a stove and heated to a minimum internal temperature that was held for a period of time required for pathogen reduction.

Another treatment procedure carried out by another frontline staff operator was the washing and disinfection of the faecal and urine collection containers. Washing water was prepared and containers were first washed with a soapy detergent, then they were left to soak in a mild disinfectant solution. After around 10 minutes spent soaking the containers were left to dry. They were not rinsed.

The different types and approximate daily volumes of waste generated along the system characterised as liquids were:

- 200l of urine in liquid collection containers at containment component.
- 200l contaminated cleaning/washing water from cleaning and disinfection processes in treatment component.

And solids:

- 10kg of soiled and used toilet paper and menstrual hygiene products, generated at containment.
- 50kg of human faeces, including carbon/cover material that was added to the faecal matter in the solid collection containers at containment.

Three frontline staff were involved in specific activities of CBS systems:

- One staff member was responsible for the collection, emptying and transportation of containers from households to the transport facility and any cleaning and maintenance of the CBS units required.
- Two staff members were responsible for the treatment and waste processing activities at a treatment facility.

The system mapping and risk assessment was confined to the first four system components; the risks associated with end-use, reuse and disposal were not regarded as part of the exposure assessment, given the substantial time allocation that would have been required to complete all aspects of the assessment.

4.1.2. Environmental Contamination

In terms of the environmental contamination of contact surfaces with *E. coli*, 41% of household toilet fomites sampled had a positive presence of *E. coli*, whereas 80% of collection containers were free from *E. coli*.

The distribution of the environmental data is presented in Figure 16. The data indicates the variability of the concentrations of *E. coli* on contact surfaces (large interquartile ranges). For all contact surfaces (1–4) the lower value and lower quartile are the same as the data is highly positively skewed to the left, indicating surfaces are free from *E. coli*. For faecal containers there is no interquartile range as there was such a high proportion (>75%) of zero values after transformation.

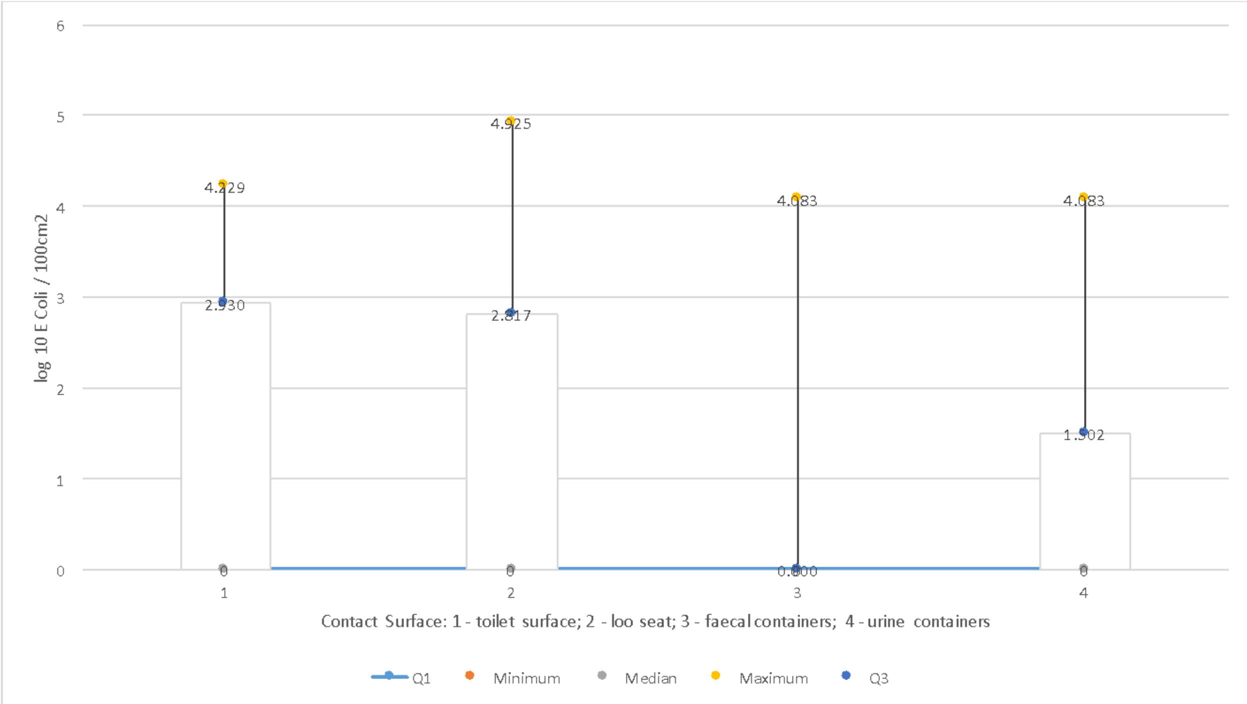

Figure 16 *E. coli* concentrations at point of surface contact on toilet surfaces

Note: The lines of the box-and-whisker plot represent, from the bottom: the minimum value, the lower quartile, the median value, the upper quartile and the maximum value.

Table 4.2 presents the log transformed mean concentrations of *E. coli* on contact surfaces. The maximum mean value was determined to be on the loo seat (1.39 log *E. coli*/100 cm^2) followed by the surfaces of the toilet (1.26 log *E. coli*/100 cm^2). Samples from the urine and faecal collection container surfaces were somewhat lower, at 1.16 and 0.4 log *E. coli*/100 cm^2, respectively (Table 4.2), although a comparable maximum level of *E. coli* concentration was observed across all fomites sampled from 4.083 to 4.925 log *E. coli*/100 cm^2.

Table 4.3 presents the estimated amount of faecal equivalent on the key contact surfaces. The highest amount of mean faecal contamination was on loo seats (10^{-2} g^{-1} faeces) and the lowest values observed were on faecal collection containers (10^{-4} g^{-1} faeces). The maximum amount of faecal contamination observed was also on loo seats, approximated at $10^{-1}g^{-1}$faeces.

Table 4.2 Transformed log data of *E. coli* concentrations found on different contact surfaces along the sanitation value chain

Contact surfaces	Log transformed *E. coli* data adjusted for sampling efficiency (log 10 *E. coli*/100 cm^2)				
	Mean	Median	Maximum	Minimum	Standard deviation
Surfaces of the toilet	1.26	0	3.73	0	1.79
Loo seat	1.39	0	4.93	0	1.95
Urine containers	1.16	0	4.08	0	1.63
Faecal containers	0.40	0	3.81	0	0.97

Note: The mean values compare the values of log 10 E. coli CFU/100cms for toilet surfaces (n=13), loo seats (n=11), urine collection containers (n=15) and faecal collection containers (n=34).

Table 4.3 Approximate amount of faecal contamination observed on toilet surfaces frequently handled during servicing activities in CBS

Contact surfaces	Human faeces equivalent grams *E. coli*/100 cm^2	
	Mean	Maximum
Surfaces of the toilet	$0.0023/2 \times 10^{-3}$	$0.016/10^{-2}$
Loo seat	$0.0104/10^{-2}$	$0.842/8 \times 10^{-1}$
Urine containers	$0.0015/10^{-3}$	$0.012/10^{-2}$
Faecal containers	$0.0003/3 \times 10^{-4}$	$0.012/10^{-2}$

Note: Comparing the mean and maximum amounts of faecal contaminations across the sampled surfaces: toilet surfaces (n=13), loo seats (n=11), urine collection containers (n=15) and faecal collection containers (n=34).

4.1.3. Exposure Risk Assessment

4.1.3.1. Collection and Conveyance

The results of the exposure risk assessment are presented in Table 4.4. The main findings of risk assessment were triangulated with findings from the sanitary survey (n=20) reported in the text and in-depth interviews with key stakeholders (n=6) presented as direct quotes in the text.

The exposure risk assessment identified a number of hazardous events that if not appropriately managed would result in exposure risks to the operator (Table 4.4). The level of risk assigned was a product of likelihood and consequences of exposure to health and resulted in low, medium and high risks. The semi-quantitative risk matrix applied is described under section 3.5 applied using the tables 3.4 and 3.5. A hazardous event categorised as high risk was the handling of “dirty” or contaminated contact surfaces during the collection and conveyance of faecal solids and urine that led to hand contamination and subsequent direct or indirect oral ingestion. The sanitary survey measured faecal smears and access to handwashing and anal cleansing materials as proxy indicators of surface contamination. Sanitary survey results showed 30% of toilets surveyed had visible faecal smears on their surfaces (an indicator of surface contamination); findings comparable to 40% of contact surfaces sampled with a positive presence of *E. coli*. The poor access to cleaning materials for anal cleansing and handwashing was an indicator of hand contamination (and subsequent transfer to surfaces); only 50% of households surveyed had access to toilet paper or newspaper (30% and 20% respectively) and an even smaller proportion (20%) had access to functional handwashing. User interviews also suggested that even when handwashing facilities are available, individual handwashing habits are not consistently adhered to. For example, one user stated that:

Because if you go to the toilet you can forget to wash your hands, it is very dangerous.

The repetitive nature of the collection activities observed (Table 4.1 above) together with the high frequency of handling contaminated surfaces for toilet operators contributed to the high risk ranking. Although the exposure risk assessment (see Table 4.4 below) revealed that certain control measures for toilet operators, such as the mandatory use of personal protective equipment (PPE), including gloves, and other hand hygiene protocols were in place, noncompliance with those measures was observed during the assessment period. It was observed that the service operators would remove their heavy-duty gloves to facilitate cleaning – assumed to improve dexterity. The in-depth interviews with operators provided insights into personal perceptions of vulnerability. The treatment facility operators expressed a higher vulnerability of exposure than the service operator, when asked how vulnerable they felt to negative health impacts associated with work. However, both treatment operators and the service operator also cited having been affected by negative health impacts, but were not able to directly associate personal health issues with faecal transmission or occupational exposure. These aspects of vulnerability are captured by the following quote:

The collector is the one who is more at risk with collecting the poop, who is at more reaching the households not only once or twice, but a lot of risk.

Hazardous events categorised as medium exposure risks for toilet operators were blockages of faecal matter in the urine-diverting portion of the toilet, or “cross-contamination” during toilet use, which had to be removed by operators (Table 4.4). The risks appeared to be elevated in instances where toilet users demonstrated difficulty using the toilet. The interviews with key informants revealed that age-specific user groups (those under five and the elderly) experienced the greatest difficulty with using the toilet, resulting in a higher likelihood of misuse and cross-contamination. These findings underscore the role of the user in potential exposure risks resulting from misuse. The sanitary survey indicated that 90% of urine diverters were free from blockage at the time of observation, which is suggestive of a low likelihood of cross-contamination and blocked urine diverters. However, user interviews referred to specific aspects of toilet design that elevated the likelihood of exposure through cross-contamination, especially for younger users. For example, the following interviewee discussed her child’s difficulties with using the toilet and elderly relatives:

Also the toilet is more up (higher), so he has to struggle to sit on it, always he has to miss, because he poops in the urine barrel instead of – even the hole is bigger than him ... He is five years.

and

Older users … are not able to sit adequately on the box; some might fall inside.

Low-to-medium exposure risks created by urine spillage from waste containers were observed during collection and conveyance (Table 4.4). Specifically, it was discovered that spillage risk was initially attributable to overfilling and/or the poor condition of collection container lids and seals and was then exacerbated during conveyance by the use of a collection vehicle that wasn’t fully sealed and bumpy road conditions. The existing spillage protocol, which clearly articulated steps to follow after a significant spillage, did not reduce or prevent the immediate causes of spillages observed, meaning the control measures were only partially effective and exposure risk cannot be completely removed. Aside from direct physical contact with human waste, the inhalation of bioaerosols presented another exposure route for operators. However, this risk factor remained relatively low during the performance of collection and emptying services, given that waste containers were fully sealed, and the operators were observed to be wearing protective face masks during collection and emptying activities. However, the interviews suggested discrepancies in the confidence in the ability of PPE (in particular gloves) to provide a safe barrier to hand transmission. Some operators felt the PPE afforded only minimal protection from exposure following hazardous events.

4.1.3.2. Waste Treatment and Processing

No hazardous events were categorised as high risk for waste treatment and processing according the exposure risk assessment (Table 4.4). During offloading, low-risk hazardous events were the overflow and spillages of urine from poorly sealed containers during the offloading of containers from the collection vehicle. The hazardous events that posed medium-to-low risks to operators occurred during the emptying of contents from primary collection containers into secondary waste collection tanks and washing and disinfection. First, spillages of raw faecal waste were observed when treatment operators were turning plastic bags inside out to remove faeces and removing waste from individual collection cartridges into the central storage. This transfer process exposed the waste handlers to potential contamination via multiple exposure pathways. Second, observation of the cleaning process of the waste containers identified that considerable volumes of water were splashed onto the operator and resulted in exposure to contaminated wastewater and may contaminate clothing, PPE and the skin directly. Ingestion of wastewater was a medium risk while the operator engaged in these activities despite the protection afforded by PPE. Splashing during the cleaning was exacerbated in the absence of a mechanised process or other physical design parameters that might have controlled exposure risks. The occupational exposure risks identified at the treatment facility were mitigated, in part, by control measures, like wearing PPE. Overall, a reasonable safety culture was demonstrated by the effective hand hygiene practised by operators during waste treatment activities and relevant hygiene and safety protocols for the waste zone area. Direct observation of operators' access to and high compliance with effective PPE measures in the treatment facility, as well as the interviews with frontline staff who discussed how pre-employment and regular training instilled in them a keen sense of risk awareness, both contributed to the low-risk rating applied overall in the treatment component. All other hazardous events identified during waste treatment and processing presented low exposure risk. There was a low risk of exposure to bioaerosols during the incineration of plastic bags as operators complied with wearing PPE masks and were trained to identify insufficient waste-burning temperatures, through the production of a black/grey smoke, and make necessary corrections. However, the risk of bioaerosol exposure could increase in instances where an insufficient chimney height on the incinerator meant that smoke generated at the level of the operators' heads.

4.1.3.3. Control Measures and Critical Control Points

Finally, ten critical control points (CCPs) were identified along the CBS system chain where exposure risks may be eliminated or reduced. The CCPs were: 1) toilet use; 2) handwashing; 3) anal cleansing; 4) cleaning of toilet surfaces; 5) collection and emptying of containers; 6) transportation of waste; 7) offloading of raw faecal sludge and urine; 8) the processing and transfer of waste to treatment site; 9) washing and disinfection; and 10) incineration of plastics (non-faecal) waste. At these CCPs, the exposure risk assessment identified hazardous events, as well as corresponding control measures and associated steps to minimise potential exposure risks. These hazardous events, control measures and associated steps are enumerated in Table 4.4, in which recommendations for new and/or improved control measures designed to reduce exposure risk are presented.

Table 4.4 Exposure risk assessment from Case Study 1, Kenya

System component	Hazardous events	Transmission pathway	Existing control measures	Risk level	Comments justifying risk assessment or effective
Containment: Toilet use, handwashing, cleaning and disinfection	Cross-contamination/blockages of urine diversion through misuse or diarrhoeal events	Hands/surfaces /ground	Training and awareness raising for users on proper use of toilets	N/A operators	Knock-on consequences for operators if misuse occurs
	Airborne particulates or offensive odours from poor sealing of collection containers	Air	Cover material/closing the lid	Low	
	Spillages or overflow from collection container (especially urine, faeces, tissue) leads to faecal smears on toilet surfaces	Hands/surface /ground/flies	Cleaning	High	
	Hand contaminated after accidental contact with faeces due to lack of anal cleansing materials	Hands	Access to handwashing facilities at household level and sensitisation to practice handwashing	High	Users do not habitually wash hands after defecation
	Surfaces contaminated from hands being contaminated	Surfaces			
	Handling contaminated toilet surfaces	Hands/surfaces	Wearing PPE – double gloves	High	High frequency of household visits

		air			Lack of cleaning protocols
					to glove protocols
Collection and conveyance: Collection and removal of full containers	Handling contaminated surfaces due to malfunctions of PPE and noncompliance to PPE	Hands/surfaces /ground	Operators possess high level of awareness and knowledge on health risks	Medium	Full PPE not worn 100% of the time
	Hand contamination and transfer to new households		Operators have received training	Low	Inappropriate glove protocol
	Spillages of raw waste onto ground/ surfaces/floors during removal	Air	Wearing PPE – double gloves and masks		No hand sanitisation between households to prevent potential transfer of contamination between households on operator's gloves
	Spillages of solid and liquid wastes from full containers during transport of waste to treatment facility	Surfaces/groun d/hands	Driver training	Medium	Signage and risk communication: Communication and emergency number clearly positioned for response in account of spillage
			Collection vehicles washed and disinfected with 0.2% chlorine solution while wearing PPE	Low	Containers missing lids and not well sealed, liable to leakage

			Environmental spillage protocol (including disinfection with 0.5% chlorine solution)		Bad road conditions increased likelihood of spillages
			Appropriate monitoring and management		
			PPE worn 100% of the time		
Treatment: Offloading at containers waste treatment and transfer of urine/excreta to storage and treatment; washing and disinfection of dirty collection containers	Handling of contaminated containers		Full PPE worn 100% of the time	Medium for urine	
			Operators possess high level of awareness and knowledge on health risks		
			Frequent training	Low for solids	
	Spillages during the emptying and manipulation of the faecal waste	Flies/surfaces/ hands	PPE is worn 100% of the time in treatment facility	Medium	Manual handling of raw faecal waste, manipulation of plastic bags to evacuate waste
	Spillages of urine during as urine emptied from collection to storage containers	Liquid	Operators possess high level of awareness and knowledge on health risks	Medium	Highly viscous waste – splashing and spillages

	Aerolisation of airborne pathogens during manipulation of raw faecal waste during removal from bags	Air	Presence of relevant risk communication in treatment facility	Low	Management/washing and appropriateness of PPE and no compliance monitoring of PPE
	Malfunction of PPE and noncompliance	Air/surfaces/ hands	Spillage protocol and wash down	Low	Training is not frequent or regularly scheduled; however, operators indicate a high awareness of risks
					Seasonal influences increased the number of flies around treatment facility
	Contaminated wastewater splashes directly onto the operator during to manual washing process	Liquid	PPE worn 100% of the time in the treatment facility	Medium	No compliance monitoring of PPE or of use of cleaning and monitoring protocols
Reuse and disposal: Incineration of solid waste	Discharge of the contaminated wastewater into environment		Operators refer to awareness and knowledge of health risks	Low	Training is not frequent or regularly scheduled; however, operators indicate a high awareness of risks
			Cleaning and disinfection protocols exist for cleaning of collection containers	Low	
	Black smoke dispersed by incinerator burning contaminated plastic waste	Airborne	Full PPE worn 100% of the time	Low	Chimney height on incinerator at eye level

	Inadequate burning temperatures leading to black smoke
	Operators not trained/aware regarding potential exposure risks to smoke

4.2. Case Study 2

The participatory exposure risk assessment was carried out during a one-day workshop with 12 participants who operated CBS systems in Central London. To strengthen the validity of the workshop data, the findings were cross-referenced with multiple data elements embedded into the Case Study, including a household behavioural survey, in-depth interviews and online forum data.

4.2.1. System Mapping

The system map developed during the participatory workshop is illustrated in Figure 17 and was verified by the participants. It is a process flow diagram of the activities and waste flows through the system components. The system mapping documented three exposure groups as (1) the toilet users (including adults and children), (2) adult users, and (3) external community groups. In this Case Study, the "adult users" are responsible for the management and operation of all activities and processes along the system chain, therefore any subsequent reference to users includes operators, and vice versa. The system map illustrated the generation and flow of waste products and processes along each of the system components. Three different waste products were identified including:

- Urine and waste liquids from cleaning
- Soiled and used toilet paper and menstrual hygiene products according to anal cleansing and menstrual hygiene management
- Human excreta, including cover material that was added to the faecal matter in the solid collection containers.

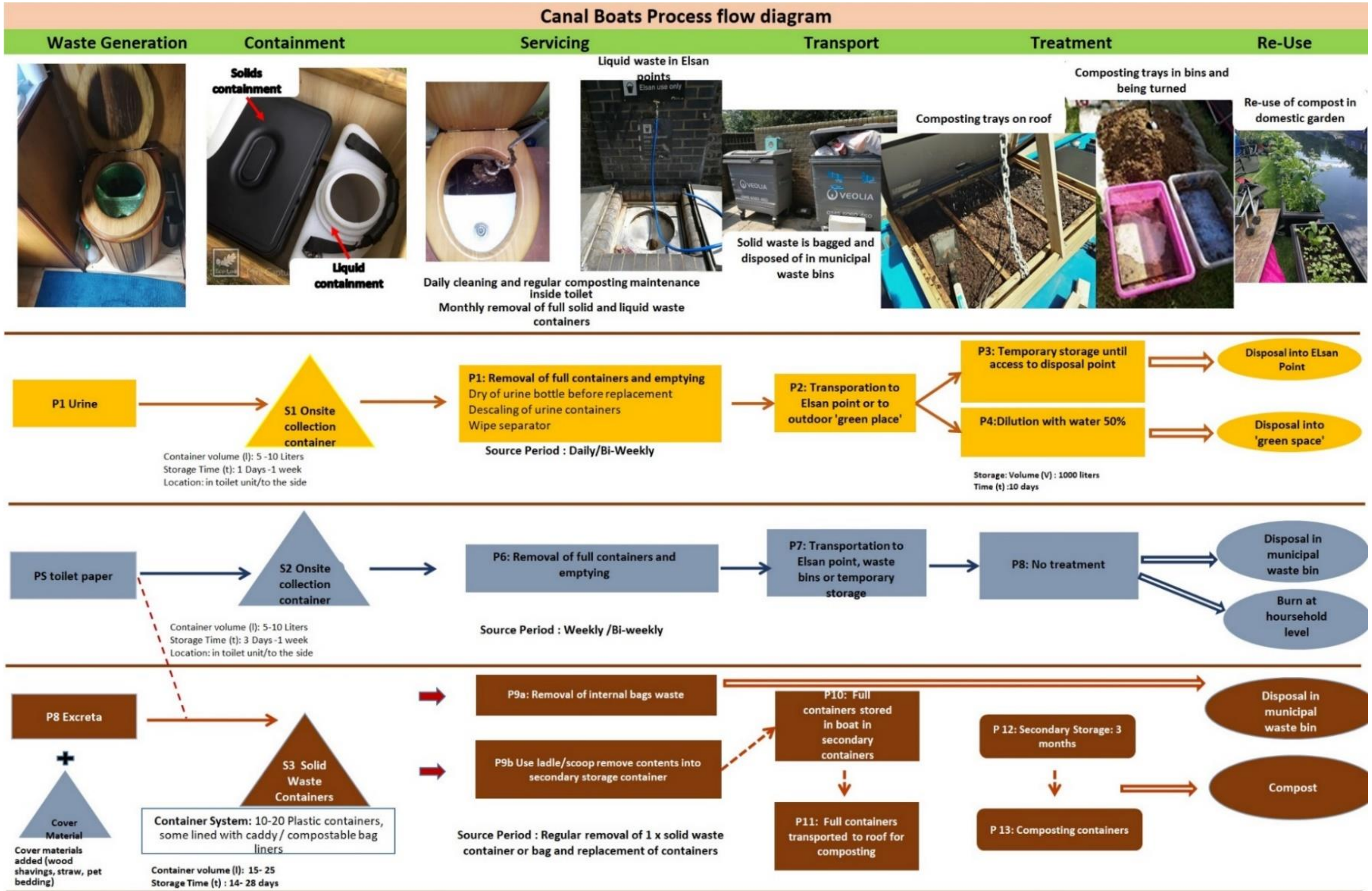

Figure 17 System map of Case Study 2

The participants listed a variety of cover materials used, and presented examples of specific types during the workshop, including:

- wood shavings
- pet bedding (cat litter, hay)
- tea leaves
- coffee grounds
- coconut coir.

The variability in type was noted to be dependent on factors such as wetness of the faecal waste matter, and the cost and availability of cover material. In addition, the analysis of the discussion on the online forum highlighted a similar variety of cover material being used, with wood shavings, sawdust, bedding, pellets and coconut coir being the most frequently mentioned in a word frequency analysis (Figure 18).

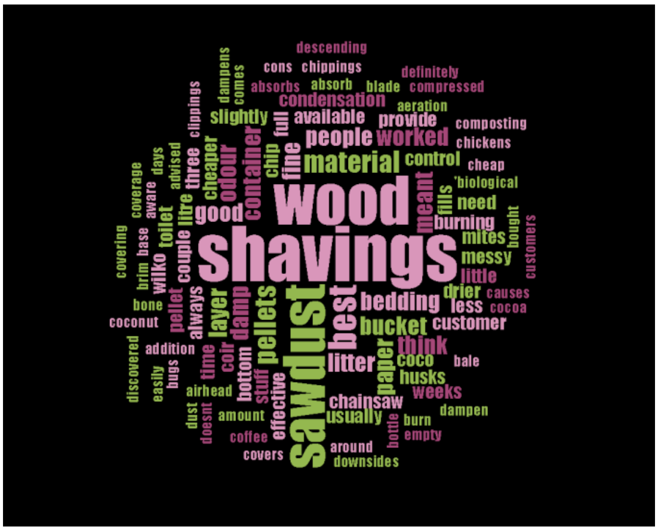

Figure 18 Results of word query of cover materials mentioned in Case Study 2 from forum transcript

An absence of a private sector organisation that dictated the supply of a specific technology or service provision and independent development of CBS systems is reflected by the variety of alternative processes as users use a range of options for toilet infrastructure and system processes. Those activities associated with containment comprised the toilet use, cleaning and disinfection of the urine separator and exterior and interior surfaces of the unit, handwashing and composting maintenance (Figure 17 above). Toilet paper was either disposed of into a separate waste bin or was collected with the solid faecal waste, while menstrual hygiene products were disposed separately to human excreta.

Some participants referred to “compost management” in primary collection containers, which referred to manual mixing of the faecal waste to aerate and facilitate the breakdown. Some toilet designs incorporated handles that mixed the solid waste inside the container. Other participants noted the use of a large wooden stick or “dog spike” to mix the waste in the primary collection container.

Activities associated with the collection and transport of different waste flows depended on the specific hardware components, the individual preferences of the operator, and the intended treatment processes. Liquid waste products generated (principally urine) were disposed of off-site in an “Elsan point”, shown in Photo 4.1. Elsan points are used for the disposal of liquid waste from canal boat sanitation systems and are positioned at regular intervals along the canal networks and are provided in resident moorings. They are free at point of use. The metal shutters seal the circular hole where waste is deposited inside and closed when not in use. The tap and hose provide a water point for cleaning containers. Elsan points are not designed for the disposal of solid materials. However, when Elsan points were not accessible for operators (too far, in poor condition, or broken), participants dispose of urine and liquids in green margins located alongside the canal (Photo 4.2).

Photo 4.1 An Elsan point for faecal sludge disposal, London, UK

Inadequate access to Elsan points encouraged frequent disposal in green spaces, and disposal was directly into the canal, although this is illegal. Various treatment processes existed for the solid waste flows (excreta, cover material and toilet paper). Excreta (and cover materials) was removed by operators from the primary collection container in plastic bags and double bagged before disposal in municipal waste bins (Photo 4.3). Alternatively, the contents were removed by operator's full and containers were removed and transferred into secondary storage containers for further treatment along the system chain. The treatment processes included extended storage in large containers intended to encourage aerobic thermophilic bacteria to proceed composting activities. Reuse of the treated solid materials generated principally comprised the use of composted materials on domestic plants including ornamental and plants for human consumption.

Photo 4.2 Canal towpath showing the green areas where canal boaters dispose of urine as a common practice, London, UK

Photo 4.3 Canal mooring where there are no green areas for urine disposal and residents must dispose of urine in Elsan points, London, UK

Photo 4.4 Solid waste disposal facilities free to use for canal boaters. London, UK

4.2.2. Environmental Contamination

In terms of environmental contamination, *E. coli* was absent from over 90% (n=36) of the toilet fomites, thus only 6% of the toilet fomites sampled had a positive presence of *E. coli*. The distribution of the data is presented in Figure 19. The data indicates the variability of the concentrations of *E. coli* on contact surfaces (large interquartile ranges). For all contact surfaces (1–5) there is no interquartile range as there was such a high proportion (>75%) of zero values after transformation.

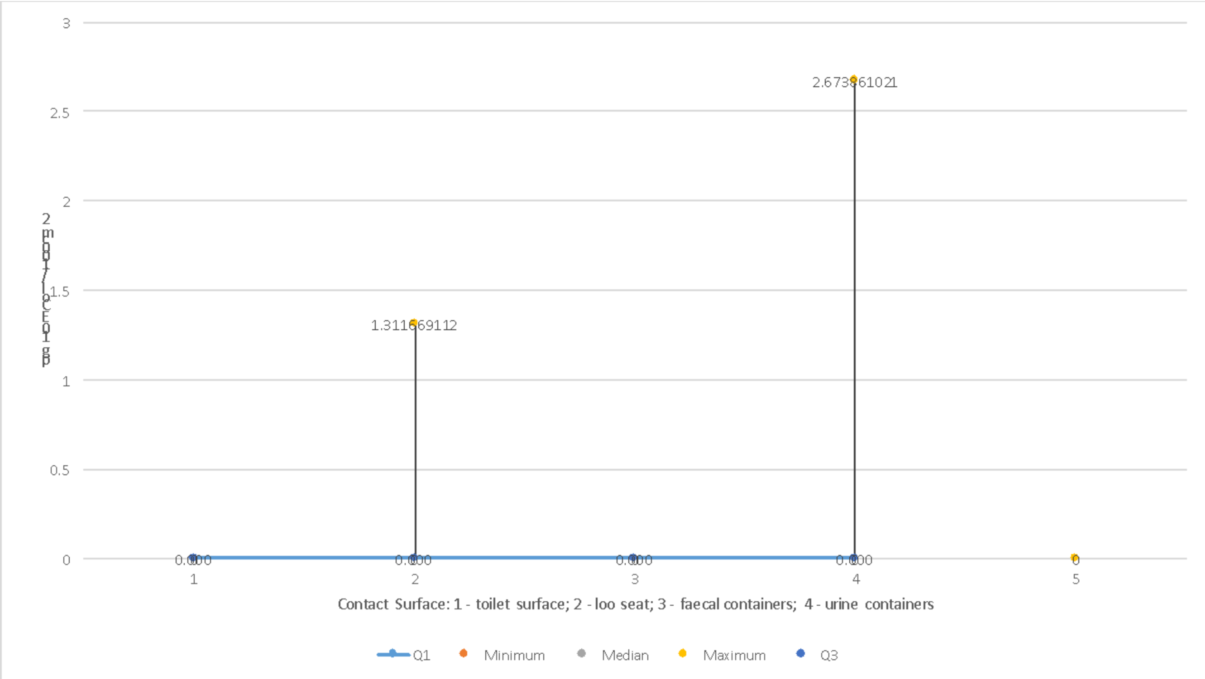

Figure 19 *E. coli* concentrations at point of surface contact on toilet surfaces

Note: The lines of the box-and-whisker plot represent, from the bottom: the minimum value, the lower quartile, the median value, the upper quartile and the maximum value.

Table 4.5 presents the log transformed mean concentrations of *E. coli* on contact surfaces. Only the urine collection containers and exterior contact surfaces of the toilet tested positive for faecal contamination. The mean contamination of urine collection containers was almost twice as high as the exterior surfaces – 0.38 log 10 *E. coli*/100 cm^2 to 0.18 log 10 *E. coli*/100 cm^2 (0.0005g/100 cm^2 – 0000002/100 cm^2) but the differences in the means were not statistically significant (P>0.05). The individual maximum values of faecal contamination were substantially higher than the overall mean levels, in part due a high proportion of samples falling between 0 and 1 CFU/cm^2.

Table 4.5 Transformed log data of *E. coli* concentrations found on different contact surfaces along the sanitation value chain

Microbiological sampling adjusted for sampling efficiency, log 10 *E. coli*/100 cm^2			
Fomite category	mean	maximum	SD
Loo seat	0	0	0
Surface	0.19	1.31	0.50
Door handle	0	0	0
Urine containers	0.39	2.67	1.01
Faecal containers	0	0	0

Note: The mean values compare the values of log 10 *E. coli* CFU/100 $cm^2$for exterior toilet surfaces (n=6), loo seats (n=6), urine and faecal collection containers (n=12) and the door handle to the toilet (n=6).

Table 4.6 presents the estimated amount of human faeces equivalents (HFE) on the key toilet contact surfaces. The highest amount of mean faecal contamination was on urine containers (10^{-4} g^{-1} faeces) and the second highest values observed were on exterior toilet surfaces (10^{-5} g^{-1} faeces). The maximum amount of faecal contamination observed was also on loo seats, approximated at 10^{-3} $g\text{-}^{1}$ faeces). As discussed in the methodology, the HFE are only approximations since the estimation are based on estimates of *E. coli* present in human faeces, which is highly variable and inconstant.

Table 4.6 Estimated values of human faeces equivalents (g) on toilet surfaces

Fomite category	**Human faeces equivalents grams/100 cm^2**	
	Mean	Max
Loo seat	0	0
Surface	0.0000244	0.0001708
Door handle	0	0
Urine containers	0.0005618	0.0039326
Faecal containers	0	0

The infection risk was estimated using HFE: where the faecal equivalent on loo seats of 10^{-3} $g\text{-}^{1}$ faeces a possible infection risk is posed by enterotoxigenic *E. coli* – assuming approximate values for HID_{50}, shedding rates, *E. coli* contamination and *E. coli* in faeces, which are variable and uncertain (Julian 2016). Since the infection risk is dependent on the prevalence or incidence of the infection in the community from which the faeces are collected, the infection risk is only an estimation of risk, and there may be no infection arising following exposure and ingestion of faecal pathogens if no infective pathogens were present or in volumes below the threshold for infection, the HID.

4.2.3. Exposure Risk Assessment

4.2.3.1. Collection and Conveyance

The main findings of the risk assessment were triangulated with findings from the behavioural survey (n=40) and in-depth interviews with key stakeholders (n=36). The results of the exposure risk assessment are presented below in Table 4.7.

Only one hazardous event presented a high risk of exposure, the remaining hazardous events and potential exposure risks identified presented low-to-medium exposure risks to operators if not managed (Table 4.7). A hazardous event categorised as a low exposure risk was the handling of contaminated toilet surfaces during cleaning and emptying. The behaviour survey (n=40) revealed that 75% of users cleaned the toilet at least once or more times a week, while 25% cleaned daily, indicating a low risk of surface contamination. The low-risk ranking was also supported by the findings from the microbiological sampling, which found only 6% of surfaces with a positive presence of a FIB. The exposure assessment also revealed that user hand hygiene practices at a household level contributed to the cleanliness of surfaces. The exposure assessment also revealed how a strong feedback mechanism between the users of the hardware and manufacturers led to more efficient and hygienic toilet design. Kildwick representatives described how toilet hardware was designed to minimise hard to reach areas and crevasses that hindered cleaning and created unsanitary surfaces on toilets.

A hazardous event categorised as a low exposure risk was cross-contamination and blockages of the urine diverter during collection activities (Table 4.7). Blockages of the urine diverter are caused by the introduction of cover material and/or excreta directly into the urine diverter portion of the toilet, or by a build-up of salts from urea in the urine diversion pipe that result in blocked pipes. The likelihood was low, but was directly linked to users' habits and specific occasions of misuse when users were unfamiliar with the toilet. The following quotes from the online forum describe this scenario:

But bog roll forced down wee section (which had to be pulled out – nice job) ...
But that had blocking it up so wee backed up and overflowed into sawdust.

Malodours were frequently mentioned as a hazardous event on the online forum but were considered to present low exposure risk to operators. Despite this, the malodour was unpleasant and was linked to the inappropriate use of cover material, which led to exposed faecal solids and proportionally more faeces in the final composition of waste. Additional analysis of the online forum content offered contrasting perspectives in the occurrence of hazardous events and exposure risks during CBS operations on the canal boats. In contrast to the risk workshop, online participants identified malodour as a significant hazardous event, while the largest proportion of the concerns with CBS systems were associated with urine malodour. The online forum participants linked potential causal mechanisms of malodour to broader risk factors such as age/diet and lifestyle factors – "pregnancy, hydration levels, diet, disease". Some participants reported specific medical conditions such as diabetes or fish odour syndrome to be associated with malodour. A typical statement from respondents concerning urine odour was:

when we go away for the weekend and come back it smells quite a bit and

I think the urine bottle smells worse if not emptied at least daily.

However, a spectrum of responses related to odour was found and some respondents thought the smell was pleasant, as noted by this remark:

Ours has an earthy smell. Like a woodland walk in autumn.

The differing views expressed on malodour are an indication of a lack of knowledge, illustrated by the following quote:

How long can the liquid container stay there without emptying? I don't mean for volume, but for smell/hygiene?

Health concerns related to the burning of dried faecal sludge were more explicit:

I admit that I know very little about burning fuel made from human waste ... but if done correctly are there health issues, or does it just smell a bit ... shitty?

Also apparent from the online content analysis was the considerable concern posed by inadequately sealed collection containers and the opportunity for flies to enter and spread disease. Flies were identified explicitly during the risk workshop, while the forum analysis identified a high frequency of coding to hazardous events associated with flies.

The hazardous events categorised as medium risk were the spillage of urine from overfilled urine containers during the collection and the “splash back” of urine onto the operator when pouring urine from small-necked containers (Table 4.7). The high likelihood of urine spillages was attributed to poorly sealed containers and the design of certain urine containers that exacerbated splash back during pouring. Also the emptying frequency contributed to the high-risk rating attributed during the risk workshop. The occurrences of spillages during emptying of urine was evident in the analysis of the forum transcripts, but operators did not appear to perceive it as a high exposure risk to health. The household survey also reported on the frequency of spillages, and the majority of respondents (66%) reported that spillages occur less than once per year. Only 10% of respondents reported spillages occurring more than a few times a year; however, the questionnaire did not distinguish between urine and faecal spillages.

4.2.3.2. Waste Treatment and Processing

A variety of treatment modalities described and implemented by individual houseboat operators gave rise to a number of hazardous events and transmission routes. A hazardous event categorised as high risk was hand contamination during the activities associated with the composting of faecal materials (Table 4.7). The handling of compost without gloves was considered to present high exposure risk, especially if handwashing was not carried out after the event. However, the interviews with operators suggested differing views on exposure risks posed by composting. The operators cited several factors attributing to a low exposure risk, including 1) the minimal or infrequent contact during handling, 2) a low hazard intensity and 3) a number of hygiene and infection control procedures (including the wearing of gloves and practising handwashing) that were followed. This quote from a CBS operator reflects these points:

> *I dunno about safety, I'm not really concerned too much about the safety elements of composting. Also the contact is quite minimal, we are … transferring the contents of one container into another container maybe a bit of stirring, it really is just transferring the contents from one container to another. By the time it has reached about 3 months, we have maybe handled it twice. Generally, I would wear disposal gloves while doing a big job. Like when I did a big transfer. I recently emptied that toilet, changed everything over to that bin, filled up the whole thing, that was done with disposal gloves.*

The hazardous events categorised as low risk included spillages and leakages of solid faecal waste due to breakages of internal bags in collection containers. Participants ranked the likelihood of spillages during removal of faecal matter as low, given effective control measures (double bagging and handwashing) to reduce exposure risks. The household survey finding that 100% of respondents reported washing their hands after emptying containers lends weight to this risk rating. Additionally, the inhalation of aerolised particulates when emptying containers was categorised as a low risk.

In terms of reuse and disposal, the participatory exposure risk assessment categorised hazardous events that posed medium-to-low risks as the unregulated bagging and binning of waste, disposal of urine into green areas and underground containment of solids. It is acknowledged that these hazardous events presented risks to the wider community but was less relevant for operator exposure risks. It was also acknowledged that, at the current scale, the resulting public health consequences to the community and environment from these events is not significant; however, these disposal methods do not have the potential to scale up, and alternatives cannot be addressed without further specific regulatory or institutional change. Further medium risks, related to personal behaviour and broader system regulations, included urine disposal into the canal and illegal disposal of solid waste and waste spillages onto tow pathways – both a public health concern of relevance to the local community.

4.2.3.3. Control Measures and Critical Control Points

The exposure risks identified in the assessment workshop were managed successfully by a number of control measures at key exposure points that ensured the safe operation and management of the CBS systems on the canal boats in London. Across the system components control measures addressed the technical design features of the toilet hardware to manage potential exposure risks from surface contamination. The material design of toilet contact surfaces reduced surface contamination by easy to clean, smooth surfaces of toilet hardware, which facilitated cleaning and enabled good hygiene. Some toilet surfaces were lined with "flo-coat" or antimicrobial silver oxide additives, which act as a background agent and reduce remaining bacteria and fungal spores on contact with surface.

The participants also referred to toilets designed with no "dead spaces" or "nooks and crannies" in the container unit, which otherwise easily harbour germs. Kildwick,[9] the toilet manufacturer, was a key stakeholder in the exposure risk workshop and referred to specific design features, which included a minimum width of the urine pipe diameter (>32mm ID) and a "drip lip", aimed at controlling a number of exposure risks, including (urine) spillages from separators and cross-contamination. The participants also cited the use of a urine bottle with a large hole (to monitor level) and limited to 11 kg (so not too heavy with carry strap) to prevent spillages during conveyance. Other aspects of structural design included controlled air flow (natural/powered) using vents to reduce malodour. Overall, it was concluded that simple less complicated designs were preferable to enable safe sanitation management.

Spillages caused by the breakage of bags during collection and transport were managed by a control measure termed "double bagging", which involved placing a second waste bag over the first which lined the collection container. An additional control measure to prevent the breakdown of the compostable bag in situ was ensuring that solid waste was frequently collected (at least bimonthly). The inappropriate disposal of solid waste was controlled by labelling the bags on the outside with a description of hazardous waste (according to regulations).

Prevention and management of exposure risk from hand contamination was successfully addressed by handwashing as opposed to the use of gloves. Handwashing practices were routinely performed at critical control points after activities involving the handling of contaminated materials or surfaces in multiple system components. The online forum also described these hygiene practices and indicated

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[9] Kildwick is a compost toilet manufacturer of urine diversion dry toilets based in the UK; see www.kildwick.com

a habitual practice of handwashing to manage exposure risks during management of CBS units. The following quotes show these elements of practice and habit:

I always wash my hands thoroughly afterwards

and

It’s down to discipline of washing your hands

A control measure to prevent or reduce surface faecal contamination was the regular cleaning of surfaces (ranging from daily to weekly). Operators cleaned and disinfected surfaces with a variety of cleaning products. Some participants mentioned the spraying of cleaning liquid into the urine diverter after use.

Overall, the responses that referred to current odour issues or implied previous odour issues indicated that offensive smells were now positively managed. The forum transcripts referred to multiple control measures for malodours, including the use of cover materials (on solids), the use of cleaning products (e.g. surface cleaning, baking soda) to remove smells, and technical controls such as improved ventilation (open window or vents) and thorough drying afterwards of the container. Other management controls related to the frequency of emptying the urine container (daily), cleaning protocols and thorough drying of the container afterwards. The ability to successfully manage the odour indicates a high level of awareness and knowledge related to the controls for odour.

In general, exposure risks were managed by the training and education participants had access to. The online forum indicated how participants were able to share problems with operation received useful feedback and advice on how to manage these exposure risks, which presumably were then implemented. However, operators received little specific instruction from the suppliers or other institutional organisations in terms of exposure risk management.

Table 4.7 Exposure risk assessment from Case Study 2, London

System component	Hazardous events	Exposure route	Existing control measures	Risk level	Comments justifying risk assessment
Containment: Toilet use, handwashing and cleaning and disinfection	Blockages of urine diverter; blockages from cross-contamination of faecal material and build-up of deposits in urine pipe	Ingestion via hands, surfaces, floors	Wipe separator after use; urine pipe diameter wide enough not to block easily (>32mm ID)	Low	Low frequency of blockages
	Handling contaminated surfaces Dirty toilet surfaces and child touching, when cleaning same height as toilet – UD		Handwashing after handling Cleaning and disinfection of surfaces (variable frequency)	High	High compliance to h/w
	Urine spillages onto base of unit from container		Awareness of need for removal – change in sound, frequency; adequate size	Medium	
	Bad odour from toilet as urine mixing with solids	Aerolisation	User behaviour	Low	Mentioned on online forum and discussed but not ranked by participants
	Faecal matter exposed in container not sealed or a lack of cover material	Flies	Sealing the toilet, ensuring adequate supply of appropriate	Low	

			cover materials, was diluting the hazard material		
	Handling and aftercare for the dog screw cleaning – with toilet paper (or puts/stores in paper bag)	Ingestion via hands, surfaces, floors	Cleaning; design of toilet and materials surfaces; no "dead spaces" or "nooks and crannies" in container unit	Low	
Collection and transportation	No handwashing during transfer/emptying	Ingestion via fingers, surfaces, floors	Wearing gloves/handwashing	Medium	Collection and emptying not a frequent event, bimonthly; handwashing compliance high
	Hand contamination when emptying urine bottle from splash back and glugging		Handwashing after emptying	Medium	
	Urine overflows/spills from containers onto floors		Appropriate container design		
	Spillages when moving containers		Sealed containers		
	; unregulated disposal, urine poured into the canal because Elsan is full/unavailable/far or no green space	Contaminated water		Medium	

	Urine poured into the canal because no green space				
	Solids spills as bag (compost bag) splits during removal as the compostable bags are not resilient	Soils/ground surface	Robust bags, double bagging, frequency of empting	Low	Control not yet implemented
	Aerolisation of solid particulates when emptying containers	Airborne		Low	
	Solids dumped in public areas without effective hazard risk communication	Hand contamination, surfaces, water	Risk communication and signage	Medium (not to operators, but to community)	Not high, likely but high consequences if it occurs
	Solids block the Elsan due to misuse/inappropriate use (mentality of people, lack of knowledge and lack of planning)			Medium (not to operators, but to community)	
Treatment: Direct disposal into municipal waste bins or composting	Hand contamination when handling/moving/treating faecal waste	Hand contamination, surfaces, soils, air, water	Wearing gloves and handwashing	Low	
		Dermal exposure			

	Solids spill onto floor during removal from containers	Skin contact, hand contamination, direct ingestion	Wearing gloves/handwashing, not frequently performing actions (<1/month)	High	
	Hand contaminations as not wearing gloves when moving waste		Operators are trained, able and experienced in handling waste		
	Wash water splashing when emptying/washing containers				
Reuse/disposal	People unknowingly handle untreated human waste	Hand contamination, surfaces, soils, air, water	Proper disposal	Low	
	Bad odour during burning	Inhalation		Low	Mentioned on online forum and discussed but not ranked by participants
	Pathogens on compost material transfer to vegetables intended for consumption	Ingestion from soil on plants		Low	Compost only used for plants (ornamental) not for growing food

4.3. Case Study 3

The third Case Study was a CBS system run and managed by Wherever the Need India Services (WTNIS) a local, nongovernmental organisation in Puducherry, a city in southern Indian. The organisation provides shared sanitation services to approximately 40 unique community groups, each of which serves an estimated 20–40 individuals.

In the context of Case Study 3, it is important to note that India is a caste-based society, and the management of faecal waste is a very low caste occupation. The term “manual scavenging” refers to an occupation that was traditionally carried out by the lowest social castes where untreated human excreta was removed from pit latrines with buckets (Wikipedia n.d.). A manual scavenging act now makes this work illegal in India and precludes organisations from hiring people to undertake work that involves the direct handling of faecal waste (Ministry of Law and Justice 2013). Accordingly, WTNIS has had to overcome regulatory barriers to enable it to carry out and provide human powered faecal sludge management services to the community and has had to demonstrate that CBS systems do not replicate any aspect of manual scavenging. To do so, the organisation has thoroughly and comprehensively developed SOPs for the collection and conveyance of waste products. WTNIS has had to demonstrate to national and local authorities that the activities and processes do not present any exposure risks to system operators. These SOPs were reviewed as part of the participatory exposure risk assessment and are included in the discussion on risk.

Following observations and sanitary surveys of the CBS system, five members of WTNIS frontline staff participated in a two-day workshop that contributed to the findings of the exposure risk assessment (see Photo 4.5). The workshop consisted of a review of hazardous events and consideration of particular risk factors, control measures and critical control points. The participatory exposure risks assessment was cross-referenced to supplementary data collection and analysis embedded in the Case Study. A sanitary survey tool randomly sampled 12 toilet units (Figure 19) and measured indicators of key hazardous events and risk factors. These additional data components are triangulated with the findings of the exposure risk assessment. The sanitary survey checklist also formed the basis for recommended monitoring tools to later inform risk assessments and operational monitoring.

The results of the exposure risk assessment undertaken in Case Study 3 are presented in Table 4.8 below. Some important limitations noted were the lack of documentation or field monitoring, which impeded a reliable assessment of the potential likelihood/frequency of some risks, since the efficacy and/or efficiency of certain control measures was unknown and not systematically monitored.

Photo 4.5 The write-up and process from the participatory exposure risk workshop, India

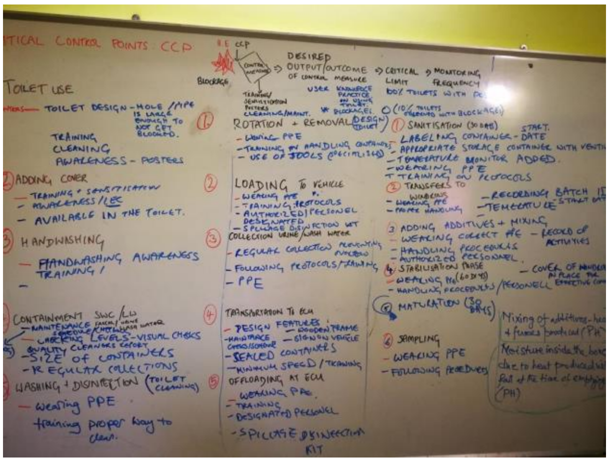
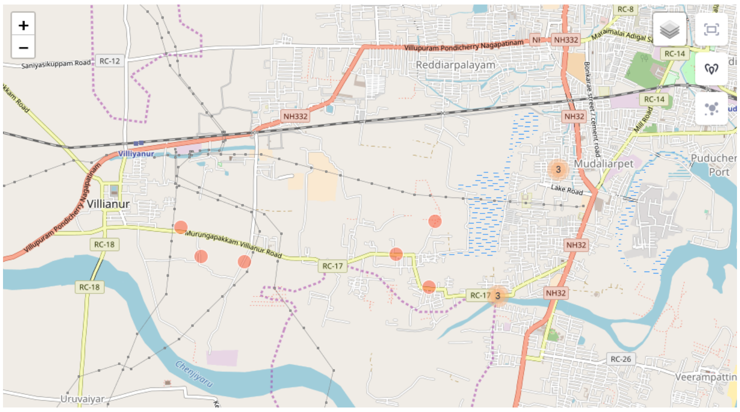


Figure 20 Map of the sites from where the sanitary surveys were conducted (red dots indicate an approximate survey location)



4.3.1. *System Mapping*

The system map illustrated in Figure 20 follows the movement of three different waste materials, namely urine, anal cleansing water and faecal matter (including carbon/cover material). These flows and volumes were mapped in each system component and hazardous events relating to the different waste flows were identified. The boundary of the study included the containment, the collection and conveyance and treatment components. The reuse component associated with the reuse of "enriched compost materials" produced by the treatment facility was not included within the system boundary. This decision related to the fact that the reuse was organisationally annexed from WTNIS and managed under a for-profit business model. The user interface technology was a squatting toilet (as opposed to a sitting throne), which provided a comparison to the user interface technologies of Case Studies 1 and 2. The squatting plate reflected the cultural practices and context in this largely Hindu society.

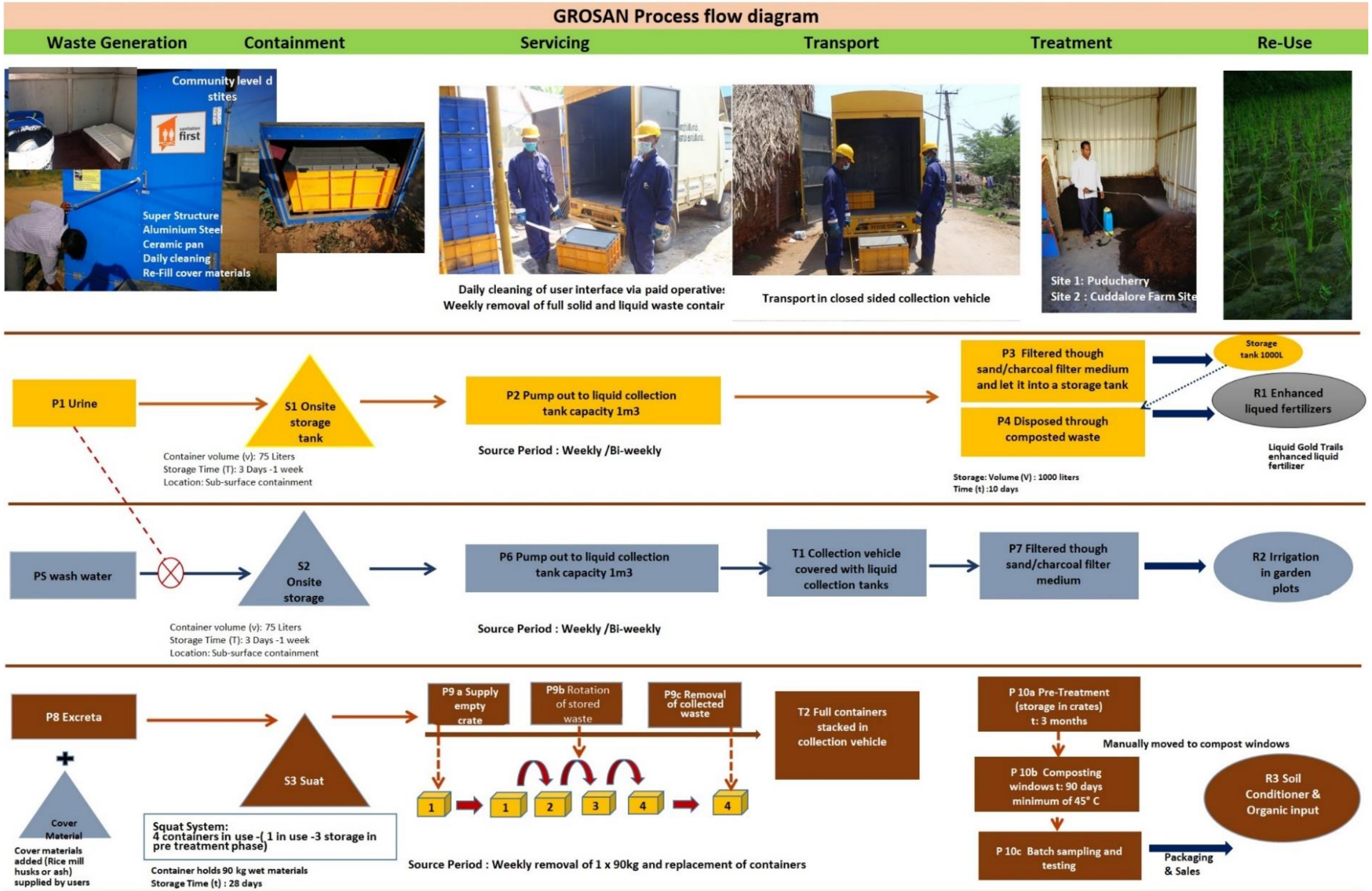


Figure 21 System map of Case Study 3

At containment three main process steps were identified: the toilet use, temporary storage of excreta/wash water and urine, and the cleaning and disinfection of the toilet units. Toilet use included the activities associated with anal cleansing and handwashing. The anal cleansing method in Case Study 3 involved water, a cultural norm in this context. The use of a squatting plate was associated with the use of water for anal cleansing, which has important implications for the design and management of CBS systems. At collection and transportation, the four main process steps were rotation and removal of solid waste containers (SWCs), collection of liquid waste containers (LWCs), transportation to the treatment facility and unloading of SWCs and LWCs. The SWCs comprised plastic boxes (volume approximately 100l), which rotated on a weekly basis.

The treatment components related to the aerobic composting of solids and the storage of liquid waste streams. In the treatment facility, exposure groups included those operators responsible for cleaning and disinfecting the crates, and those responsible for the transfer and mixing of composting process. The latter group comprised WTNIS staff and also daily labour who were hired on an ad hoc basis.

The sanitisation phase was the first process step of solid waste treatment that comprised an initial storage period of 90 days of faecal waste in sealed crates intended to inactivate harmful faecal pathogens due to processes occurring inside the crates. The SWCs were stacked on arrival at the treatment facility and labelled with a date of entry. The main stabilisation phase was the second process step where, after the initial 90 day period, crates were emptied into windrows and remained for a further 60 days. The windrows were turned and moisture was added as required for the remaining inactivation of pathogens in the solid waste. After this period, additional materials were added to the stabilised waste. These additional materials include poultry and farmyard manure from external sources, neem cake and other additives (said to improve the overall quality of the final compost material). The final stage of reuse was the direct application of enriched products on fields by farmers. This was outside the boundary defined as part of the participatory exposure risk assessment.

A separate process at the treatment facility included the washing and disinfection of SWCs (crates). The composting of liquid waste involved filtering it through the compost medium.

4.3.2. *Exposure Risk Assessment*

4.3.2.1. *Collection and Conveyance*

Those hazardous events categorised as high risk were spillages of faecal solids from containers due to disturbance from rats. The likelihood of spillages was also due to the deterioration of the physical integrity of the both SWCs and LWCs/soakaway units. The risks caused by rats was supported by the findings of the sanitary survey, which found over 50% of sites had a lot or some rubbish (23% and 33% respectively) and may therefore be associated with presence of rats. A direct indicator of vector transmission was the presence of flies: 83% of toilets had no (0) flies observed, while a few (1–9 flies) were observed at the remaining 17%. Observation of faecal matter around the toilet area was a direct indicator of exposure risk from spillages. The sanitary survey found 25% of units were observed to have a small spillage around the toilet area and 100% of the urine diverters were free from blockage at the time of observation. However, the physical condition of the toilet unit and seals, as an indicator of isolation of the waste during containment, found only 12% of units were in good condition (brand new), 67% were in fair condition, while 17% were in deteriorated condition. The use of high density plastic for containers, with heavy-duty plastic clipper locks that seal the lids shut, and the removal of inadequate and poorly maintained containers from service were cited (during the workshop) as effective risk control measures for spillages; however, the sanitary survey indicated some physical deterioration occurred despite these control measures.

A hazardous event categorised as a low-to-medium risk was hand contamination due to the failure of cleaning staff to comply with hand hygiene and glove protocols. A low compliance with hand hygiene was observed by the researcher, including cleaning without the use of appropriate PPE (including badly fitting gloves, masks, footwear) and no compliance monitoring of the use of PPEs. The lack of PPE left them exposed to risks during the cleaning process. It was observed that cleaners appear not to have been following designated cleaning and disinfection SOPs or have adequate training. Recently, similar findings have demonstrated the poor provision of PPE, health management and lack of training procedures for frontline staff involved in sanitation occupations in Bangladesh (SNV 2017, 2014). These reports highlight exposure risks in individual Case Studies of employees in similar cleaning occupations who are exposed to dangerous working conditions without due attention from employers to health and safety procedures.

A hazardous event that was categorised as low risk was the handling of dirty toilet surfaces during cleaning, and the handling of contaminated containers during rotation and removal. Effective control of cleanliness was managed by daily house-to-house sensitisation of use and management of toilets at a household level, resulting in a low frequency of misuse and a low likelihood of contaminated surfaces. The sanitary survey showed only 33% of toilet units observed had faecal smears. The survey also showed that 92% of toilet facilities had functional handwashing available and 100% of users reported using handwashing facilities after defecation as a proxy indicator of hand contamination.

This control measure appeared to be effective; 100% of users surveyed had been sensitised in the last month and 100% of users surveyed considered themselves to be well informed about the use and maintenance of the toilet unit. The low risk was also attributed to the operators being prevented from direct manual handling of containers due to the comprehensive set of control measures stipulated in the SOPs. The participatory risk assessment noted the use of specially adapted tools that prevented the direct touching of collection containers during the rotation and removal of containers. Hazardous events categorised as low risk included spillages during the pumping out of liquid waste containers and risks related to contamination of the operators from splashing and spillages due to overturning and movement during transportation. The risk of the latter exposure was managed effectively by the collections vans being fitted with wooden grooves that held the containers in place during transit, and avoiding any spillages or breakages due to road conditions, sudden braking or accidents.

In addition, a hazardous event categorised as medium-to-high risk was the spillage and overflow from SWCs and LWCs during rotation and removal of containers to collection vehicles. The likelihood was elevated for a number of reasons, including the poor condition of the containers, a lack of regular service or overuse of the units leading to overflow of the both SWCs and LWCs.

Unfortunately, during the field work period, the collection vehicle was undergoing essential maintenance and thus collection processes could not be directly observed. This prevented any observation of the process or sanitary surveys.

4.3.2.2. Waste Treatment and Processing

The hazardous event identified as high risk during the initial sanitisation phase was spillage during transfer of faecal waste in crates to windrows. The physical deterioration of crates during storage (sun exposure, wear and tear) confirmed during observation of the treatment facility and activities increased the risk ranking. The stacking of crates also presented physical hazards while accessing crates for transfer and spillage risks. It was observed that there was significant variability in physical conformity between the crates (considered to have affected critical treatment parameters) that may have resulted in inadequate pathogen reduction during the sanitisation phase. Although this could not be verified during the risk assessment, it was noted as a potential hazardous event. There was a lack of handwashing points or facilities for hand hygiene, and a lack of risk information for operators at the treatment facility. Overall, the observation and risk assessment process concluded that there was a lack of risk communication in or around the treatment site. The risk profile for daily labourers was also elevated since these individuals did not receive formal or regular training and risk awareness; nor were they able to access reliable health management. However, WTNIS staff identified to the researcher that health management was a weakness of the organisation. This meant that staff were more vulnerable to the health impacts of exposure and could have affected the risk scoring.

During the stabilisation phase the hazardous event that presented the highest risk was inhalation of aerolised fungi or faecal pathogens during the manual turning and mixing of compost windrows. A high risk at this step was also hand contamination due to inadequate use or provision of PPE, or poor hand hygiene facilities (as noted above). The potential cross-contamination of newer batches into older batches also reintroduced pathogens into treated waste. In general, a lack of zoning in the treatment yard between high risk and low risk (untreated and treated) materials increased the risk of cross-contamination between unsanitised material and sanitised materials. An additional hazardous event was the addition of fresh “inputs” after the stabilisation phase. These inputs were poultry or farmyard manure that posed a hazardous source of pathogens that may remain in the final product. The additional handling of new waste would also have exposed handlers to pathogens during preparation of the final product. The control measures in place to minimise this risk were not well defined and although this risk was not ranked highly during the SSP process, it was noted as significant if more compost was being processed and reused as compost for food production.

Table 4.8 Exposure risk assessment from Case Study 3, India

System component	Hazardous event	Transmission pathway	Risk score	Comments justifying risk assessment
Use and containment (SOPs steps)	Blockages of urine (new users) not habituated with diversion toilets	Ingestion via hands, surfaces, floors	Medium	Higher risks with young children/elderly/drunk people
	Blockages of urine due to misuse (putting ash or cigarette butts)			
	Exposure due to dirty toilets		Low	
	Exposure and malodour if no ash used		Low	
	Hand contamination if lack of hand hygiene after defecation (users < 5 and elderly users, facilities)		High	Reporting bias – self-report always handwashing (alcohol abuse)
	Exposure (spillages) into environment due to movement by rats		High	
	Hand contamination/skin contamination from uncontained wastewater		Low	
	Spillages due to containers breaking and lack of physical integrity (86 containers)		Medium	The containers' material = high density plastic and are physically robust. Avoid using old containers
Collection	Hand contamination during cleaning due to failure to comply with hand hygiene/glove protocols		Low	

	Overflowing of urine due to compression of urine tanks	Urine and wastewater	Medium	
	Overflowing wastewater into environment		Medium	From flooding, however, very low likelihood of disaster event
	Inhalation of aerolisation of pathogens when sweeping	Airborne	Low	Poor cleaning protocols
	Hand contamination from handling waste containers	Ingestion via hands, surfaces, floors, urine and wastewater	Low	
	Spillages during removal/collection of containers		High	If overuse
	Overflowing due to lack of service/overuse		Medium	
Transport processes	Spillages during pump out of LWCs – environmental and personal contamination	Ingestion via hands, surfaces, floors, urine and wastewater	Medium	Gloves and PPE worn
	Spillages due to overturning during transportation		Low	Vans are fitted with wooden grooves that hold the containers in place during transit, to avoid any spillages or breakages due to road conditions, sudden braking or accidents
Treatment processes: Solid faecal composting	Spillages during removal/collection of containers	Ingestion via hands, surfaces, floors, urine and wastewater	Low	
	Contaminated solid waste handling of immature compost not stored for entire period (90 days) due to lack of appropriate storage time (no batch ID)			

	Contaminated solid waste handling due to lack of appropriate moisture or excess water		
	Spillage during transfer due to breakdown of crates during storage (sun exposure, wear and tear)		
	Cross-contamination during transfer of newly sanitised material in windrows' stabilisation phase		
	Hand contamination during transfer of materials due to poor hand hygiene due to lack of facilities		
	Hand contamination during manual transfer caused by incompetence/mishandling	Ingestion via hands, surfaces, floors, urine and wastewater	Low
	Aerolisation of bioaerosols (spore-forming fungi and bacteria) during transfer and turning	Airborne	
	Sanitary pads, plastic cover/containers, cigarette butts, cloths, glass bottles, stones, ash box and condoms found in SWCs	Ingestion via hands	Low

4.3.2.3. Control Measures and Critical Controls Points

The exposure risk assessment documented that the use of control measures successfully managed a number of exposure risks to operators. As described, a comprehensive SOP for manual handling managed the risk of exposure related to the handling of faecal waste or contaminated materials. Overall, though, there was poor follow-up to the implementation of control measures or verification that the control measures are operating as intended. In addition, the risk assessment noted a tendency to rely on single behavioural controls, which are least reliable due to poor compliance and human failure due to incompetence.

Control measures at the treatment facility were designed to prevent the handling of contaminated waste and materials. These included the application of formal SOPs for composting, which included specifying the key parameters (time, temperature, moisture levels, and turning when in windrows), that must be achieved according to safe pathogen reduction. Monitoring records for critical parameters for treatment, including the moisture, pH and temperature monitored on a daily basis, were critical for quality and safety assurance of the final product. As above, the monitoring of these control and treatment parameters was poorly carried out. Minimum details captured should include a unique batch ID and storage times (i.e. start and end dates). This was facilitated with technical resources and clear procedures.

Critical control points (CCPs) were defined where exposure risks existed and where it was possible to reduce or prevent exposure risks with control measures along with systematic monitoring (Table 4.9). Fifteen critical control points (CCPs) were identified where it is possible to eliminate or reduce specific exposure to faecal pathogens resulting in possible health risks along the CBS system chain by adopting control measures. These fifteen CCPs included: 1) toilet use; 2) adding cover material; 3) handwashing; 4) containment of LWCs and SWCs; 5) washing and disinfection ; 6) rotation and removal of solid waste; 7) loading on vehicle ; 8) pumping of liquid waste; 9) transportation to treatment facility; 10) offloading of raw faecal sludge and urine; 11) the sanitisation of waste;12) the stabilisation of waste in windrows; 13) compost sampling; 14) disposal of rejected (non-faecal) waste and 15) product preparation. At these CCPs, hazardous events and associated exposure risks can be minimised by control measures identified that derive from a combination of corresponding controls. The CCPs and control measures identified in Table 4.9 also include recommendations for new and/or improved control measures designed to reduce exposure risk.

Table 4.9 The 15 critical control points identified in Sanitation First

Process step		Critical control point	
P1	User interface		
		1	Toilet use
		2	Cover material added (rice husk ash)
		3	Handwashing/hand hygiene (at household level)
		4	Excreta containment
			Urine containment
			Wash water containment
		5	Washing and disinfection
P2	Collection and conveyance		
		1	Rotation and removal of SWCs by collection operators according to the collection SOPs
		2	Full containers loaded onto collection vehicle
		3	Collection of urine/wash water
		4	Transportation to ECU
		5	Containers are offloaded at ECU
P4	Treatment		
		1	Sanitisation phase: initial storage of crates (90 days)
		2	Stabilisation phase: transfer of crates to windrow (60 days)
			Manual turning and mixing of material
			Addition of compost additives (sugarcane press mud, poultry manure, farmyard manure)
		3	Compost sampling: composite site batch sampling
		4	Disposal of rejected (non-faecal) waste
		5	Product preparation

4.4. Limitations

Certain biases that may have affected the classification and risk ranking exercises during the participatory exposure risk assessment have been previously described in the literature (Delgado-Rodriguez 2004) and were expected during the participatory exposure risk assessment. The limitations of participatory risk assessments are mentioned to make the reader aware of the constraints under which the data should be interpreted, but also in order to bring these concerns to bear on future implementations of participatory workshops used in exposure risk assessments in CBS systems, as advocated by the WHO's Sanitation Safety Planning (WHO 2016).

An initial limitation is selection bias, which refers to the fact that participants who volunteered may have had different perspectives on risk and exposure from the users of the CBS systems who choose not to volunteer (Wilmot 2005). An information bias was observed in all workshops, where the participants consciously or subconsciously cherry pick information, or were unable to fully recall information (Rajaratnam et al. 1992). A similar phenomenon is a psychological effect where people find it easier to recall events that happen most frequently as opposed to those less frequently (Winterfeldt 1992). Although it appears rather obvious, this may be an important limitation in the participatory exposure risk assessment if events that come easily to people's mind are rated as more probable than events less mentally available. Similarly, the perception of risk level and perceived properties of risk is affected by familiarity with risks (Winterfeldt 1992) (i.e. diarrhoea being considered normal may reduce the perception of the risk). Similarly, it is known that a long lag time between observed health impacts and work activities impedes an accurate assessment of occupational exposures (Swuste and Eijkemans 2002). Due to this delay between exposure and health impacts, or non-clinical infections, operators were not able to conclusively or decisively link their health status with work activities, observed in other occupational risk assessments.

Likewise, an underreporting bias was observed during the hazard identification exercises, since some hazardous events or exposure pathways were socially undesirable. To overcome this, it was necessary to ensure that people participating felt comfortable describing intimate or potentially shameful experiences and that the shared knowledge would be confidential and only used as an aspect of the PhD research. Another limitation of the participatory approach was that participants may not identify expected hazards (Acker et al. 2016) and selection biases exist, in that stakeholders may not be truly representative. This was mitigated to some extent by ensuring experts were a part of the participatory risk ranking group. The influence of such biases was also addressed by the use of other data collection methods to enable an informed identification of risk. Lastly, these biases were controlled by providing clear instructions and training to participants during the hazardous event and risk ranking exercises.

In particular, the workshop setting raised a number of important problems related to participation, power and biases. It was apparent during participatory risk workshops that the presence of a CEO (or person of higher rank) was a barrier to employees of a lower rank from openly contributing to the discussion. Submissive behaviour is perhaps explained by findings that have highlighted that, in certain contexts, cleaning staff (generally women) occupy a lower status than other staff (usually men) in the hierarchical organisational structure, meaning their voices may be marginalised (European Agency for Safety and Health at Work 2009). This is of particular relevance for their contributions in "participatory" types of risk assessments. Although these power relations were acknowledged and addressed to support the participation of all members to freely, by encouraging participants to provide accurate and realistic portrayals of work settings would face repercussions, such perceptions of rank were difficult to overcome. In other scenarios, the participation and involvement of the whole team of key stakeholders charged with risk assessment was not always possible, which necessitated that the risk rankings relied heavily on individual expert opinion when assigning risk levels (CS 1).

Potential researcher bias may occur during the interpretation of interview data with key informants, observation and work shadowing and text analysis. To reduce researcher bias, field notes were documented using neutral and objective language at the end of each day, while more reflective or subjective interpretation was reported in a second column to indicate the separation between the two. The qualitative analysis sought to recognise the subjectivity of the interview process, biases and subtle power relations that exist and distort responses. For example, biases may have occurred during interviews with operatives and agents of the organisations if they felt uneasy reporting the actual nature of risks or accidents that occur. Although it was explained that the research would not be used in any way, there is no doubt that the organisation would likely be able to identify the interviewees, given the limited number of operators in some organisations. However, given consideration and a reflexive approach, all responses are valid. The participants were encouraged to actively direct the flow of the conversation by using follow-up questions to their statements.

Lastly, a substantial time allocation would have been required for a complete risk assessment according to the SSP modules and placed significant resource demands on small sanitation service providers. This is also noted in the summary of a report on SSP workshops for CBS systems (see full unpublished report in Annex 1).

4.5. Concluding Remarks

Each of the Case Studies highlighted instances of exposure risks that arise to the operator during work-related activities and demonstrated the successful application of the SSP framework with additional data collection components. The exposure risk assessment successfully detailed potential hazardous events and transmission routes, the critical control points and relevant control measures to manage these risks that are useful practical examples of exposure risks within CBS systems.

The additional tools embedded into the frameworks, such as transect walks and sanitary surveys, were supplementary to the main feature – of the participatory work – but raised additional issues and allowed the triangulation and deeper enquiry into some of the major exposure risks and driving factors. Moreover, the conducting of regular and proper risk assessments, which include the participation of the entire team, is itself an important risk management exercise that leads to effective risk management.

The comparison of multiple Case Studies is required to evaluate the extent to which exposure risks are replicated between the cases and the development of consistent evidence of exposure risks. In order to yield maximum benefit from these examples, a Cross Case analysis to identify the trends and distinctions between Case Studies was conducted. A Cross Case analysis is expected to identify similar processes or findings within and between the cases and therefore produce wider generalisations relevant to exposure risk assessment and management for numerous CBS organisations and practitioners.

Chapter 5 compares the results of the exposure risk assessment between the cases and discusses the replication of exposure risk between the cases.

5. Cross Case Analysis of Exposure Risks

To date, little information has been available on the exposure risks to operators posed by CBS systems. The preceding section presented a nuanced understanding of the pertinent hazardous events, transmission pathways and control measures within the context of CBS systems (to a level not previously found in the sanitation research) based on the identification and assessment of occupational exposure risks as the subject of three independent Case Studies. The discussion of the individual Case Study findings is now undertaken as a Cross Case analysis that does not directly compare occupational exposure risks across the cases, as this would destroy the integrity of the cases; instead, the characteristics and emerging patterns within the cases are compared. The discussion of the findings also considers the support of the findings for the generalised conceptual model of exposure and illustrated exposure risks as a product of linkages between the hazardous events and transmission of faecal pathogens along pathways to a receptor.

The main purposes of the Cross Case analysis are 1) to summarise and discuss the exposure risks and implications for management, given the comparison of findings across the Case Studies, and 2) to evaluate the characteristics and emerging patterns between the cases in the form of immediate and primary causal mechanisms of occupational exposure risk in CBS systems. The Cross Case analysis highlights the behavioural and contextual themes that shaped exposure risk outcomes in terms of the risk level in the individual cases and enhances understandings of the primary risk drivers in CBS systems to workers.

5.1. Exposure to Faecal Pathogens and Health Risks with Implications for Exposure Risk Management

Table 5.1 below summarises the occupational exposure risks from the Case Studies and system components delineating hazardous events with their associated multiple transmission pathways and associated control measures. The risk rating is relative to the individual Case Study and reflected the internal conditions of the case and so could not be summarised. Overall, a number of hazardous events result in occupational exposure to faecal pathogens, which, if unmanaged, may lead to adverse health consequences for operators. The identification of potential exposure to biological hazards in the sanitation waste management sector aligns with previous exposure risk assessments in the sector, which refer to long lists of occupational hazards faced by workers (Bleck and Wettberg 2012). Indeed, the sewage and waste worker sector acknowledges the adverse health impacts that arise from work activities that bring workers into contact with excreta (HSE 2006). Although there is little comparable evidence in the

CBS sector, poorly managed water and sanitation systems that result in exposure to faecal pathogens and adverse health impacts are described in the literature (Prüss-üstün et al. 2004; Katukiza, Ronteltap, van der Steen et al. 2014). Similarly, poor working conditions that exacerbate occupational exposure are typical of the informal industries and waste management sector, particularly in LMICs, explained by the low profile of occupational exposure on the political agenda (Swuste and Eijkemans 2002a).

In terms of the severity of environmental exposure to microbial hazards, the Cross Case analysis compared the presence of the microbial contamination estimated on toilet contact surfaces from Case Studies 1 and 2. The modest levels of bacterial contamination revealed that toilet surfaces were contaminated with potentially pathogenic organisms, although the contamination of surfaces was relatively infrequent. Positive presence of *E. coli* varied between 41% of contact surfaces sampled to just 6% of contact surfaces sampled (CS 1 and 2, respectively). The mean surface contamination in Case Study 1 was 1.39 log *E. coli*/100 cm^2 compared to the mean value 0.38 log 10 *E. coli*/100 cm^2 in Case Study 2 but this was not statistically significant ($p>0.05$). There was no significant difference ($p>0.05$) in the concentrations of *E.Coli* on surfaces compared between Case Studies 1 and 2. Further, the large interquartile ranges indicate the variability of surface contamination. For all contact surfaces sampled in Case Study 2 and one contact surface in Case Study 1 there is no interquartile range as there was such a high proportion (>75%) of zero values after transformation. However, the maximum values of surface contamination reached 2.67 to 4.93 log 10 *E. coli*/100 cm^2 in Case Studies 1 and 2. These maximum values indicate that the maximum extent of faecal contamination between the Case Studies was more closely related than the mean values would suggest. The contamination identified in Case Study 2 was likely to be of little importance, since many of the sites had zero FIB (faecal indicator bacteria) present, but the samples did highlight areas of hazard and suggest potential pathways of transmission to the operators. In Case Studies 1 and 2, the level of environmental contamination revealed by the surface sampling indicated that toilet surfaces are a potential source of infective pathogens.

The infection risk posed by the environmental exposure to faecal pathogens is complex, determined by a great number of variables, which, at a minimum, would include the susceptibility of the operator (Rheingans et al. 2012), the behaviour and frequency, intensity and duration of the exposure. The level of exposure is compounded in Case Study 1 by the frequent handling of potentially contaminated surfaces several times per day, especially for operators performing collection activities. In assuming the importance of contamination, the extent of the hazard depends on the inherent characteristics of the disease agent itself, which determine the number of infective organisms shed from infected persons, the infectious dose and the environmental persistence (see Table 2.3, section 2.6) (Katukiza, Ronteltap, van der Steen et al. 2014; Julian 2016).

The study used FIB as a proxy measure to estimate exposure risks posed by the surface contamination, which overcame the lack of quantitative pathogen data. The FIB was linked to the probability of infection using the human faecal equivalent (see section 3.7.3). In case Studies 1 and 2 the results of the FIB on surfaces corresponded to amounts of faecal contamination (g) that could result in probable infection from a number of faecal pathogens, including ETEC and *Shigella* (Julian 2016). The level of faecal contamination corresponded to volumes of 10^{-2} to 10^{-4} g faeces on surfaces (CS 1) and 10^{-3} to 10^{-5} g faeces on surfaces (CS 2). ETEC and *Shigella* are both bacterial pathogens and would thus follow similar pathways to *E. coli*. As a proxy measure of infection risk – risk is highest when people are exposed to more than 10^{-3} g faeces considering the infectious doses and pathogen shedding of most common faecal pathogens (see section 2.6). However, given the high shedding rates for *Shigella*, environmental contamination of 10^{-7} g^{-1} faeces represents a “non-negligible risk of infection for exposure” to *Shigella* (Julian 2016). In the context of case Studies 1 and 2, transmission concerns exist with even the lowest estimation of faecal equivalents observed on collection containers (10^{-5} g^{-1} faeces).

In studies of household fomites in LMICs, Julian (2016) describes comparable levels of faecal contamination occurring, with values from 10^{-3} to 10^{-5} g faeces and occasionally more than 10^{-2} g faeces. Other studies describe the risks of exposure to faecal pathogens posed by dirty toilets for both toilet users and operators (Baker et al. 2016; Stenström et al. 2011; Höglund 2001). Comparably high levels of FIB contamination on surfaces are also revealed by evidence from bathroom surfaces in domestic household and public environments (Scott, Bloomfield and Barlow 1982; Barker and Bloomfield 2000; Rajaratnam et al. 1992; Gerhardts et al. 2012; Flores et al. 2011). Although it is possible for faecal contamination to derive from external sources (not related to the toilet faecal matter), the study by Scott and colleagues (1982) controlled for significant external environmental contamination, thereby establishing a precedent for a conclusion that the levels of toilet contamination encountered originated from faecal matter from the toilets themselves.

Furthermore, the risk of exposure and possibility of infection from surface contamination depends on the ability of surfaces to transmit pathogens to other surfaces (Julian 2016). Previous studies point to a high variability of transfer rates, ranging from <0.01% to 50%, with the highest bacterial transfer rate corresponding to the presence of hard, non-porous surfaces (Rusin, Maxwell and Gerba 2002; Julian, Leckie and Boehm 2010). The use of non-porous surfaces was encouraged as a particular control measure in the Case Studies to enhance cleanability, but this may have an unintended consequence in enhancing transfer and transmission. Another variable is from Lingaas and Fagernes (2009) who found bacterial transfer from the hands occurred more readily from gloved hands than bare hands during person-to-person contact. Conversely, disinfection efficacy appears to be greater for gloved as opposed to bare hands (Scheithauer et al. 2016). Given the role of gloves in hand hygiene observed in CBS systems, the potential implications for exposure warrant further investigation. Overall, little research has been conducted on the efficacy and role of gloves and other hand hygiene procedures in field trials (Fuller et al. 2011) and is conspicuously absent in sanitation and CBS systems. The transmission of *E. coli* from surfaces to hands and the possibility of infection was investigated and is described in more detail in sections 0–0.

Although the aetiology of diarrhoeal diseases at a pathogen level is often not available, recent global evidence has determined that just five pathogens – rotavirus, *Shigella*, enterotoxigenic *E. coli* (ST-ETEC), *Cryptosporidium* and typical enteropathogenic *E. coli* (EPEC) – are responsible for the majority of diarrhoeal diseases in LMICs (Kotloff et al. 2013). ETEC is one of the most common causes of diarrhoeal disease (Firdausi et al. 2005), but, given the large volumes required to be ingested for infection (Enger n.d.), it is not typically spread from human to human (Levine et al. 1980). However, for some microbial hazards, the infectious dose required is far smaller, from 10^2 to 10^3, while in theory only one egg of *Ascaris* is required to cause infection (Schönning et al. 2007). Rotavirus was identified as the most common cause of infant diarrhoea (Kotloff et al. 2013) and it is likely to be excreted in the faeces of infected adults and children, especially in communities without proper access to water and sanitation, which increases the risk of faecal-oral diseases. Ward and colleagues (1991) have shown that rotavirus can be transmitted from surfaces to either the fingers or mouth. RoV is also highly persistent in the environment and only requires a small amount of cells for infection – meaning its presence on surfaces would pose a high risk of infection to operators. In contrast, *Cryptosporidium* rapidly desiccates on surfaces and would therefore be less likely to survive environmental transmission or pose an infection risk to operators. It was not the aim of the study to gather precise information on disease aetiology and quantify infection risk posed by the surface contamination. Nevertheless, the proxy measure using the HFE indicated that the level of exposure observed would theoretically be able to initiate certain infections in operators.

Thus the possibility of infection based on surface contamination is variable and uncertain based on the type and volume of pathogens present. The presence of FIB cannot therefore be used to directly indicate the infection risk posed, but it does indicate the potential risk posed and that fomites are a pathway of contamination for operators. The HFE findings demonstrated the risk of surface contamination and highlighted the need for control measures are not considered. The application of HFE also demonstrated a useful methodological approach for exposure and infection risk, which is less resource intensive that quantifying pathogen data, instead relying on FIB. Of course, the inherent assumptions made in the estimations of HFE and infection risks mean the results are uncertain and variable.

The use of disinfection and other control measures to prevent the transmission of faecal pathogens from surfaces to operators during activities undertaken along the CBS system chain are justified by the findings of environmental contamination. The use of disinfectants to reduce faecal contamination of surfaces is described in previous studies (Bloomfield and Scott 1997; Rusin, Orosz-Coughlin and Gerba 1998).

The results also provided evidence to support the conclusion that faecal smears are a reliable indicator of surface contamination, although far larger numbers of samples would be required for this to be statistically relevant. Dirty toilets are a known risk factor for exposure (Tumwebaze and Mosler 2014), and while sanitary survey indicators are poor predictors of microbial contamination (Snoad et al. 2017), the value of faecal smears as a risk tool has relevance for this study. The presence of faecal smears as an indicator of surface contamination, observed in 30% of households surveyed, broadly corresponded to the 41% frequency of *E. coli* contamination found on toilet contact surfaces (CS 1). Inversely, the self-reported cleaning frequency reported in Case Study 2 was an indicator of surface contamination and to some extent inversely correlated with the intensity of microbial contamination found on surfaces. Again, the empirical evidence is not able to support this conclusion. Common sense would suggest that increased cleaning frequency would reduce surface contamination, given the known effects of a cleaning regime and disinfection on microbial hazards (Rusin, Orosz-Coughlin and Gerba 1998; Strauch 1991).

5.1.1. Combining the Evidence on Hazardous Events and Critical Controls Points

The exposure risk assessments, which followed SSP guidelines, were combined with the HACCP framework to identify critical control points (CCPs) where it was possible to prevent or reduce exposure risks, thereby protecting the health and safety of toilet operators. Collectively, the CCPs in the individual Case Studies informed a set of 12 CCPs associated with containment, cleaning and disinfection, collection and transport, treatment and composting stages, reuse and the final disposal of contaminated waste materials, where it was possible to reduce and prevent the exposure risks with relevant control measures (see Table 5.1). Under each CCP are a number of hazardous events with corresponding control measures that can be employed to prevent, reduce or mitigate occupational exposures. It is acknowledged that toilet use (CCP 1) would likely be relevant for most sanitation systems and is not unique to these Case Studies or CBS systems in general. Indeed, toilet use has been associated with the positive presence of pathogens on hands (Feacham et al. 1983), while the transportation of faecal pathogens into the environment after defecation is linked to secondary contamination of foods, fomites and water (Mattioli, Davis and Boehm 2015; Wang et al. 2017). The remaining CCPs relate to the specific processes and steps associated with the cleaning, collection and emptying, transportation, treatment and disposal of human waste in these Case Studies, yet the CCPs would be expected to vary according to the processes and steps occurring in the different CBS systems. The control measures at individual CCPs are connected across system components due to linkages between and within those system components, meaning that the controls exerted in one system component will allow or impose restrictions on behaviour in another system component. The CCPs and associated control measures reflect a holistic approach to risk management, based on the complexity of sociotechnical systems that a CBS system, with its numerous interdependences, reflects (Leveson 2012a).The Cross Case analysis highlighted the use of CCPs in risk management which, when combined with successful control measures, is a fundamental approach to health risk management across the entire CBS sanitation value chain. Comparable health risk management frameworks that apply CCPs are noted in the management of health risks, from disposal of contaminated waste in global contexts(Edmunds, Elrahman et al. 2016). The goal of exposure risk management is to protect operators from exposure risks by enforcing safety constraints in the design and operation of the CBS system to limit exposure. To accomplish this, control measures must be established (Leveson 2012a). The discussion of control measures arising from the Cross Case analysis follows in section 5.3.

The Cross Case analysis paid close attention to the narratives of the individual Case Studies to identify key themes that emerged as opposed to the risk assessment tables, which were either incomplete, or inadvertently selective in capturing information. However, Table 5.1 highlights key hazardous events that occurred across all cases and contributed to exposure risks to operators. Multiple transmission pathways were associated with individual hazardous events, as shown in Table 5.1. The Cross Case analysis evaluated the individual contributions of the transmission pathways observed to simplify the analysis, and these are discussed in relation to the relevant literature. This does not imply that transmission pathways act independently though; and the complex linkages are highlighted during the discussion.

The main hazardous events leading to occupational exposure risks were identified as:

HE 1: Spillages/overfilling of urine and faecal containers

HE 2: Blockages of the urine diverter

HE 3: Accidental contact with faecal matter/urine with hands

HE 4: Misuse of toilet infrastructure

HE 5: No handwashing/noncompliance with protocols

HE 6: Aerolisation of organic and non-organic particles

HE 7: Lack of time/temperatures or storage treatment processes.

Spillages of urine and faecal matter were a key hazardous event across the Case Studies. As previously observed in risk assessments, spillages are inevitable during the manual emptying and processing (Stenström et al. 2011) and the Case Studies documented consistent evidence of spillages of faecal matter and urine along the CBS system chain, although the frequency and volume of the spillage was variable across the Case Studies. For instance, small volumes of faecal waste were spilled when removing the contents of collection containers/bags into secondary treatment containers (CS 1 and 2). All the case studies highlighted urine spillages – caused by the overfilling of urine containers and during conveyance, spillages from poorly sealed containers were a consistent hazardous event. At these points a number of control measures to prevent the spillages were identified. In Case Study 2 the operators were attentive to the sound emitted during urination to indicate the need to empty the container. In Case Studies 1 and 2 the overfilling was controlled by regular servicing and adequate sizing of the containers. Despite these control measures, urine spillages were a frequent hazardous event across the Case Studies. The sanitary surveys documented evidence of spillages, cross-contamination and faecal smears on toilet surfaces and established poor access and availability of handwashing facilities – indicators of surface contamination observed at both household and facility level. Operators' exposure to faecal pathogens from handling contaminated surfaces was highlighted as a common and generic exposure risk across all system components. The link between hand hygiene, surface cleanliness and diarrhoeal transmission is well proven and similar findings are replicated in other studies (Baker et al. 2016; Mattioli, Davis and Boehm 2015; Mattioli et al. 2013b; Cairncross et al. 2010).

From a health perspective, urine and faecal matter spillages may led to subsequent risk of exposure to faecal pathogens along a number of the transmission pathways. The exposure risk assessment format identified the role of contact surfaces as a key transmission pathway from spillages and the transfer of contaminated faecal material onto surfaces and the high frequency of exposure to these same surfaces for operators during servicing or treatment activities. In particular, exposure to dirty toilets during cleaning or servicing the toilet was observed across all the Case Studies. Differences in the intensity of surface contamination, frequency and duration of exposure and appropriate control measures were due to the extent of exposure risk from surface contamination. For instance, in Case Studies 1 and 3, risks of exposure from contaminated surfaces to operators was higher than the risk posed to operators in Case Study 2 due to frequent and repetitive handling of the toilets. The subsequent transmission of pathogens from soil or ground surfaces was considered to pose more of an exposure risk to the community, in particular children who are more liable to geophagy (Medgyesi et al. 2018; Belyhun et al. 2010).

A second key hazardous event was blockages of the urine diverter with faecal matter. Cross-contamination of the urine diverter with faecal matter led to accidental contact with faecal material for operators where they had to clean and remove blockages. The cross-contamination of the urine-diverting portion of the UDDT toilets with faecal matter has been noted as a key issue with such technology in previous reviews (Stenström et al. 2011; Tilley et al. 2014). Cross-contamination is also the main source of faecal pathogens in urine collected from UDDT systems (Hoglund et al. 1998). The age of the user led to difficulties with the use of a UDDT, which increased the likelihood of the hazardous event occurring, identified as a risk factor in all three Case Studies. This common hazardous event was dependent on user behaviour. Similar hygiene-related issues were cited in reports from Sweden where UDDTs were implemented on a small scale. In particular, problems were associated with children using the toilets, leading to misuse and blockages of urine pipes. Overall, the technology was criticised and not scaled up after a trial in Sweden due to such issues (Alter 2014). However, CBS systems are novel and innovative solutions, and as the technology matures, associated behaviour changes will need to be incorporated to fully deliver the intended benefits. In eThekwini district, Durban, South Africa, over 80,000 UDDTs were installed in 2010 and over 97% are in use, although children under five were reportedly discouraged from using them and, in general, the toilets are not well liked by users. A further issue was a lack of maintenance, with the majority of toilets with missing or broken toilet seats, covers and doors (Mkhize, 2017). Despite these issues, the toilets contributed to a 41% risk reduction in relation to diarrhoeal diseases for users, although the study by Knight (2011) acknowledged that the reduction could not be wholly attributed to the intervention, due to the issue of confounding factors and variability across the system components (Stenström et al. 2011).

Exposure to stored urine generated as an output from the CBS system was a key hazardous event for operators. As has been established above, observations of cross-contamination at the user interface, which resulted in faecal blockages, also led to the assumption that urine was contaminated. Previous studies established that urine from urine-diverting systems was not sterile (Bischel et al. 2015; Bischel et al. 2017; Höglund et al. 2002). Processes involved during the collection and conveyance system components splash back and spillage of urine was identified as a common hazardous event (since urine is less viscous than solid waste). In this instance, urine facilitated the transmission of faecal pathogens, although it is acknowledged it would be very bizarre behaviour for operators to knowingly ingest urine. The potential risk exists when highly viscous material is agitated, which may occur accidentally (Höglund 2001). Exposure to urine on contact surfaces and transferred to hands may result indirectly in oral ingestion. The risk of exposure to pathogens in urine was also exacerbated by an absence of, or inadequate, treatment mechanisms. The correct storage of urine is able to achieve pathogen log reduction, which is temperature dependent, ranging between four months to five days (Ahmed et al. 2017). Urine may also pose a transmission risk when it is applied as a fertiliser and indirectly consumed on contaminated food products (Ahmed et al. 2017). The Cross Case analysis did not evaluate this particular exposure pathway since none of the Case Studies reused urine nor was the reuse of secondary outputs included within the system boundary of the exposure risk assessment.

The lack of compliance with hygiene protocols, including handwashing with soap, PPE, proper glove/hand hygiene or proper food hygiene, was a hazardous event in all Case Studies. In Case Study 1 and 3, noncompliance was observed and the likelihood was enhanced due to lack of access to handwashing facilities, in particular during collection and conveyance. Inadequate access to soap or hand sanitiser and water for effective handwashing (Pickering et al. 2010; Bohnert et al. 2016) was highlighted in the sanitary surveys as relevant indicators of occupational exposure. Compliance with the use of gloves was often not 100%, neither were the SOPs for glove wearing well defined or implemented. In Case Study 2, operators only wore gloves when handling other people's faecal matter: compliance appears to be related to individual perceptions of vulnerability or severity of consequences to exposure risks. However, high rates of self-reported handwashing were reported by the majority of operators surveyed. It is speculated that the high compliance is linked to the access to facilities at a household level. The importance of handwashing in diarrhoea prevention after exposure accounts for up to 41% of diarrhoeal disease reduction in major reviews (Cairncross et al. 2010). In healthcare settings associated with high-risk populations, the effect of handwashing had significant reductions in mean episodes of diarrhoea (Ejemot-Nwadiaro et al. 2015). However, there is evidence that even where handwashing is practised after handling contaminated materials and objects, hands may still be contaminated if handwashing is not performed correctly. Across all the Case Studies, operators' contaminated hands were an important transmission pathway that tended to consolidate the other transmission pathways (Wang et al. 2017). Hands contaminated via accidental direct contact with faecal matter or by handling other contaminated objects may lead to exposure to the operator if the operator then touches their eyes, nose and/or mouth with their hand, thus leading to direct ingestion. Contact with mobile phones was also observed when operators used them during work periods and ingestion of pathogens by operators can occur, given the close proximity of phones to the mouth. Previous occupational exposure studies of healthcare workers have found mobile phones highly contaminated with a range of pathogens, including faecally derived pathogens (Pal et al. 2015; Famurewa and David 2009), and they play a role as a media for the transmission and spread of diseases, in particular between healthcare workers sharing phones. Overall, person to person contact was infrequent for operators, which limited interpersonal transmission more frequently encountered as a common method of person to person transmission (Ferrer et al. 2008) in public health exposure research.

There were multiple routes to hand contamination of operators, including from 1) handling other contaminated surfaces or objects, 2) accidental contact with faecal matter or urine, and 3) poor hygiene practices. Hand hygiene and glove protocols played an important role in managing the spread of faecal pathogens on hands. The use of gloves prevented the contamination of operators' hands during work-related activities and therefore reduced their risk of exposure to faecal pathogens. The SaniPath study acknowledged that hands play a pivotal role in exposure (Moe 2000). That said, as Wang and colleagues (2017) point out, significant hand contamination does not necessarily imply high exposure, given a rapid temporal variability in hand contamination and, therefore, limited occurrence of actual ingestion. The simulated transfer of *E. coli* between surfaces and hands during CBS activities modelled hand contamination and how hands may transfer contamination from hands to contaminated surfaces to other surfaces in a chain of infection (Gould et al. 2017). The full results and discussion of this are in Chapter 6.

The aerolisation of bioaerosols is a hazardous event that may pose subsequent risk of exposure to microbial hazards. Health risks from the inhalation of airborne particles is poorly understood, but may lead to a variety of adverse health impacts (Buttner and Stetzenbach 1993). The transmission of bioaerosols was mainly associated with activities in the treatment component, in particular during composting and the incineration of contaminated solid waste products. The activities associated with composting – turning and mixing the compost windrows (CS 3) – generated bioaerosols, and without effective controls, such as risk awareness and effective PPE measures, operators inhaled these particulates. The exposure risk from bioaerosols is well documented in the exposure assessment literature and can lead to chronic health impacts (Maricou, Verstraete and Mesuere 1998; Pearson et al. 2015; Tschopp et al. 2011). One study of note identified the presence of helminth eggs on sanitation operators' face masks and so established this as a viable transmission pathway and exposure risk if operators did not wear masks to prevent inhalation (Buckley et al. 2008). The Cross Case analysis also established that unpleasant odours to which operators were exposed were perceived to be a possible exposure risk. Although pathogens are not carried by odour (in this manner) and may not reflect a hazardous event in itself, it may indicate that containers are not well sealed and that exposure through transmission from flies or spillages might arise. Operators also requested their organisation to provide milk after work-related activities, as milk is thought by operators to reduce the risk of exposure to inhaled faecal pathogens (CS 1). In other contexts, sanitation workers drink “soda” to mitigate the potential risks from odours they are exposed to (Stenström et al. 2011).

The inadequate treatment of faecal waste was a hazardous event that subsequently exposed operators to faecal pathogens that remained post treatment in waste. Operators were exposed to handling contaminated biosolids derived from the faecal products post treatment. Accidental ingestion of soil through occupational exposure is in the order of ingestion of 0.48 g of contaminated soil for occupational exposure associated with an adult performing rigorous activity (US EPA 1997). The exposure is also relevant to consumers of food products produced on land treated with biosolids from amended composted products (as in CS 2 and 3). Insufficient treatment of faecal solids in the Case Studies was a hazardous event observed due to a lack of monitoring of parameters or even of SOPs for following procedures. Human faecal pathogens are known to remain viable in biosolids if not exposed to the minimum temperatures required for die-off (Strauch 1991). Parasitic eggs in sewage sludge have been found after two years in soil treated with biosolids (Strauch 1991). Conversely, recent evidence showed that EcoSan composting processes were effective in reducing *Ascaris* viability to zero (Berendes et al. 2015). Given that *Ascaris* is one of the most environmentally persistence faecal hazards, its absence is a good indication of positive treatment processes. However, the importance of time and temperature parameters and specific guidelines for EcoSan and composting processes are still lacking and not definitive from recent studies (Berendes et al. 2015). The European Commission set out minimum requirements for effective aerobic or anaerobic thermophilic composting temperatures: faecal sludge be kept at 40 ^{0}C for at least five days and at a minimum of 55 ^{0}C for four hours during this period (Carrington 2001a). The lack of consistency or monitoring of key treatment parameters identified in Case Studies 2 and 3 does not ensure these parameters are met. Such evidence of noncompliance in the risk assessment was a key hazardous event leading to occupational exposure to contaminated biosolids.

Furthermore, although fungi are of a non-enteric origin, their production during the composting process posed an additional occupational exposure risk during the turning of windrows (CS 3) and lack of correct PPE used by workers. The exposure risk is based on previous studies, which identified considerable quantities of *Aspergillus* spp. emitted during compost turning that can be inhaled (Avery et al. 2012).

In Case Study 1 faecal waste transformed by heat pasteurisation using solar treatment achieved temperatures were well over the 60 ^{0}C for one hour – a type of pasteurisation that is considered sufficient for die-off of all faecal pathogens and risk reduction (Tremolet, Prat and Monsour 2014). Further, an internal separate study (Annex 3) showed that the solar treatment achieved the WHO guideline value for *E. coli* in treated faeces (<1000/g total solids).

Lastly, the washing and disinfection treatment process generated contaminated water at the treatment facility. The splashing of contaminated water during cleaning activities was an occupational exposure risk due to accidental ingestion, which, if not properly managed, could release harmful pathogens into the external environment leading to contamination of drinking water systems. Studies have shown exposure results from licking splashes on the skin that expose workers to a range of hazards, including reports of leptospirosis, hepatitis and *Helicobacter pylori* infection in sanitary workers (Tiwari 2008).

The exposure risk assessments did not reject the expectation that uncontained waste was a common hazardous waste where flies could transmit faecal pathogens from contaminated matter. The presence of flies was observed in all Case Studies, evidenced by the sanitary surveys and during the observations and transect walks. In particular, flies were attracted to faecal material spillages in the treatment facility (CS 1). Flies are attracted to both faeces and food (Julian 2016), and the transference between the two creates potential exposure routes for up to 24 diarrhoeal diseases transferred on the feet of flies (Feacham et al. 1983). Flies pose a significant risk as mechanical vectors that can transmit faecal pathogens without modifying the structure of the pathogen to secondary sources. In Case Study 1 operators were disturbed by the presence of flies in the treatment facility, and perceived themselves vulnerable to the risk of exposure posed by flies. The transmission of faecal pathogens via flies in CBS systems was facilitated by a lack of physical barriers between faecal waste and the environment. Facilities containing the waste treatment activities were not physically isolated, allowing flies to enter the environment and land directly on the waste. The temporary storage containers at household level were also not always fully sealed, and flies were able to enter waste containers. Operators were aware of the ability of flies to spread pathogens (CS 1). Likewise, this awareness and perception was also evident in the frequent references to flies in transcripts from the online forum data analysis (CS 2). The exposure risk was also noted to be seasonal in nature, as hot weather increased the presence of flies (Levine and Levine 1991).

Table 5.1 Summary of exposure risks at CCP points through the CBS systems indicating the process step and associated hazardous event, exposure route and control measures

Step	Process step	Hazardous event	Exposure route	Control measures
		1. Containment (urine and excreta)		
	Toilet use Temporary storage of urine and faecal waste products	Spillages of solid and liquids due to breakdown of materials Urine overflows from containers due to overuse or poor seals The cross-contamination of the urine diverter leading to blockages of the diverter	Flies, surfaces, hands, ground/soil	Collection containers are sealed and leak-proof regularly monitored for wear and tear and replacement in good time Regular and frequent servicing: EG. SMS based collection dispatch service and emergency number clearly positioned for response in account of spillage. Users habituated with the toilet practice Operators wear full PPE (masks, gloves) worn 100% of the time
		2. Cleaning and disinfection toilet surfaces		
	Daily and weekly cleaning of toilet surfaces	Handling dirty toilet surfaces from faecal spillages	Surfaces	Cleaning protocols in place and effective
	Cleaning and sweeping of floors	No handwashing and malfunctions of PPE and noncompliance with PPE	Hands	Regular training and compliance monitoring
User Interface	Removing blockages from urine diverter	Aerolisation of particles by sweeping of toilet floors/facilities	Air	Handwashing facilities accessible / Full PPE worn 100% of the time

	3. Rotation and removal of solid waste container		
Accessing full container by lifting or removing the toilet hardware Removing full bag/container from under toilet pedestal or squatting plate, sealing the full bag and placing into collection vehicle. Replacing the full container with an empty one	Lack of handwashing and/or malfunctions of PPE and noncompliance to PPE Airborne emissions from collection containers agitated during removal Spillages of raw waste from poorly sealed containers or overfilled containers Handling contaminated containers and potential transfer of contamination between households on operator’s gloves	Hands Surfaces Air	Enable handwashing and hand sanitisation between households Glove protocol and compliance e.g. Disposal latex gloves used where red gloves are not appropriate providing they are exchanged between households Strong sealing mechanism (lid/cap/bag fastening) for waste collection containers and use of cover material Regular and frequent training to communicate health risks and increase perception of exposure risks among operators
	4. Rotation and removal of liquid waste container (if applicable)		

	Accessing full container by lifting or removing the toilet hardware	Malfunctions of PPE and noncompliance with PPE, no handwashing	Flies, surfaces, hands, ground/soil	As above
	Removing full container from under toilet pedestal or squatting plate and placing into collection vehicle	Spillages of waste and handling contaminated containers Airborne emissions from collection containers agitated during removal	Air inhalation	
	Replacing the full container with a new one			
	5. Transportation			
Conveyance	Loading full containers onto collection vehicle Transportation to depot	Spillages during transportation Handling contaminated containers Malfunctions of PPE and noncompliance with PPE Airborne emissions from collection containers agitated during removal	Flies, surfaces, hands, ground/soil Air inhalation	Covered collection vehicle to prevent leakage and environmental contamination. Environmental spillage protocol (including disinfection with 0.5% chlorine solution) Washing and disinfection of vehicles with 0.2% chlorine solution while wearing PPE. Emergency number clearly positioned for response in account of spillage. Compliance monitoring and management / PPE worn 100% of the time

		6. Offloading of containers at waste treatment facility		
		Handling of contaminated container and raw waste No handwashing Spillages and flies	Hands Surfaces Flies	Unloading/loading protocols Regular and frequent training PPE worn 100% of the time
		7. Transfer of urine/excreta to storage/treatment		
	Evacuating the raw waste from collection bags	Spillages leading to accidental contact with raw waste	Hands, surfaces, air, skin, flies	Spillage protocol and wash down, Handwashing and full PPE worn 100% of the time
	Pouring urine into larger storage containers	Aerolisation and emissions of bioaerosols		Physical fly barrier in waste transfer zone
		Malfunction of PPE and noncompliance		Regular and frequent training to communicate health risks to operator
Treatment	**8. Treatment process**			
		8.1 Pasteurisation/sanitisation		

Minimum storage period (hrs/days/wks) Moisture level maintained in windrows Temperature treatment ranges 40–75 ^{0}C Turning of windrows	Incomplete pathogen die-off due to lack of appropriate storage time/inappropriate moisture/excess water/lack of appropriate temperature Hand contact with raw material during treatment process (turning, forming windrows) Handling contaminated fomites (containers, tools, PPE equipment) Spillages of waste due to breakdown of crates during storage	Hands, surfaces, air	Record of batch formation and monitoring Temperature and moisture monitoring and recording/ Turning monitoring and recording Correct PPE and compliance monitoring Frequent training Maintenance of materials Handwashing facilities Signage and risk communication
	8.2 Composting stabilisation		
Compost is stored again to finalise the treatment process	Cross-contamination of sanitised waste from fresh materials during transfer into windrows Inhalation of bioaerosols during the movement process		Adequate separation between windrows to prevent cross contamination Microbial testing of sample batches

		9. Washing and disinfection of contaminated equipment		
	Washing of solid and liquid collection containers	Splashing of contaminated wastewater Not wearing proper PPE	Direct ingestion	Full PPE worn 100% of the time
	Wash down of collection vehicles, PPE and other contaminated materials	Surfaces remain contaminated due to effective disinfection Unregulated disposal of wastewater Dermal exposure to strong chemical	Hands, surfaces air drinking water	Regular and frequent training Cleaning and Disinfection Protocols Effective design of the soak away/discharge infrastructure
		10. Incineration of solid waste (if applicable)		
	Incineration of the contaminated waste	Release of airborne particulates and inhalation by the operator	Air	Full PPE worn 100% of the time Training on efficient and safe incineration. Signage and Risk Communication
Reuse		**11. Reuse of treated materials**		
		12.1. Spreading of compost onto fields		
		Handling and ingestion of contaminated compost during spreading/application	Hands, flies, soil	Hand hygiene after farming activities
		12.2. Use of harvested products		
		Consumption of contaminated vegetables	Food	Application and harvesting Washing vegetables before use

5.2. Characteristics and Emerging Patterns of Exposure Risks from the Cross Case Analysis

5.2.1. *Immediate Causes of Hazardous Events*

To simplify the complexity of exposure for operators, the Cross Case analysis focused on the immediate causes of hazardous events that gave rise to the release or transmission of pathogens (HSE 2006). These are shown in Box 1.

Box 1 Immediate causes of hazardous events

Immediate causes of hazardous events:

- Spillages and leakages of urine/excreta
  - Failure of physical integrity of equipment and collection containers, transport vehicles
  - Wear and tear
  - Blockages and corrosion
  - Damage
- Overfilling of containers
  - Irregular servicing of containers
  - Too small/underdesigned
  - Overuse of containers
- Blockages of urine diverter
  - Cross-contamination through misuse/person error
  - Build-up of salts in urine diverter pipe
- No handwashing/hand hygiene
  - Poor compliance and behaviour
  - No access to functional handwashing facilities
  - Lack of access to appropriate PPE
- Accidental direct contact with contaminated liquids/solids
  - Diarrhoeal episodes or outbreaks
  - Viscosity of waste
- Handling of contaminated surfaces
  - Poor cleaning and disinfection
  - No SOPs in place
- Bioaerosols of pathogens inhaled
  - Agitation (mechanical) of waste leading to aerolisation of bioemissions

5.2.2. *Primary Causal Mechanisms*

Due to the complexity of transmission, exposure and infection risks, difficulties in empirically testing influential variables are well recognised (Wang et al. 2017). The Cross Case analysis overcomes this by identifying the different features and classifying them into four causal mechanisms. Based on the immediate causes of hazardous events, and taking in the narrative accounts of the case reports, the Cross Case analysis classified exposure risks that shared common affinities of primary causal mechanisms (Box 2), namely technical and hardware factors, behavioural dimensions, system safety culture and environmental factors. The hazardous events were aligned to these classifications as set out in the narrative below and in Table 5.2. The analysis identified risk drivers that influenced the extent to which transmission routes existed and dominated in specific contexts. The classification of these causal mechanisms is not intended to undermine the importance of recognising multiple, interrelated causal mechanisms and exposure risks. This classification is also expected to support the management of exposure risks, and the development of appropriate risk management guidelines is likely to reflect these mechanisms. This understanding led to the generalisation of control measures for risk management linked to primary causal mechanisms (see section 5.3). The classification was useful to understand the role of primary causes in more detail but ultimately recognises multiple causal mechanisms for exposure risks and rejects a focus solely on linear causal chains.

Box 2 Primary causal mechanisms of exposure risks

Primary causal mechanisms of exposure risks: Technical and hardware failures:

- equipment and infrastructure design, raw material selection, and durability and condition of equipment (Tilley et al. 2014; Leveson 2012b).

2. Behavioural failures:
    - individual behaviours, knowledge and awareness that drive misuse and noncompliance with hygiene and safety protocols, as well as community and organisational behaviours (HSE, 1999).
3. System safety management failure:
    - a lack of internal safety culture (Hurst 1998), represented by failures to develop SOPs and good manufacturing practices (GMPs)
4. Physical environment failures:
    - biological aspects of disease outbreaks that affect the intensity of exposure and transmission pathways (Barker and Bloomfield 2000; Julian 2016), as well as seasonal and physical conditions that affect exposure (Maponga et al. 2013).

5.2.3. Technical and System Design

The role of technical and system design was an important causal mechanism of exposure risks (Table 5.2). Technical design was a factor in technical and hardware failures observed in the Case Studies and contributed to the exposure risks identified in section 5.1.1 by facilitating spillages, cross-contamination caused by blockages of the urine diverter, lack of handwashing and certain hardware features that contributed to the transmission of pathogens along specific (surface) pathways. This classification also included the role of maintenance and the condition of facilities and toilet equipment in causing hazardous events and subsequent exposure risks.

The Case Studies specifically highlighted that the toilet design contributed to surface contamination or "dirty" toilets: the presence of "dead spaces" in toilets posed challenges for effective cleaning and disinfection. Specific aspects of toilet design led to blockages of the urine diverter and cross-contamination (CS 2). The separator design contributed to cross-contamination and, operators, highlighted cross-contamination as an immediate fault of the toilet design. Alter (2014) reported that UDDT design in Sweden was inappropriate for some users, especially children, but the use of child-adapted seats encouraged the correct use of the toilet (CS 1). Although the extent to which people were habituated with the toilet was noted to effect the likelihood of cross-contamination; operators also identified cross-contamination occurring where users were habituated with toilet use. The separator design and misuse by people (drunk, elderly, unaware) were often apparent in cases of cross-contamination. Urine diverter blockages were also caused by a build-up of urea in the urine pipe, which occurred when the urine pipe diameter was too small (CS 2). Further design issues included the type and quality of surface material, which varied from porous, unpainted wood (CS 1) to plastics enhanced with antimicrobial additives (CS 2). The surface material influenced cleaning efficacy and so indicators of surface contamination. Similarly, in the treatment facilities, a lack of cleanable/wash down surfaces led to challenges of cleanliness.

A lack of maintenance caused the technical failure of equipment, collection containers and transport vehicles. The physical integrity, size and condition of collection containers influenced the frequency and severity of spillages during transportation. General wear and tear leads to breakages and failure of operational capacity of equipment and infrastructure not "fit for purpose" (Aliu, Adeyemi and Adebayo 2014; Mkhize n.d.). Wear and tear on the collection containers caused by physical abrasion over time and poor maintenance compromised the containment of waste and led to spillages during collection and transportation. Also, the breakage of compostable bags led to spillages of faecal contents during removal (CS 2), while the physical deterioration of containers (CS 3) exposed operators to uncontained faecal waste.

Aspects of facility design contributed to exposure risks; poor zoning and/or separation in treatment facilities between contaminated and sterile areas allowed for cross-contamination of pathogens from high-risk to low-risk areas. In general, a lack of access to handwashing hardware (sinks, water and soap) along the system chain led to noncompliance with hand hygiene protocols, despite operators having a good awareness of and training in hygiene practice and personal hygiene. The absence of physical barriers allowed flies to land on faecal waste and mechanical transmission of faecal pathogens across the treatment facilities.

The design of system processes and physical characteristics of the workflow operations were primary causes of hazardous events. In general, the intensive and repetitive operations associated with waste handling during collection and treatment activities exacerbated occupational exposures to spillages and direct accidental contact. The composting treatment activities included the agitation and turning of windrows that emitted harmful bioemissions (*Aspergillus* spp.). High occupational exposure risks resulted via inhalation of bioaerosols where no effective control measures existed. The dry sweeping of the toilet floors during cleaning (CS 3) also augmented exposure risks from bioaerosols to operators, as dust and other particles on the floor were aerolised and could be inhaled during working.

Another aspect of physical workflow characteristics was that operators perceived a higher level of individual exposure risk from the cumulative effects of repeated activities, as opposed to a single one-off event. The results of in-depth interviews from Case Study 2 indicated how operators perceived a low risk of exposure during treatment steps when handling faecal waste infrequently (once or twice a month). In contrast, in Case Studies 1 and 3, service operators involved with cleaning or servicing the toilet and visiting multiple households per day perceived a higher vulnerability to risk of exposure due to the repeated handling of toilets. Even where operators conformed to protocols in terms of hygiene behaviour and treatment steps, the level of risk was still associated with the intensity and frequency of handling contaminated surfaces or waste. This finding is reported in risk analyses of industries similarly characterised by a predominance of manual handling of municipal waste in contexts similar to the study area (Bleck and Wettberg 2012b). This point is addressed later in the discussion of appropriate control measures.

5.2.4. Behavioural Causes

Table 5.2 lists the hazardous events associated with behavioural factors observed across the Case Studies. The occupational exposures related to elements of human behaviour included dirty toilets, cross-contamination, failure to adhere to proper hand hygiene procedures and subsequent hand contamination. Noncompliance with SOPs (e.g. manual sweeping, instead of mechanised cleaning of the facilities) was a hazardous event consistently observed across the Case Studies. In particular, the Cross Case analysis identified that noncompliance with hand hygiene practices and glove protocols was a key driver of occupational exposure to hand contamination, indicating that the control measure in itself was not fully effective or efficient at reducing exposure risks. Similarly, exposure risks during cleaning associated with a lack of compliance with PPE were found in workers cleaning their rest rooms (Gonese et al. 2006).

The level of operator noncompliance with various PPE safety protocols leading to occupational exposure varied across cases and across system components. This appears to be attributable to differences in risk perceptions affected by training, relevant risk signage and peer-to-peer enforcement. Compliance (or lack of) appears to be a systemic problem across various industries and geographies. Safety reviews of occupational health risks have demonstrated compliance with hand hygiene protocols commonly to be as low as 40% in healthcare workers and noncompliance to be linked to an increased risk of gastrointestinal disease (Peasey 2000; Drechsel et al. 2008; Enger et al. 2013; Stenström et al. 2011). In other scenarios, poor compliance with PPE protocols contributed to 30% of sick leave and time off for waste operators (Haagsma et al. 2012). It was also found that compliance with PPE protocols alone was insufficient to reduce specific exposure risks to operators during some of the activities performed during waste treatment due to the limitations of existing PPE equipment.

From a risk management perspective, being able to control and change behaviour to manage these exposure risks requires an understanding of the complex psychological processes that occur in an individual mind and drive behaviour (Mosler 2012). The HSE (1999) identifies three aspects of human factors that determine health and safety related behaviour: the job, the individual and the organisation. Compliance is considered an individual characteristic of behavioural exposure risks (HSE 1999; Hurst 1998) and noncompliance may result from genuine mistakes in complying with protocols, including a lack of awareness of the correct procedures or a lack of the relevant skills or knowledge. Lapses in attention or concentration, despite an awareness of the correct procedures, may have given rise to compliance issues. A third option that remained was of wilful noncompliance, which may have arisen if the operator considers the procedures to be redundant/unhelpful for exposure risk management. In the Cross Case analysis, it was difficult to identify behavioural exposure risks driven by lapses in concentration but they were assumed to occur, given that noncompliance existed in situations where operators were both well trained and had access to materials and facilities, especially in regard to practising hand hygiene.

Significantly, toilet user behaviour also determined exposure risks to operators through their influence on surface contamination and spillages. For instance, misuse by the toilet user at the user interface exposed operators to faecal pathogens via multiple pathways during cleaning and collection activities, and presented differing degrees of occupational exposure for toilet operators across all the Case Studies. The risk of exposure from dirty toilets was ranked highest in Case Study 1 and was attributable to a failure by some toilet users to wash their hands properly post defecation, and inadequate access to anal cleansing materials and handwashing products, which increased surface contamination. The level of surface contamination was supported by quantitative results of the presence of *E. coli* on toilet surfaces. Although it is possible that the presence of *E. coli* was not associated with toilet use, comparable evidence of faecal contamination on toilet surfaces (Bloomfield and Scott 1997; Barker and Bloomfield 2000) suggests an association between user behaviour and contamination. In Case Study 2, the risk of exposure to operators posed by contaminated surfaces was ranked lower, considering both user handwashing post defecation practices and the reported frequency of cleaning and disinfection. The microbiological results appeared to support this exposure assessment, as the presence of *E. coli* on surfaces was much lower than in Case Study 1. The Cross Case analysis clearly points to misuse by toilet users as a primary causal mechanism of cross-contamination, in addition to the technical design. Multiple reasons for misuse were identified in the analysis and included a lack of familiarly, age and social issues, such as being drunk (CS 2 and 3). This behavioural causal chain is also noted in the grey literature and reviews of CBS systems, where correct behaviour change was difficult to implement, particularly when people are not accustomed to separator style toilets. How long before people become "accustomed" is also not clear, since the cases included in the present study had been operating the CBS system for over one year.

Given the important role of behaviour (both user and operator) as a key aspect of hazardous events and exposure risks across the Case Studies, as discussed further in chapter 7.

5.2.5. System Safety Culture

Hazardous events associated with the third classification of causal factors are those driven by failures of system safety culture (Table 5.2). The Cross Case analysis identified occupational exposures linked to aspects or absence of organisational safety culture, preventive management and monitoring of controls.

These types of management control systems exist at different operational level (Fobil et al 2008; Leveson 2011) and create a causal chain of exposure along the CBS system.

The Cross Case analysis identified a failure to develop, train and apply critical SOPs, which are described as a tangible manifestation of safety culture within the organisation (Hurst 1998). A lack of composting SOPs may have contributed to occupational exposures (CS 3). Aerobic thermophilic composting is a complex process requiring a significant number of exactly timed procedures and executed activities. Annex 2 presents this complexity in SOPs for green composting of organic wastes. Where faeces are within the compost material, the requirements and parameters are comparable, if not higher, given the faecal pathogens present in untreated human excreta (Carrington 2001; Piceno et al. 2017). The WHO (2006) and US EPA (2007) have appropriate guidelines for faecal sludge treatments, but organisations must have the incentives to monitor and ensure efficacy of the treatment processes. An absence of cleaning SOPs (CS 3) led to occupational exposures from inhalation and contaminated surfaces. A lack of cleaning protocols was associated with elevated health risks to cleaning staff in a Europe-wide based review (European Agency for Safety and Health at Work 2009). A lack of relevant external regulations and weak or non-functional institutions reduced pressure on organisations to comply with relevant safety measures (Tadesse and Kumie 2014; Medland et al. 2015). In Case Study 2, potential exposure risks posed by unregulated urine disposal are not well managed by a coherent institutional response. On the present scale, operators and the researcher acknowledge that it is unlikely to be an important concern, but the system is unable to scale up. These types of specific regulatory system failures are observed when there are not suitable institutional frameworks in place to deal with waste generated (Giusti 2009).

A lack of proper staff health management increased the vulnerability of operators to infection post exposure. Health management procedures are a tangible aspect of a positive system safety culture (Hurst 1998), whereby vaccinations and health checks reduce the susceptibility or severity of infection. In Case Study 3 staff interviews identified a lack of proper health insurance, regular health checks or having received appropriate vaccinations. The degree of vulnerability is critical in determining the absolute risk to operators in CBS systems (Avery et al. 2012). Temporary or daily workers were most vulnerable (CS 3). In contrast, a positive system safety culture was reflected where frontline staff and field managers seemed highly aware of and proactive about potential health risks, and frontline staff could bring risks to the attention of management and advocate for methods of improving health and safety across the organisation (CS 1). At the management level, field managers distributed health and safety manuals to staff, and their commitment to ensuring that staff received the relevant vaccinations demonstrated a proactive attitude towards risk management.

5.2.6. Physical Environment

The fourth classification presented in Table 5.2 was aspects of the biophysical environment. The role of seasonality, land use characteristics and infrastructure were observed across the Case Studies. Spillages occurred during conveyance because of the deterioration of roads due to seasonal rain events affecting road conditions. The absence of tarmac roads in certain contexts (CS 1 and 3) increased the likelihood of spillages or turnover during transportation. Extreme weather events led to flooding and increased the risk of poor performance of soakaway or drainage units, encouraging environmental contamination of groundwater and subsequent exposure risks across the Case Studies. Operators in flooded sites, or sites liable to flooding, encountered higher exposure risks due to contact with highly contaminated flood water during collection and conveyance. Flooding has set off outbreaks of epidemic disease (Curtis 2000). The actual likelihood of flood risk is exacerbated by the particular context of CBS systems. CBS systems serve lower income communities, most frequently situated in low-lying areas and therefore highly prone to the impact of flooding (Burgess 2016). Indeed, many dense urban populations (233 cities) are located in or close to areas with a high risk of flooding (UN 2012). Although some cities have developed infrastructure to prevent the impact of flooding, seasonal flood risks in urban centres, especially in the global south, are associated with a number of potential disease risks (Few et al. 2010). This interaction between the physical and environmental contexts within which the CBS systems exists is likely to be a key driver of occupational (and public health) exposure in future.

The Case Studies collected secondary community health surveillance data and informal and anecdotal references, which linked occupational exposure to outbreaks of diarrhoeal diseases in the community that affected both the likelihood and severity of the exposure incident. In general, a higher risk of transmission from surfaces has been observed during the acute infection stage of diarrhoeal diseases (Barker and Bloomfield 2000) due to higher pathogen load in faeces. Although primary data on disease aetiology in the community is often not available and the technical challenge and expense of defining microbial hazard to pathogen level may have precluded quantitatively assessing infection risks, it is recommended to formalise the collection and surveillance. In general, the influence of environmental factors was managed by preventive risk control strategies, which included the practice of emergency scenarios or developing emergency preparedness plans.

Table 5.2 Typologies of hazardous events derived from the analytical generalisations across the Case Studies

Sanitation step				Typologies of hazardous events
Person error:				
1	2	3	4	
x	x			Surface contamination associated with misuse (e.g. age related)
x	x	x	x	Spillages onto surfaces and floors due to overflow of the collection containers from overuse
	x			Spillages due to poor driving skills or driver error
x	x			Surface contamination associated with poor cleaning and disinfection behaviours
x	x	x	x	Hand contamination due to lack of handwashing/hand hygiene practices
x	x	x	x	Noncompliance with protocols. For example, sweeping the toilet during cleaning (not advised as per cleaning protocol) poses a risk to workers due to agitation of aerolised organic and non-organic particles
x	x	x	x	Noncompliance with PPE due to a low perception of risk or threats
				A lack of relevant skills or knowledge or a lapse in concentration or individual perception of risks, vulnerability or severity
	x		x	Illegal dumping of waste into the environment due to malpractice
Equipment/technical failure:				
x	x	x	x	Spillages due to failure of physical integrity of containers (open lids, broken sides) and poorly maintained collection containers compromised the containment of waste
x	x			Spillages due to breakage of bags
x	x			Spillages due to containers too small or underdesigned
	x	x	x	Splash back during emptying due to poor (neck) design of urine containers
x				Urine spills into unit due to poor separator design
x				A common technical failure in the design of some CBS systems was blockages of the urine diverter caused by a build-up of urea (pipe diameters under <32mm)
x	x	x	x	Unfavourable toilet design, with dead spaces or difficult to disassemble, also posed cleaning challenges

x	x	x	x	The extent of surface cleanliness was affected by materials used for toilets construction since certain types of materials (e.g. porous wood) presented difficulties to clean
x	x	x	x	Facilities lacked sufficient access to handwashing hardware and prevented compliance with hand hygiene protocols despite a good awareness and training
		x	x	Incomplete combustion of waste during incineration due to low temperatures
		x	x	Ineffective treatment mechanisms does not kill pathogens/microbes
x	x	x	x	PPE failure or not performing as expected (e.g. breakages or poor equipment)
		x	x	Poor wastewater/soakaway design/efficacy
Regulatory and system safety culture:				
x	x	x	x	Redundant or ineffective PPE protocols
x	x			Urine or excreta from one household is inadvertently transmitted to another household (cross-contamination) due to poor emptying and conveyance hygiene protocols
x	x	x	x	Poorly implemented/inadequate/ineffective disinfection and treatment protocols
x	x	x	x	Inadequate treatment due a lack of internal/external regulations
	x	x		Illegal tipping of untreated waste due to lack of internal/externa regulations
x	x	x	x	Inadequate staff health management leaves workers vulnerable to infection risks post exposure
x	x	x	x	A lack of proper health insurance, regular health checks or having received appropriate vaccinations
x	x	x	x	Hiring of temporary or daily workers to perform potentially hazardous activities was a significant breach of exposure safety management, as workers are highly vulnerable to infections as they do not receive regular health checks
x	x	x	x	A failure to develop, train and apply critical SOPs. A lack of defined SOPs prevented specific training or compliance with protocols/staff awareness. Cleaning and disinfection of toilets was rarely defined as a SOP and treatment and reuse protocols are not standardised across the industry
x	x	x	x	In certain contexts, cleaning staff (women) occupied a lower status than other staff (men), in the hierarchical organisational structure, meaning their voices may be marginalised in participatory types of risk assessments
x	x	x	x	Absence of internal and external regulations and monitoring reduced pressure on organisations to comply with safety measures
Physical/seasonal/environmental variables:				

	x			Spillages during conveyance due to deterioration of road/transport routes
		x	x	Excreta (diarrhoea) splashes onto handler during emptying due to low viscosity of waste
x	x			Diarrhoeal events/outbreaks of infectious diseases cause contamination on toilet surfaces
x			x	Wastewater/urine soakaways overflow due to extreme weather/flood events
	x			Urine and excreta spills caused by deterioration of road/transport routes
	x	x	x	Repetitive exposure to urine and excreta due to type and intensity of manual handling tasks
	x	x	x	Pathogens aerolised due to agitation/mechanisation of processes

Note: 1 = Containment; 2 = collection; 3 = conveyance, 4 = treatment and/or disposal.

5.3. Characterisation of Control Measures with Critical Control Points (CCPs)

The classification of HE and subsequent exposure to faecal pathogens, through a causal lens, led to a similar analysis of appropriate control measures for exposure risks that is likely to be controlled through management of the same causal mechanisms of exposure. In doing so, the analysis distinguished between types of control measures, implemented at CCPs, most effective at controlling and managing risk. The Case Studies produced consistent evidence that control measures at critical points along the system chain have successfully managed occupational exposure risks. The Cross Case analysis recognised that effective control measures imposed constraints on the mechanisms that contributed to exposure risks. There was strong evidence of direct replication of these four types of control measures applied across the Case Studies. A similar classification of control measures following the constraint to the causal mechanisms was developed (Table 5.3). The four types of control measures are:

1. Equipment or technical controls
2. Process controls
3. Regulatory and organisational controls
4. Behavioural controls.

The Cross Case analysis noted a general reliance on behavioural and personal control measures, which were less effective in controlling hazardous events and exposure risks due to the inconsistency and fluidity of human behaviour. The following discussion of control measures alludes to a hierarchy where technical and process controls are preferred over organisational and behavioural controls and personal behaviour. This is intended and reflected in a hierarchy of control measures inspired by the STOPP (Substitution of hazardous process, Technical measures, Organisational measures, Personal protective equipment, Personal behaviour) principle (Bleck and Wettberg 2012b). According to the STOPP principle, wherever *"an activity, step or process which resulted in significant exposure risks to operators'; substitution of this hazard may be the most effective precaution"* (Bleck and Wettberg 2012b). Thus, it is suggested that the elimination of the hazardous activity should be prioritised in risk management together with multiple control measures as opposed to singular controls.

5.3.1. Technical Controls

The Cross Case analysis highlighted that the control measures that stipulated minimum specification for equipment and technical design of facilities and equipment successfully managed occupational exposures associated with these causes (Table 5.3). Across the Case Studies, operators and management were actively engaged in research and product design modifications. These included modifications to the urine separators and collection containers, and to technical equipment in the treatment facility, to minimise operators' contact with raw waste. These examples also demonstrated the requirement for effective communication and feedback between the workers using the equipment and the designers and manufacturers (Grodos and Tonglet 2002). Technical specifications for non-sewered sanitation systems are reflected in the development of ISO standards (IWA 2016). However, these standards do not reflect the precise needs and requirements for CBS systems, as the ISO PC 305 does not include specifications for any treatment or components that are off-site. The scope of the ISO PC 305 is limited to various user interfaces at the containment and collection system components. The recognition of design in exposure risk management reflects the principle of "safety-guided design" from the field of systems engineering (Leveson 2012b), which embeds the concept of safety into the design process, rather than adding barriers or devices to protect individuals from risk at a later date. The development of appropriate minimum standards or specifications for equipment and infrastructure may address cross-cutting issues that can manage exposure risks. The minimum standards in *The Sphere Handbook* offer guidelines to address and integrate issues within humanitarian responses (Cardona et al. 2012). Although the development of such guidelines and standards cannot ensure compliance, which depends on the capacity of organisations and specific contexts (SNV 2014), there is nonetheless a strong argument to develop minimum standards and specifications related to aspects essential for exposure risk management. Based on the results from Cross Case analysis was the characterisation of design standards that ensured exposure risk management. These included the appropriate design, cleanability, durability, usability, isolation and containment of solid waste, isolation and containment, minimum dispersal through air and appropriate risk signage and communication in CBS systems components.

A list of suggested minimum standards is found in Appendix 15, which address the following in each of the CBS system components:

- The toilet structure, design and technical measurements, including well-fitting lids and components that are easy to remove and replace.

- The facility specifications, including the provision of handwashing and welfare facilities to practise proper hygiene.
- The material design, including cleanable and microbial resistant surfaces for toilet hardware.
- The standards and specifications for the collection vehicle standards.
- Treatment standards and protocols for pathogen reduction.

5.3.2. Process Controls

Process controls were distinguished through their direct control on the activities and physical processes (such as treatment processes) along the CBS system to prevent exposure and manage the potential health risks (Table 5.3). As discussed earlier, aspects of system design (frequent hand contact with contaminated surfaces) augmented occupational exposures. It was observed that the elimination or substitution of container removal in the self-managed and communal level CBS systems (CS 2 and 3, respectively) minimised hazardous events and subsequent risk of exposure to service operators, in contrast to the procedures involved with household collection (CS 1). Additional occupational exposures created by the requirement for workers to remove internal collection containers (CS 1) included cleaning the toilet interface, removing faecal materials causing blockages in the urine diverter and cleaning contaminated surfaces at the household level. Moreover, exposure risk management associated with handling the collection container was heavily dependent on the use of PPE and compliance with hand hygiene behaviours. Given the complexities in addressing hand hygiene (low compliance, lack of effectiveness, transfer to other surfaces) noted in other waste management (Eliah 2000) and healthcare sectors (Fuller et al. 2011; Scheithauer et al. 2016), it is preferable to remove contact opportunities where possible in order to eliminate potential exposure events. Therefore, by requiring householders to manage this activity the occupational exposure is controlled, since the exposure risk is transferred to the householders and away from operators. Since operators perform this activity multiple times per day, the cumulative risk is higher than that which the householder would face. From a risk management perspective, the substitution or reduction of high-risk activities involving manual handling is more effective (Bleck and Wettberg 2012b). Control measures that prevent exposure occurring in the first instance are widely recommended (Bleck and Wettberg 2012b; Swuste and Eijkemans 2002b). However, it is noted that there is a tension with this control considering the potential displacement of risk to the householders if they are not sufficiently skilled or trained. It is therefore noted that this process control requires careful consideration – especially regards the context in which it is being considered.

Other process controls included the maintenance of key infrastructure and facilities, cleanliness and regular and scheduled servicing (Table 5.3). The maintenance of equipment was a vital control measure to maintain the physical integrity and hygienic conditions of the equipment and facilities, which provided controls against a number of hazardous events, notably spillages. Cleaning to prevent the spread of pathogens and disintegration of equipment is a necessary control measure, despite the potential risks it creates. Laboratory experiments demonstrating the persistence of pathogens on surfaces are correlated with cleaning and disinfection intervals (Gerhardts et al. 2012), while the periodical cleaning of surfaces with relevant products is recommended for controlling the transmission of viruses (Nicas and Jones 2009).

Lastly, the effective pasteurisation of faecal waste resulted in the successful inactivation of faecal pathogens and reduced the subsequent exposure risks to operators and consumers who handled the biosolids. Process controls regulate the treatment procedures and included training the operators carrying out waste treatment. In Case Studies 2 and 3 treatment procedures were not systematically recorded, and operators may be exposed to faecal pathogens while handling the composted product. SOPs for aerobic composting (Annex 2) are relevant process controls.

5.3.3.Organisational Controls

The third set of control measures managed occupational exposure, and refer to the use and implementation of a range of measures that addressed and strengthened the safety system culture (Hurst 1998). Tangible examples documented were GMPs and SOPs, health surveillance and staff health management, risk communication and emergency scenarios (Table 5.3). Where SOPs exist an operation is followed routinely using established methods, which, together with the effective operational monitoring of critical SOPs, ensured that control measures were achieving the intended outcomes. Some of the critical SOPs observed are outlined in Appendix 16.

The external regulatory environment was also an important aspect of risk management that service providers used to manage risks to differing degrees. The structural context influenced the extent to which external regulations were in existence or implemented. In Case Study 2 there was pressure on operators to comply with legislation from the Environment Agency that prevented disposal of urine from CBS systems into aquatic ecosystems and appeared to be an effective control against this risk. In Case Study 3, the legislation referring to manual scavenging (Ministry of Law and Justice, n.d.; Wikipedia n.d.) was a strong influence on the regulation and control of exposure and risks to operators. Similarly, in Case Study 1, the fact that the government had adopted CBS systems into the national list of improved sanitation systems resulted in a formal framework that regulated standards associated with the delivery of CBS services and, to an extent, supported the management of occupational exposure risks (personal communication, CTO Sanivation).

Staff health management is an important non-technical control observed as a package of health protection measures (CS 1 and 3) to all staff employed. In Case Study 2, there was no service provider to deliver such a service. The minimum health protection measures included vaccinations against hepatitis A and B and tetanus. Health experts have recommended additional vaccinations, such as polio, tetanus, typhoid, rotavirus (if available and relevant) and cholera when there have been recent/acute cholera outbreaks or following a local, seasonal outbreak pattern (see Annex 1). In addition, it is recommended that staff health records should be maintained and regularly updated, ensuring regular boosters and regular health checks to monitor staff health. Experts refer to a regular health check every 6–12 months and whenever a new staff member joins. Recommendations for specific treatments include anti-helminth drugs, such as praziquantel, albendazole and metronidazole, to protect workers, as documented in Annex 1. There was evidence that daily workers were more vulnerable to exposure, which should be addressed.

The less tangible control measures emphasised the importance of effective leadership and frequent consultation with staff, which, in turn, will empower staff to raise health and safety concerns. Overall, it may be argued that the collaboration between frontline staff and field managers (as a part of this PhD study) is itself an embodiment of a positive safety culture, as the risk assessment process raised awareness and internalised the assessment of health risks. Leadership at an institutional and governmental level is already recognised as a crucial aspect of health risk management in the broader sanitation sector (SNV 2014). Community leadership is also recognised as an important community level factor in determining specific behaviours (Dreibelbis et al. 2013), which may be of relevance in certain scenarios.

5.3.4. Behavioural Controls

The fourth set of control measures reduced exposure risk caused by aspects of operator behaviour or mitigated exposures through facilitating improved behaviours. Addressing the role of personal behaviour is an important factor to manage across all fields of exposure (Hurd et al. 2017). Across the Case Studies there was consistent evidence that behavioural control measures, such as PPE, training and education, handwashing and personal hygiene measures (Table 5.3), prevented risky and dangerous behaviours.

These control measures focused on the management of occupational exposure primarily driven by operator (and also user) behaviour. The enabling environment (Peal et al. 2014) surrounding hygiene behaviours was also key to ensuring the success of behavioural control measures and enabling them to work efficiently. For example, the facilitation of handwashing practices and sensitisation of operators (and users) must be combined with access to specific facilities, which concerns the technical and non-technical processes that allow opportunities to carry out positive handwashing behaviours. In some Case Studies the enabling environment along the CBS system was not strong: operators did not have convenient access to mobile handwashing facilities, in particular during collection and servicing, nor were they provided at all times with appropriate PPE. Similarly, despite the relevant training and risk awareness to encourage glove wearing, it was observed that gloves were not readily available for operators in some circumstances.

In general, the use of PPE, which included the use of boots, gloves, overalls and eyewear, was essential for controlling occupational exposure. The provision of suitable PPE must be combined with the relevant training components, so that operators have adequate skills and abilities to carry out required behaviours. However, the actual practice was affected by operators' individual preferences, constraints and sociocultural perceptions and went beyond the SOPs defined by the management team. For example, it was observed that operators removed gloves to facilitate cleaning and make it more efficient in the interest of time (CS 1). Likewise, operators' individual risk perceptions determined the very low proportion of operators wearing gloves (CS 2). Also, operators did not wear boots due to high temperatures that made it unpleasant, but also left them exposed to dermal exposure routes and physical harm (CS 3).

Similarly, the role of handwashing to reduce hand contamination was a key personal behavioural control to reduce exposure risk for operators across the Case Studies and is supported by the literature as an effective barrier in disease transmission. However, like glove wearing, the practice is influenced by individual values and preferences, fears and constraints. The reliance on handwashing, often as a sole control mechanism for operator exposure, was a significant weakness in the risk management approach and left operators very vulnerable to exposure risks. Beyond the enabling environment, though, the complexity of behaviour and implications in managing individual behaviour were explored in Case Study 2 and is described in chapter **Error! Reference source not found.**.

Table 5.3 Types of control measures for exposure risk management with examples of typical control measures found across the cases and appropriate control measure validation

Typologies of control measures	Typical examples of control measures	Control measure validation
Equipment or technical control measures (includes environmental controls)		
Container-based sanitation specifications	Toilet structure (e.g. no dead spaces, easy to clean, durable)	Observations, pre-design checks
	Toilet design (e.g. spillages contained in toilet unit, sealed, easy/safe removal of solids and liquids)	Operational experience of the unit
	Strong sealing mechanism (lid/cap/bag fastening) on collection containers	Observations, pre-design checks
	Technical (e.g. minimum pipe diameters, minimum angles, sizes of collection containers)	Observations, operational experience of unit, pre-design checks
	Toilet and container fomite materials (low stick, antibacterial, inert, smooth)	Observations
Vehicle and facility specifications	Covered collection vehicle to prevent leakage and environmental contamination	Observations
	Control of intermediate hosts and vectors (e.g. fly barriers)	Observations
	Floor surfaces/wash down surfaces	Observations
	Protected soakaway provided for urine disposal/drainage	Observations
	Location of food preparation area (e.g. separated from any processing/waste treatment activities)	Observations
Treatment control measures	Pasteurisation (e.g. heat treatment)	Measurement (temperature monitoring) and sampling (pathogen die-off)
	Biological inactivation (e.g. composting)	Measurement (temperature monitoring) and sampling (pathogen die-off)
	Chemical inactivation (e.g. sludge drying controlled by pH and temp, and disinfection)	Measurement (temperature monitoring) and sampling (pathogen die-off)
	pH shocks (e.g. urine/wastewater)	Measurement (temperature monitoring) and sampling (pathogen die-off)

	Bacterial process (e.g. activated sludge)	Measurement (temperature monitoring) and sampling (pathogen die-off)
	Adsorption (e.g. wastewater in constructed wetlands)	Observations and sampling (pathogen die-off)
Process controls		
Reduce/substitute hazardous events or processes	Increased automation and reduce manual handling	Activity tracking
Household toilet cleanliness maintained	Cleaning and disinfection protocols in place and effective	System audit
Regular servicing	Servicing schedule	Measurement and tracking operational records
Maintenance of key facilities	Seals should be regularly monitored for wear and tear and replaced in good time	Observations
	Operation and maintenance plan	
Withholding/storage times		Operational experience
Regulatory and organisational (non-technical) control measures		
GMPs, SOPs and system protocols existing and followed	Spillage protocol	System audit
	Appropriate environmental spillage protocol (including disinfection with 0.5% chlorine solution)	Operational experience
	Hand hygiene and glove protocol for “key hand hygiene moments”	Operational experience
Vaccination and preventive chemotherapy	Vaccination protocol for all staff at risk of occupational exposure to hazards	Tracking
Health surveillance	Outbreak surveillance and response plan	Health records
	Diarrhoeal diseases incidence/prevalence community monitoring and response plan	Health records
Emergency scenarios	Flood event scenario planning	
	Infectious disease outbreak scenario planning	
Signage and risk communication	Biosecurity warnings	Observations
	Communication and emergency number clearly positioned for response in event of spillage	Observations
Personal protective equipment		
Use of personal protective equipment	Gloves, masks, overall, boots and eyewear	Observations
Training and education	Regular and frequent training to communicate health risks and increase perception of exposure risks among operators	Observations

	Restricted access to treatment or use sites	
Personal hygiene controls		
Handwashing practices at key moments	In hand hygiene "key moments" and handwashing techniques	Hand hygiene observation tools
	Hygiene promotion of hand hygiene "key moments"	Hand hygiene observation tools
Hygiene awareness	Promotion of threat of exposure to faecal hazards in exposed population	Behavioural diagnosis
Ability and confidence	Increase the ability and confidence to conduct activities required	Behavioural diagnosis
Enabling environment for behavioural controls	There are physical and social structures to perform necessary behavioural controls	Behavioural diagnosis
	Increase access to handwashing stations at household and facility level	Behavioural diagnosis

Note: Behavioural controls are often in combination with the technical (treatment and non-treatment) process and organisational barriers. Behaviour practices are dependent on individual values and preferences (e.g. fears, phobias and habits), constraints (e.g. cost, time, interest), sense of responsibility, and sociocultural perceptions and practices and can be reinforced with health and hygiene promotion. Collective protective measures preferred to individual behavioural measures where relevant, and a hierarchy of control measures should always be used, following the above.

5.4. Concluding Remarks

In conclusion, the Cross Case analysis described and synthesised the key exposure risks that arose during the operation of the CBS systems and contributes to the first objective. The exposure risks were summarised at CCPs throughout the CBS systems, indicating the process steps and associated hazardous events, exposure routes and control measures (Table 5.1). There are no previous studies of which the researcher is aware that examine in comparable detail the occupational exposure risks faced by CBS operators. This study provides a timely update to the assessment of health risks arising from urine diversion dry toilets (UDDT) undertaken by Stenström and colleagues (2011), which identified similar potential exposure points, equivalent to CCPs. However, it is important to keep in mind that the analysis is based on a few Case Studies, performed from June 2016 to January 2018, and the results are liable to date quickly, given the advances in this sector. The Case Studies are not presented as a representative sample for all CBS systems; however, the analytical generalisations and replication of the exposure risks and causal mechanisms highlighted across the cases strengthen the base of evidence from which conclusions may be drawn. Overall, the replication of exposure risks leads to the logically justifiable position that such exposure risks and management mechanisms would be evident in contexts with similar internal conditions.

The detailed analytical generalisations of exposure risk identified seven key hazardous events (section 5.1) that were consistently replicated across the cases: spillages of faecal matter, blockages of urine diverter, failure to perform handwashing or carry out hand hygiene, misuse of toilet infrastructure, accidental contact with faecal matter/urine with hands, aerolisation of organic and non-organic particles and inadequate treatment procedures.

The characterisation of exposure risks and analysis of emerging patterns identified the immediate causes of hazardous events mentioned above. The factors influencing exposure risk are complex, but the Cross Case analysis overcame the difficulties in empirically testing influential variables by classifying hazardous events into four primary causal mechanisms: (1) technical and hardware failures, (2) behavioural failures, (3) system safety failures and, (4) physical environmental failures. These four factors were key drivers of hazardous events and transmission of faecal pathogens to operators in system components, and were supported by relevant evidence in the literature. However, the analysis acknowledges multiple causal mechanisms and rejects any focus on linear causal chains. Instead, exposure risk management is a property that emerges from synergies across the CBS system.

The Cross Case analysis found a general reliance on behavioural control measures at all CCPs across the Case Studies, which were imperfect controls of exposure risks due to human error. Control measures that stipulated technical specifications to manage exposure risks were considered more effective at exposure risk control; the development of ISO standards for the non-sewered sanitation systems reflects this. Similarly, the concept of safety is embedded in the safety-guided design process, used in high-risk engineering sector (Leveson 2012b). The control measures were characterised into four typologies, which correspond to the four causal mechanisms (Table 5.3). These typologies allude to a hierarchy of control measures in risk management: elimination of hazardous activity, followed by technical control measures, organisational controls, process controls and behavioural controls, as described by Bleck and Wettberg (2012). Overall, risk reduction was more effective where multiple control measures were applied. At a minimum, it is recommended that control measures for CBS must address appropriate facility and technical equipment design, maintenance, system design and operation that minimises the number of contact events with contaminated material where possible, the inactivation of faecal pathogens using effective treatment parameters and comprehensive staff health management. The development of minimum design standards (Appendix 15) based on the technical controls in the Case Studies is one of the key results and conclusions from the Cross Case analysis.

The transmission of faecal particles across contaminated hands and contaminated fomites was noted by a failure of adequate control measures at critical points and contamination of toilet fomites was verified by environmental microbial sampling. The importance of hands and fomites as a transmission route was especially applicable for operators, given the frequency of contact during work-related activities described in the system mapping. The interaction with contaminated fomites was expected to transfer contamination to hands and vice versa in what has been previously described as a “chain of infection”. The exposure assessments highlighted this exposure risk, but to better understand the potential extent of hand contamination and fomite transmission, a fuller investigation was required. The potential hand contamination of operators was simulated using Monte Carlo models to better understand the potential role of hands and fomites in operator exposure, which is discussed in Chapter 6.

The role of individual operator compliance behaviour regarding hand hygiene and potential hand contamination was consistent across cases. To better understand mechanisms of behaviour, motivation and control, a separate formative analysis using the RANAS framework was required and led to the results presented in Chapter 7.

An important conclusion drawn from the Cross Case analysis of exposure risks must be that it is not possible to identify exposure risks by looking at only one CBS component or by exploring in detail the reliability of hardware or compliance behaviour. A system perspective is thus highly relevant for a true deconstruction of exposure risks, which acknowledges the presence of the multiple, interrelated causal mechanisms and risk factors (illustrated in Figure 2.2)

6. Simulated Hand Contamination during CBS Work-related Activities

This embedded element of Case Study 1 explored the role of surfaces in the spread of *E. coli* and subsequent levels of hand contamination of operators during collection activities in the CBS system.

The aims of the study element were twofold:

- To investigate the role of surfaces in the spread of faecal contamination to the hands of operators and the associated level of concentration of faecal indicator bacteria on operators' hands.
- To utilise the first person videography (FPV) as an alternative method for obtaining accurate descriptions and activity data of operators' interactions with contact surfaces during collection activities.

An exposure model combined the microbiological data of contact surfaces with activity data and estimated the level of *E. coli* concentrations on the right and left hands of operators over the course of 10 sanitation container emptying events. The fomites appeared to act as a reservoir for contamination to the operator. Overall, the nature of the infection risk is dependent on the hygiene habits of operators and other control measures that may be adopted by the company. It was further recognised that the operator may act as a vector in a chain of infection that could result in the transfer of infective agents between households. We postulate that without appropriate interventions, the movement of operators from house to house may be a factor in disease spread or outbreaks. The implications of these preliminary findings on hand hygiene and other control measures are considered.

The study collected unique micro-level activity data of hand to fomite interactions that took place during the collection activities of CBS systems. This study provides valuable information on human–environment interactions in this sanitation service sector. Increasing the volume of service events and microbiological data for a wider range of services would improve the strength of the conclusions that can be drawn from this model. Furthermore, broadening the investigation to capture the concentration of *E. coli* in other sanitation activities would provide a useful comparison for policy and regulatory decisions.

6.1. Human–Environment Interaction Data

The micro-level activity time series (MLATS) data from FPV is summarised as the frequency and duration of contact events in service emptying events for the left and right hand. A summary of characteristics of the contact events for each surface category is presented, highlighting the specific surface category, for the left and right hands of operators. First, the concentrations of microbial contamination found on contact surfaces are summarised. Second, the results of the exposure model are presented considering median and maximum levels of hand contamination through time following contact events with the contact surfaces.

6.1.1. *Micro-level Activity Data*

The operator was recorded for a total of 69 minutes and performed 10 individual service events. Each of the 10 service events and individual contact events were recorded as a unique data point in the analysis of the raw video data. The mean frequency and duration of contact events for each object the operator handled are summarised in Table 6.1. On average, during a service event, the left hand of the operator contacted fomites 43 (12 SD) times compared to the right hand of the operator that contacted fomites 54 (21 SD) times. An individual service event (described in system mapping) lasted on average 6.9 mins (standard deviation 2.6 mins).

Table 6.1 Total number of contact events

	Left hand			**Right hand**		
Service event # (n=10)	Ce (n)	D (s)	D (min)	Ce (n)	D (s)	D (min)
1	51	462	7.70	48	451	7.51
2	22	220	3.67	29	194	3.23
3	40	286	4.77	49	274	4.56
4	45	294	4.90	40	281	4.69
5	29	259	4.32	34	259	4.32
6	56	445	7.41	54	434	7.23
7	45	379	6.31	45	371	6.19
8	45	379	6.31	67	573	9.54

9	62	699	11.65	101	696	11.60
10	38	477	7.95	72	477	7.95
Mean ± SD	43 ± 12	390 ± 140	6.50 ± 2.34	54 ± 21	401 ± 156	6.68 ± 2.61

Note: Contact Events (Ce) for the each service event (n=10) for the right and left hand. The total duration (D) the hand was in contact with any surface is presented for each service event in seconds (s) and minutes (min).

There were 19 different types of fomites handled by the operator, as presented in Table 6.2. On average, across the service events, the operator spent the largest proportion of the entire service period in contact with “nothing”. The operator’s hands were not in contact with any surface or object for 20% and 58% duration per service hour (right and left hands respectively) (Table 6.2). Both hands were in full view of the camera for the majority of the time. On average, the left hand was “not in view” 2 + 1.1 (SD) times per service event compared to the right hand “not in view” 1 + 1.8 (SD) times during each service event. On average, this accounted just over 1% of the total time per service hour.

Table 6.2 Frequency and duration of hand contacts with surfaces

		Left hand						Right hand					
		Average + SD (for n=10 service events)				% per hour		Average + SD (for n=10 service events)				% per hour	
Fomites		Ce (n)	D (s)	Ce (n)/hr	D (s) /hr	Ce	D (s)	Ce (n)	D (s)	Ce (n)/hr	D (s) /hr	Ce	D (s)
1	Household doors	0.8 + 0.9	3.7 + 3.9	7.4	27.7	1.8%	0.2%	2.5 + 2.0	11.1 + 9.6	22.4	99.8	5.6%	2.8%
2	Identification labels for containers	0.5 + 0.7	21.3 + 23.4	4.6	98.4	1.2%	0.8%	1.0 + 0.8	26.7 + 29.8	9.0	239.0	2.2%	6.7%
3	Red gloves	2.0 + 2.4	13.5 + 22.0	18.5	249.2	4.6%	2.1%	3.0 + 2.2	13.7 + 14.8	26.9	123.1	6.7%	3.4%
4	Report sheet	1.3 + 1.0	27.8 + 25.2	12.0	335.5	3.0%	2.8%	1.9 + 1.4	18.4 + 16.3	17.0	164.6	4.3%	4.6%
5	Clean tissue/cleaning paper	2.4 + 2.4	32.2 + 33.6	22.2	713.4	5.5%	5.9%	2.9 + 3.3	22.1 + 18.9	26.0	198.3	6.5%	5.5%
6	Driving compartments	3.4 + 1.8	12.1 + 8.0	31.4	378.2	7.9%	3.1%	1.9 + 1.4	5.9 + 3.7	17.0	53.1	4.3%	1.5%

7	Metal surfaces of tuk-tuk	3.2 + 1.4	33.6 + 31.0	29.5	464.3	6.9%	3.7%	3.5 + 2.5	29.3 + 29.6	31.3	262.7	7.3%	7.3%
8	Collection containers clean	6.3 + 6.9	59.3 + 78.5	58.2	1035.2	12.7%	7.9%	5.6 + 5.3	31.9 + 40.5	50.1	285.5	11.0%	7.4%
9	Ash (for cover material) containers	0.2 + 0.4	0.4 + 0.9	1.8	0.8	0.5%	0.0%	0.6 + 0.7	2.5 + 3.0	5.4	22.1	1.3%	0.6%
10	Air freshener	0.5 + 0.5	1.3 + 1.5	4.6	6.1	1.2%	0.1%	1.4 + 0.9	7.8 + 6.2	12.5	70.2	3.1%	2.0%
11	Faecal collection containers (dirty)	2.5 + 4.4	18.8 + 42.2	23.1	147.0	5.5%	1.2%	6.2 + 5.7	52.6 + 64.1	55.5	471.4	13.1%	11.6%
12	Urine collection containers (dirty)	3.5 + 2.9	33.3 + 39.9	32.3	869.7	7.5%	6.7%	3.0 + 3.7	22.0 + 35.8	26.9	197.1	6.2%	5.2%
13	Loo seat/urine diverter	0.2 + 0.4	1.4 + 2.9	1.8	2.5	0.5%	0.0%	0.7 + 1.2	6.7 + 10.7	6.3	56.1	1.6%	1.6%
14	Exterior toilet surfaces	2.1 + 2.4	20.0 + 41.8	19.4	341.8	4.6%	2.8%	3.7 + 4.5	29.1 + 36.1	33.1	260.2	7.9%	6.8%
15	Used tissue/cleaning paper	1.4 + 1.0	17.3 + 13.5	12.9	224.0	3.2%	1.9%	2.6 + 2.4	30.6 + 26.1	23.3	274.1	5.8%	7.6%
16	Face mask	0.1 + 0.1	0.7 + 2.1	0.9	0.7	0.2%	0.0%	0.1 + 0.3	0.8 + 2.5	0.9	7.4	0.2%	0.2%

17	Mobile phone	0.1 + 0.3	15.1 + 47.8	0.9	13.9	0.2%	0.1%	0.2 + 0.6	2.2 + 6.7	1.8	20.0	0.4%	0.6%
18	Nothing	11.1+ 5.7	68.5 + 48.7	102.5	7015.6	25.6%	58.1%	11.7 + 6.7	82.6 + 51.2	104.8	739.6	26.2%	20.6%
19	Hands not in view	1.7 + 1.1	9.4 + 7.7	15.7	147.0	3.9%	1.2%	1.4 + 1.8	5.1 + 7.3	12.5	46.0	3.1%	1.3%
	Total number per service event	43.3 + 37.1	389.9 + 483.5	399.7	12071.1	100%	100%	53.9	400.9	482.7	3590.3	100%	100%

Dirty faecal collection containers were the most frequently contacted surface by the right hand (13% of Ce), and the duration of contact with dirty faecal containers also represented the largest duration (12%) of contact relative to duration of contact made with other surface types (Table 6.2). Specifically, the right hand contacted dirty faecal collection containers an estimated 55 times per service hour for a duration of 471 s per service hour. In contrast, the left hand contacted dirty faecal collection containers 23 times per service hour, or 5% of contact events per service hour, and made up only 1% of the total duration per service hour. The operator was right handed, which may explain the higher rate of contacts with the collection containers. The weight of the containers also affected the contact frequency – since the operator was right handed, he employed his left hand to handle lighter objects – typically the lids of containers, whilst the right hand was used for tasks requiring more dexterity and to carry heavier objects – which were usually those which had been used for faecal or urine collection.

On average, the operator handled the “dirty” urine containers 27–30 times, equating to 6–7% Ce per service hour. Specifically, the left hand made contact with the urine containers 32 times, making 7% total duration (s) per service hour, and the right hand made contact with the urine containers 27 times, or 6% total duration (s) per service hour. The inversion between dominance of left and right hands in handling urine and faecal containers indicates an operator preference between the left and right hand for carrying out activities.

Surface contacts by the operator to exterior toilet surfaces, which included the toilet box, pedestal or immediate infrastructure, represented 5–8% of total contact events per service hour and 3–7% of the duration (s) per service hour. Specifically, the right hand made an average of 4 Ce per service event (SD 4.5) and the average duration of each Ce was 29 seconds (SD 36). The left hand made an average of 2 Ce per service event (SD 2.4) and the average duration of each Ce was 20 seconds (SD 41.8). The right hand favoured handling dirty surfaces while the left hand favoured handling clean surfaces.

The relative frequency of contact with clean collection containers (both faecal and urine) was 11% and 12.7% per service hour for the right and left hand respectively. This is approximate to the relative frequency of handling of dirty collection containers (faecal 5.5% and 13.2%, urine 7.5% and 6.2% per service hour) by the left and right hands respectively.

The operator made zero contact with the face, lips or mouth during the service event (Table 6.2). The operator made contact in the facial area when adjustments to the face mask were made during the service event – considered an event that may transfer pathogens on hands to the facial area. The face mask was contacted once per service hour for a total duration of 7 and 8 seconds/service hour for the left and right hand respectively.

On average, the operator made one/two hand contacts with the phone, representing 0.2% and 0.6% of the total duration/service hour for the left and right hand respectively.

6.1.2. Environmental Contamination

The exposure model parameters, values and references are set out in section 3.7.5. The *E. coli* concentrations from results of environmental contamination in Case Study 1 were used to populate the minimum and maximum surface values of *E. Coli* attributed to each surface category in the exposure model. The model assumed –10 for the initial concentration of surfaces. The mean value was found on the interior toilet seats, representing the loo seat and urine diverter (1.4 log *E. coli*/100 cm^2) compared to exterior toilet surfaces (1.3 log *E. coli*/100 cm^2) but the difference was not statistically significant ($p>0.05$). Mean values of contamination on urine and faecal collection container surfaces were somewhat lower, at 1.2 and 0.4 log *E. coli*/100 cm^2, respectively (Table 4.2), although, again the difference was not statistically significant. However, comparable maximum levels of *E. coli* concentration were observed across all fomites sampled from 4.1 to 4.9 log *E. coli*/100 cm^2. Many samples were above the lower limit of detection. No hands were sampled.

6.1.3. Exposure Modelling

Modelled concentrations of faecal indicator bacteria (FIB) on the left and right hands follow similar temporal trends (Figure 21). The concentration of FIB on the hands increased rapidly in the first 100–300 seconds, coincident with first contact events. On the right hand, the median concentration of FIB reaches a maximum of 1.83 log CFU/100 cm^2 after 261 seconds and 20 sequential Ce. The level of concentration of FIB on the hands appears to slowly decrease after this point. Decreases in concentrations on the hands can result from inactivation of the FIB and/or transfer of FIB away from the hand. On the left hand, the median concentration of FIB reaches a maximum after 362 seconds at 1.6 log CFU/100 cm^2. Given the fact that only one operator was employed, any influences that arise from the operator being right or left handed cannot be observed. Due to the model construct, the concentration of FIB on the hands is driven by a difference in concentration between the hands and the surface. Therefore, the net direction of transfer most often occurs from surfaces to hands, as the level of contamination on surfaces is consistently higher than that of the hands. Net transfer towards a surface would lead to a decrease in concentration on the hand and would indicate that the hands contributed to surface contamination. In reality, *transfer likely occurs in both directions* with each contact event.

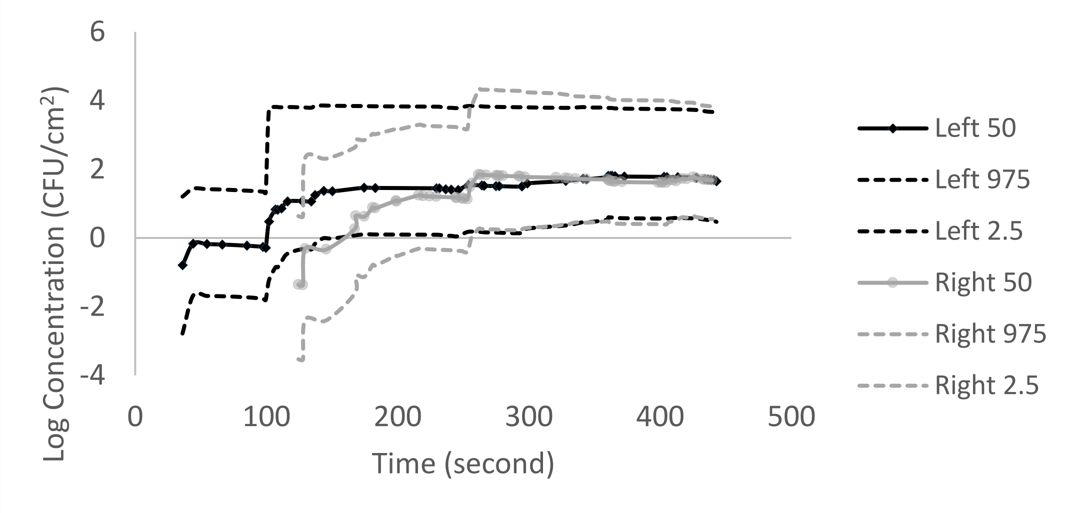


Figure 22 Simulation of one container emptying event

Note: Simulation shows right hands (grey lines) and left hands (black lines), showing median result (solid lines) and 95% confidence interval bounds (dotted lines) of 10,000 simulations. Each surface contact is shown as a point on the graph. The time course begins with a first contact resulting in a detectable concentration (prior to this time, the concentration of *E. coli* on the hand is negligible)

The modelled concentrations of FIB in Figure 22 compare the concentration of FIB on the left hand of the operator from 10 service events. The simulations indicate a rapid increase in FIB concentrations over a short period of time, followed by a gradual increase to maximum FIB concentrations. The maximum concentration of FIB simulated on the left hand was 2.09 log CFU/100 cm^2, reached after 328 seconds from an initial hand concentration of 0.03 log CFU/100 cm^2. The modelled concentrations demonstrate a significant increase in the number of FIB present on hands over an emptying period as a result of hand contacts with contaminated surfaces. While the precise timing of the increase in concentrations on the hand was different depending on the timing of the first contact with a highly frequently contacted surface, the increase in concentration on the hands resulting from contact with presumably highly frequently contacted surfaces was observed in all service events monitored.

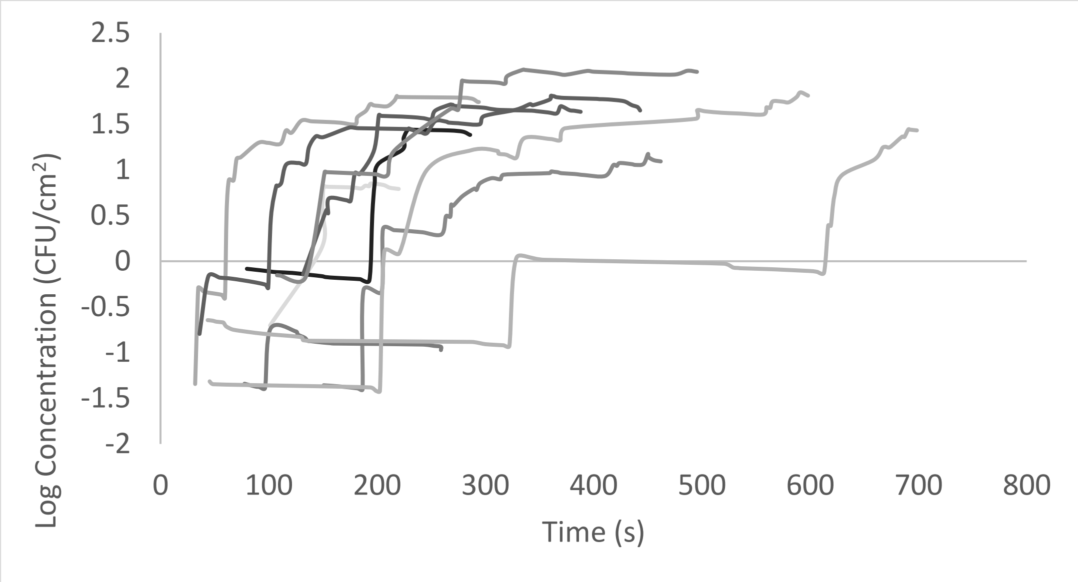


Figure 23 Median concentrations of *E. coli*

Note: Model showing results of Monte Carlo simulation 10,000 times on the left hand of the study participant for each of 10 emptying events

6.2 The Transmission of Faecal Pathogens from Surfaces to Hands and the Possibility of Infection

Hands and surfaces may play an important role in indirect transmission pathways for faecal pathogens contained in human excreta (Pickering et al. 2012; Julian and Pickering, 2015a; Julian et al. 2018; Medgyesi et al. 2018). However, the role of surfaces in the occupational exposure to faecal pathogens in CBS systems is only beginning to be explored in the literature. Previous studies have considered the microbial health risks from faecal pathogens to municipal sanitation workers when collecting stored urine as part of a CBS systems (Bischel et al. 2017).

6.2.1. Activity Data and Risk Management

The first aim of the study was to obtain descriptions of activity data in terms of operator hand interactions with contact surfaces during collection activities in CBS systems. To meet this aim, first person videography was used to record the operator's interactions with contact surfaces at a micro-level. The research findings provide preliminary activity data that is a useful contribution to help build a database of activity data relevant to occupational scenarios for common activities conducted in decentralised/dry sanitation systems.

The activity data presented information on Ce with a large number of fomite categories (Table 6.2). Ignoring the Ce and duration when the operator's hands were not in contact with any surfaces (captured as nothing), the most frequently contacted surface categories were: 1) dirty faecal collection containers, 2) urine collection containers, 3) interior toilet surfaces and 4) exterior toilet surfaces. Notably, we found no evidence for hand contact to the operator's lips or face during the emptying events (except when readjusting the mask). Therefore, even though the simulated level of hand contamination poses a potential infection risk, an absence of hand to mouth contact prevented the ingestion of pathogens. However, the absence of hand to mouth contact observed during the video translation does not preclude its presence absolutely. These results may be considered anomalous, as obtained by following only one operator for a limited number of servicing events. Indeed, our findings deviate from the normal rates of hand contacts with the face observed in other studies, which have found a mean rate of contact with the lips eight times per hour.[10] We surmise that, in this case, the fact that the operator was wearing gloves contributed to the total absence of facial contacts, as this effect is reported in healthcare studies. If so, it presents a strong reason for the development of relevant glove protocols for CBS and to encourage operator compliance in order to reduce exposure risks.

6.2.2. The Role of Surfaces in Spread of Faecal Contamination to Hands of Operators

In addressing the second objective – to investigate the role of surfaces in the spread of faecal contamination to the hands of operators – a model of exposure to faecal material during CBS emptying events was developed. The key contact surfaces were sampled for *E. coli* as an indicator of faecal contamination and, together with activity data, were successfully used to simulate the transfer of FIB from the contaminated contact surfaces to the operator's hands.

The exposure model indicated a net transfer of microbial contamination from surfaces to the hands of operators through time. The simulations of hand contamination over the course of 10 household emptying events demonstrated that both hands reached similar levels of median concentrations of *E. coli* on hands, with detectable values over 1.6 to 1.8 log CFU/100 cm^2 reached after 200 secs (left and right hands respectively). Simulated median hand contamination concentrations comparing 10 emptying events found comparable maximum levels of FIB on the operator's hands of 2.09 log CFU/100 cm^2. The study highlighted that rapid increases in FIB concentration on hands resulted from

[10] http://qmrawiki.canr.msu.edu/index.php?title=Human_Environment_Exposure_Parameters (accessed 23/05/2018)

initial contacts with highly contaminated surfaces during operations. Following transfer of FIB from surfaces to the hands of the operator during collection activities, FIB concentrations on hands remained relatively steady. Although Wang and colleagues (2017) warn against hand contamination necessarily implying high exposure results, given a rapid temporal variability in hand contamination and therefore limited occurrence of actual ingestion, the modelled FIB concentration on hands was rapidly reached following initial contacts and indicates that the level of hand contamination in this context was fairly consistent and perhaps not subject to the variability observed by Wang et al. (2017).

6.2.3. Fomites and Barriers to Transmission

The model indicated that the net direction of transfer occurred from surfaces to hands, as the level of contamination on surfaces was consistently higher than that of the hands. However, *in reality*, it is expected that transfer probably occurs in both directions. In fact, the decrease in hand contamination in the exposure model after the maximum levels are reached might be a transfer of contamination away from the hand. The model therefore indicates a scenario where the transfer of *E. coli* from the hands to surfaces in a second house may occur. Figure 23 illustrates how the transfer of *E. coli* from contaminated surfaces to the hand and back to sterile surfaces in the same household or a different household might arise, thus spreading diseases. This interpretation of the spread of faecal pathogens between fomites in CBS systems is supported by the observation made by Gerhadts et al. (2012) that "objects serve as significant pathogen reservoirs in chains of infection". This implies that there is a potential for transfer between households, with the operators as the vector of diarrhoeal disease. Without hand disinfection or washing between emptying events, contamination on the hands or gloves could theoretically be carried from one household to the next during container emptying (Figure 23).

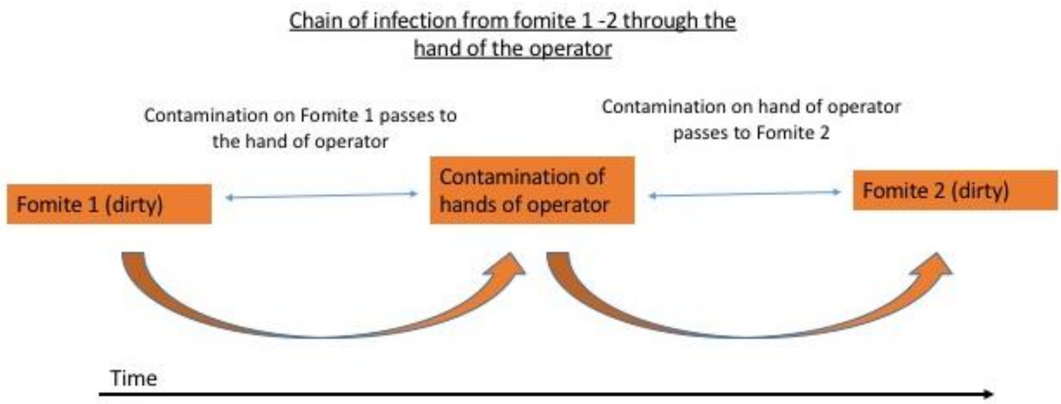


Figure 24 Chain of contamination (Eve Mackinnon)

Hand contamination is typically tackled through use of handwashing and, in the Case Study 1 here, the use of protective personal equipment (PPE) such as gloves. However, recent studies suggest that gloved hands can be a vehicle for disease transmission and further enhance the transfer of pathogens when compared to bare hands (Lingaas and Fagernes 2009). Lingaas (2009) demonstrated that the transfer efficiency of bacteria to gloved hands may be higher than that to non-gloved hands, with studies finding 68% of gloves contaminated by environment compared to 37% of hands in the same context (Lingaas and Fagernes 2009). Despite such concerns, it is well proven that gloves are highly protective in terms of personal hand contamination and the wearing of gloves reduces the likelihood of hand contamination and potential transmission of pathogens (Fuller et al. 2011). The use of PPE is a recommended protection measure for sewage waste operators (HSE 2011). At the same time, the use of gloves (Fuller et al. 2011) has been associated with a negative impact on the frequency of handwashing practices. Moreover, handwashing must be performed correctly to sufficiently remove bacteria (Gerhardts et al. 2012) to prevent the transmission of faecal pathogens. Handwashing with soap relies on a mechanical action to decontaminate hands. This is only effective if done rigorously enough and, in particular, using fresh water for rinsing (Bloomfield and Scott 1997). Potential mitigation strategies to prevent the inadvertent transfer of pathogens from contaminated to sterile surfaces would be based on the disinfection of gloves or hands between household visits. Although the single use of disposal gloves is still recommended by manufacturers, a recent national hand hygiene campaign in Germany recommended disinfection of gloves in healthcare management.

6.2.4. Possibility of Infection from Surface Transmission

The concentrations of *E. coli* on operator's hands modelled through time during the collection events indicate the possibility of infection to the operator. The exposure model does not calculate or precisely answer such questions as the actual dose or the probability of infection posed by non-pathogenic *E. coli*. The use of FIB as an input parameter does not represent infection risk per se, and equivalent values of specific pathogen dose would need to be estimated to calculate the infection risk posed from the expected values (Table 6.3). To calculate the ingested dose or the probability of infection, the FIB would have to be converted to pathogen dose using the HFE (Julian 2016) and would require dose-response information and values of a specific pathogen (Walser et al. 2015; Nicas and Jones 2009; Wang et al. 2017). However, the modelled concentrations of FIB on the operator's hands indicate a potential scenario where infection is possible.

Pathogens with a low HID pose a higher infection risk from hand and fomite transmission. For instance, as set out in Table 6.3 below, toilet surfaces hosting pathogenic colonies of *Shigella* at similar concentrations to those of measured *E. coli* may pose a higher infection risk to the operator than that posed by pathogenic *E. coli* or less harmful strains of *Salmonella*, given the lower infective dose of *Shigella* required for infection (Barker and Bloomfield 2000). Similarly, rotavirus and *Cryptosporidium parvum* pose a higher risk of infection from surface transmission, given the low HID compared to strains of enteropathogenic *Escherichia coli* (EPEC) and enterotoxigenic *Escherichia coli* (ETEC). However, since the model parameters were based on the transmission of bacteria, different model parameters would be required to accurately estimate the infection risk posed by viruses and protozoa.

Table 6.3 Infectious dose for *E. coli* levels harmful for health

Pathogen	Shedding rate/g faeces	References	HID_{50}	References
ETEC	10^7–10^8/g faeces	Enger website	25–1000 CFU	Hara-Kudo and Takatori 2011
EHEC	10^5–10^9/g faeces	Feacham 1983; Enger website	<10^2 CFU	Gerhadts 2011; Daschner et al. 2006
***Shigella* (close relation to *E. coli*)**	10^5–10^9 CFU g-1 of faeces	Feacham 1983	<10 CFU	Gerhadts 2011; Kothary and Babu 2001
Salmonella	10^{10}–10^{11}/g faeces	Feacham 1983	10^6 OR 10-100 CFU depending on the strain	Barker and Bloomfield 2000

6.3. Strengths and Limitations of the Study

There are a few notable limitations to the study findings. First, the validity of the exposure model is based on the inputs to the model. The empirical data available for surface concentrations was only available for four categories of contact surfaces. Therefore, many of the fomite categories were assumed to be zero, which is probably an unrealistic representation of the context in which the study took place. Moreover, the use of surface swabbing is a notoriously unreliable way to elucidate information on environmental contamination (Moore and Griffith 2007), but was the most economic choice. The use of *E. coli* as an indicator species was a limitation, since *E. coli* is very susceptible to drying (Gerhardts et al. 2012) and therefore the results may underestimate contamination. The use of *E. coli* as a measure of faecal contamination is a limitation, since *E. coli* may originate from animal and human faecal sources and even non-faecal sources (Mattioli et al. 2015). Alternatives, which measure pathogen specific analyses, were precluded due to high costs and resource constraints.

The parameter distributions set in our model do not represent time-dependent contexts whereby the ability of the surfaces to transfer pathogens is dependent on a number of environmental conditions. Humidity, for example, varies temporally between states of wetness and dryness, and was assumed constant in the model. Differences of contamination can depend on whether surfaces are wet or dry (Barker and Bloomfield 2000).

There was only one operator responsible for the collection and conveyance activities in Case Study 1. This restricted activity data collection to one individual source. A larger sample, including left and right-handed operators, would have contributed to the activity data being more representative.

The study's strengths relate to the use of FPV (first person videography) compared to traditional overt observation (Ulin 2005) to collect accurate activity data. First, the use of FPV reduced the subjectivity and bias associated with the recording of activities as the researcher was not involved in first-hand observation. Participant observation entails a subjective interpretation on the part of the researcher and can lead to biased results (Ulin 2005). Second, participant observation is associated with methodological challenges, not least the "Hawthorne effect", which describes alterations to and/or avoidance of doing particular behaviours due to being observed. The effect is not consistent or predictable, as, for example, one study reported that overt observation increased hand hygiene compliance (Gould et al. 2017). The rigour of this finding would be supported by a study that directly compares video data capture with overt observation (i.e. having a second person capture data via traditional overt observation). It is speculated that FPV is less intrusive for the operator than being directly observed by a third person.

In the context of public health management in the developing world, where this study took place, subtle power relations between the observed and the observer may become more pronounced. The observer is typically of a higher social status, so any methodological approach that is less demanding on the observed is better. Moreover, given the consensus that observation alters behaviour (Gould et al. 2017; Spielholz et al. 2001), and the need to collect accurate activity data, identifying more reliable methodological approaches is paramount. The observation or "translation" of the video data as it is examined later by a third person allows a further distancing between data collection and analysis, which protects the person being observed. Further investigation into the potential role of FPV in exposure modelling would be a valuable avenue for future research. Additionally, the FPV collected activity data without apparent distress to the operator and any expected effects of wearing the head camera on the operator's actions or functionality were not observed. However, to reduce any effect of wearing the head camera on operator's normal activities, the study would be improved if there was a longer acclimatisation period that allowed the operator to overcome any initial snags. Due ethical procedures were adhered to and protected the rights of both the operator and any public captured during the recording.

6.4. Concluding Remarks

The findings have demonstrated potential hand contamination of operators and spread of faecal pathogens as a substantial occupational exposure risk to operators in CBS work-related activities.

The behavioural activity data on hand contacts, frequency and duration of such service and collection events highlights the important human–environment interactions with implications for occupational exposure which is conspicuous from the exposure assessment literature. The detailed timing information could even have value beyond health risk assessments to business development for similar CBS models.

The modelled results based on the hand to surface transmission to operators highlight that these exposure points must be appropriately managed and not overlooked simply because of the urgency to scale up sanitation. From a public health perspective, the potential health impact of a transfer of enteric pathogens within and between households, to operators or other exposed individuals, with operators positioned in a "chain of infection", as discussed in previous studies (Gerhardts et al. 2012; Barker and Bloomfield 2000), is essential to consider, in particular during outbreak scenarios. The findings highlight the need for effective control measures at critical points of exposure – specifically toilet fomites and hands. Chapter 5 characterised these exposure points (section 5.1) and associated control measures (section 5.3).

The behavioural control measures (section 5.3) include hand hygiene protocols and hand hygiene practices for the management of contaminated hands and surfaces in the spread of faecal pathogens. The efficacy of these behavioural controls depends to a large degree on operator compliance with hand hygiene protocols and practices. Compliance management at the level of the individual requires a closer look at what factors – referred to as "behavioural determinants" (Dreibelbis et al. 2013) – drive such behaviours in order to improve behavioural outcomes. To understand the behavioural determinants of operator compliance with hand hygiene, including handwashing and glove use, a second embedded formative behavioural analysis was required. Chapter 7 presents the results and discussion of a formative analysis that considers these important behavioural determinants in view of improving compliance and hand hygiene efficacy.

7. ‘Operators’ Safe Sanitation Behaviours on London Canal Boats

Human excreta contains harmful pathogens and as such the handling of faecal waste presents a problematic matrix. The human dimensions of exposure risk were highlighted in the Cross Case analysis, whereby controlling exposure risk, involves controlling individual operator behaviour. This important aspect of operator behaviour in the exposure risk outcomes is not surprising; the literature previously identified aspects of human failure as a central cause of a large majority of workplace accidents (HSE 1999). An alternative view of human failures was based on barrier analysis, which considers the individual perceptions that shape intentions to perform behaviours, such as susceptibility and self-efficacy, as barriers to action (Rosenstock et al. 1998). The formative analysis was based on similar assumptions, understanding behaviour to be driven by individual perceptions. The formative analysis thus set out to measure and assess the determinants of targeted operator behaviours relevant for exposure risk management in CBS system operations. The study was embedded into Case Study 2 and sought to identify both the behavioural and contextual factors that appeared to facilitate, or oppose, these desired target behaviours associated with the human dimensions of exposure risk. The specific behaviours targeted were hand hygiene practices and the emptying and cleaning procedures critical to “human-powered sanitation systems” consisting of manual collection and transport of faecal sludge products generated in onsite sanitation (Tilley et al. 2014) such as CBS. The formative analysis used the RANAS (risk, attitudes, norms, abilities, self-regulation) behavioural framework to measure and assess the influence of behavioural factors on targeted behaviours (section 3.6.4).

This section presents, first, the findings of the closed-ended behavioural survey in terms of demographic data, and individual behavioural factors corresponding to the RANAS framework. Second, the findings relating to the behavioural factors measured from primary and secondary interview data are presented. Lastly, the discussion combines the findings and elaborates the key behavioural and contextual determinants that shape the sanitation behaviours of operators on canal boats in London.

7.1. Closed-ended behavioural surveys

The closed-ended survey sampled 40 respondents randomly selected along the canals of East and Central London. Figure 24 shows the locations from data downloaded from EpiCollect software. The number depicted in the circle refers to number of respondents from the proximate area. The survey questions measured both the targeted safe sanitation behaviours and the associated individual RANAS behavioural determinants included in the model.

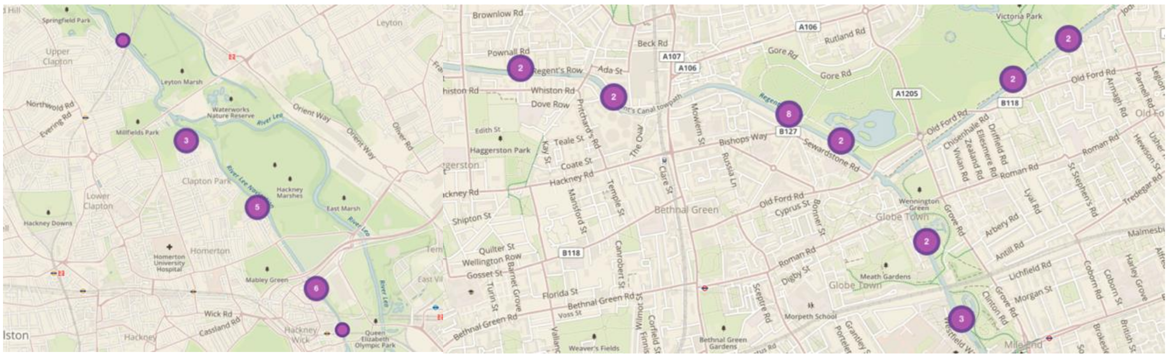


Figure 25 Mapping of survey respondents along the canals in London, UK.

The modal number of persons living on board canal boats was two, and only 4% of houseboats had two or more persons aboard. Table 7.1 presents the three types of CBS system represented in the survey and the relevant percentages. The highest proportion of respondents used a cassette type toilet (42%), followed by pump out toilet (34%) and the remaining (24%) were composting type toilets.

Table 7.1 Types of toilet technologies considered as CBS systems used on canal boats

	1. Cassette toilet	2. Pump out toilet	3. Composting type toilet
%	42%	34%	24%
Description	Store urine, faeces and flush water in a single storage container of volume 40–60l	Urine, faecal matter and wash water is stored in a steel tank. The contents are mechanically pumped out	Urine diversion dry toilets with separate containers for urine and faecal matter. No water or additives are added to the system
Disposal (solids)	Elsan point	Sewage network	Municipal rubbish disposal/composted on site
Disposal (liquids)	Elsan point	Sewage network	Grass, Elsan point

7.2. Safe Sanitation Behaviours

Frequency of emptying and cleaning (self-reported): The self-reported cleaning frequency indicated the cleanliness of toilet units, while the self-reported emptying frequency of toilets indicated the operational effectiveness and management of the toilet units. The survey findings showed that the majority of respondents (46%) cleaned the toilet a "few times a week", a quarter of respondents (25%) cleaned the toilet on "a daily basis", and the rest (29%) cleaned "weekly". The cleaning frequency was not related to the toilet type. The survey findings indicated that cassette toilets were emptied the most frequently compared to pump out or composting type toilets. Survey respondents with pump out or composting type toilets reported a monthly emptying frequency compared to bimonthly for cassette toilets (82%). The specific requirements of the toilet were expected to have determined the frequency of emptying.

Frequency of spillages (self-reported): The self-reported frequency of spillages indicated operational effectiveness and safe management. The majority of respondents (66%) reported spillages occurring less than once per year, 25% reported spillages occurring once or twice a year and only 10% reported spillages occurring a few times a year. The data did not reveal any differences in spillage frequency associated with toilet type.

Self-reported hand hygiene practices: Self-reported handwashing practices indicated compliance with practices related to the safe handling of faecal matter and after handling the toilet units. The survey found 100% of respondents reported practising handwashing after emptying containers. The majority of respondents (75%) reported not wearing gloves when handling faecal waste, or emptying containers.

The interview data supported these survey findings. The wearing of gloves while handling faecal matter was not a consistent practice – operators reported that they took additional precautions (wearing gloves) when they handled faeces from unknown persons. Gloves were typically not worn during day-to-day operations associated with the cleaning and maintenance of the CBS system in the household or during emptying and removal of full containers that contained only faecal matter from their own household.

7.3. RANAS Behavioural Factors

Primary text sources were the transcripts from three interview respondents who operated a composting type toilet on board their own canal boats. The level of education of respondents was described as post-secondary/university, their occupations being public health specialist, dietician and film producer and maker. They used different technical composting type toilets designs: two models were self-built, the other was a Separett. Two of the interviews were conducted face to face and one via the telephone. The transcripts of these interviews are located in Appendix 7 and 8. The secondary text sources included 34 threads that were directly taken from the online forum from January to April 2017. The selection criteria of the threads ensured that the content referred to the operation and management of the toilets on board canal boats. The forum mainly focuses on discussions relating to composting type toilets, but, given that all canal boaters have access to the forum, other toilet types are represented in the contributors. Two online reviews written in the first person perspective of user/operators of composting type toilets were also included as secondary text sources.

The coding process deductively coded the attached identifiers of RANAS to segments of text according to the format in Table 7.2. The coded segments were grouped together and compared to present a more systematic view of the situation relating to each RANAS behavioural determinant. A total of 182 text segments were deductively coded to a total of 18 codes and subcodes relevant to the RANAS theoretical framework. The codebook in Table 7.2 presents the frequency (as numbers of sources and references) of coded text segments to nodes associated with the RANAS behavioural determinants.

Table 7.2 Coded items and frequency counts in structural coding analysis

RANAS deductive codes	Description and identifiers	No. of sources	No. of refs
Risk factors			
Knowledge and awareness	Awareness, training, knowledge specific to composting and treatment of faeces, pathogen breakdown, hand hygiene and transmission	6	16
Perceived severity of diseases	Fear, worry about sickness, taking care	8	13
	High perceived severity	3	3
	Low perceived severity	2	2
Perceived vulnerability to disease	Likelihood of falling sick (or not), frequency of illness, previous illness and occurrence	8	41
	Deferring risk	4	6
	High	2	4
	Low	3	12
Ability factors			
Self-efficacy	Performing specific behaviours	7	25
	Ease of operation	2	3
How to do	How to run the CBS system overall	3	10
Norms			
	Other people's perceptions of handling waste (words self-conscious, embarrassing, not nice for others, conversations with the public) when dealing with waste	3	4
Attitudes			

	Confidence and positive emotions, indications of satisfaction	9	22
	Comparisons to other systems	3	5
	Joyous emotions	6	8
Self-regulation			
	Experimenting and coping with problems	3	8

Risk Factors

The survey findings demonstrated that operators had a high level of knowledge and awareness related to diarrhoeal disease transmission. Almost all respondents (n=40), 94%, were aware of the potential transmission of diarrhoeal diseases from handling faecal matter. The transmission routes with the highest salience are shown in Table 7.3. The most salient reference to transmission was "lack of handwashing", followed by "through unhygienic food preparation and "drinking dirty water". The median number of transmission routes supplied by operators was three.

Table 7.3 Ranking of the most salient word references describing transmission routes of diarrhoeal diseases

Ranking	References
1	A lack of handwashing
2	Through unhygienic food preparation
3	Drinking or swallowing dirty water
4	By touching contaminated objects in the environment
5	From ingesting soil, gardening, playing
6	Nothing

The coding identified the three distinct behavioural determinants of risk that govern behaviour, namely 1) knowledge and awareness of the risk, 2) perceived vulnerability to the risk, and 3) perceived severity of the risk. The three risk factors were separately coded with sub-codes (Table 7.2).

Almost all respondents, 88%, perceived a low risk of catching diarrhoea and "strongly disagreed" or "disagreed" with the statement that they were likely to catch diarrhoea associated with activities concerning the toilet. There was a balance of responses in terms of subjective perception of the seriousness of the diarrhoea if they were to catch it. The majority, 59%, agreed that "diarrhoea has a severe consequence on my ability to function", while 41% disagreed with this statement. The differing perceptions of seriousness were not associated with cleaning, frequency and safe sanitation behaviours.

A low perception of vulnerability to risk emerged as the most frequent coded text references (41 times, 8 sources). The code was attached to text that referenced a low frequency and/or absence of illnesses during recent years of using and operating composting type toilets. A few of the responses acknowledged the severity of the risk posed by faecal matter, but vulnerability remained low since adequate precautions were followed. The following quotes illustrate respondents' low perception of vulnerability to exposure:

We have used a composting toilet for two years and I mix and handle the secondary composting in boxes and on large mixing areas with no illness issues at all.

and

Four years of composting on my boat, no health problems.

In terms of awareness and knowledge of risks, coded text segments indicated that operators appeared to be highly informed and aware of the risk posed by faecal pathogens and of the control measures, which included hand hygiene practices, treatments and processing parameters. In particular, the text highlighted operator awareness in relation to hand transmission and was a key behavioural determinant in the performance of hand and general hygiene practices, as shown by the following quotes:

If you're running a compost system … you keep your hands clean. You don't put your hands on your mouth, and you don't scratch your nose while you're doing it.

and

Not wanting to get shit on my hands and the safety elements seem pretty close. It's generally just good hygiene.

There are relevant sociodemographic factors attributable to these behavioural practices and associated findings. Despite reference to personal time invested in self-education, the basic level of secondary education in the UK contributes to a high level of hygiene awareness surrounding the transmission of infectious diseases. The physio-environmental context of sites also governed certain aspects of handwashing and hand hygiene. In UK households, handwashing facilities are almost universally sited next to toilet facilities and this largely extends to canal boats' living environments. Although this does not correspond to universal handwashing practice, it does make the practice more likely, and may have encouraged operators to wash hands after cleaning and removing containers. It certainly makes the practice achievable if people are suitably motivated.

Despite the relationship between hand hygiene practices and operators' low perception of vulnerability to disease and their awareness of risks, multiple perspectives were apparent and appeared to be related to the nature of waste handling and, specifically, the *origin* of the faecal matter. Operators' responses implied that the perception of vulnerability to infection was associated with the origin of the faeces at an individual level. When faeces from unknown persons were handled, the perceived risks of exposure were higher and this resulted in more stringent hand hygiene practices. This additional perceived vulnerability when handling other people's waste is illustrated by this quote:

because we didn't know what they were eating we would use rubber gloves to remove the waste from the dustbin

Another aspect that appeared to impact the perception of vulnerability to exposure was the volume of waste handled. Where respondents only handled their own faecal matter, handling was regarded as minimal in terms of frequency and volume, and was associated with perceptions of low vulnerability to faecal exposure. The following quote from an operator reflects this:

I dunno about safety, I'm not really concerned too much about the safety elements of composting. Also the contact is quite minimal, we are … transferring the contents of one container into another container, maybe a bit of stirring, it really is just transferring the contents from one container to another. By the time it has reached about three months, we have maybe handled it twice. Generally, I would wear disposable gloves while doing a big job. Like when I did a big transfer. I recently emptied that toilet, changed everything over to that bin, filled up the whole thing that was done with disposable gloves.

Overall, the coded text segments indicated that operators perceived a low severity of exposure to faecal pathogens and diarrhoeal disease. There was a notable absence of text that referred to fear, anxiety or worry about sickness associated with the handling of faecal waste (Table 7.2). Instead, operators referred to faecal matter as having a low concentration of harmful pathogens and noted "a low level of parasites in faeces". The frequent references to operators never falling sick, or worrying about such illnesses also indicated the perceived low severity of diarrhoeal diseases. There was even an element of ironic humour detected in terms of people's own faeces being dangerous. In contrast, operators perceived a higher severity of exposure risk to other hazards, in particular, exposure to coal ash:

> *Quick Google check says "the waste material left after coal is burned – contains arsenic, mercury, lead, and over a dozen other heavy metals, many of them toxic". I would therefore be careful in handling and disposing of it.*

Ability Factors

Survey responses were indicated by responses to statement related ease of cleaning and emptying toilets. Almost all respondents, 90%, indicated a high level of self-efficacy related to the cleaning and emptying of the toilets and agreed with the statement "it is simple and easy to clean the toilet", while 88% agreed with the statement "it is simple and easy to empty".

The last behavioural factor measured was self-regulation based on indicators of how people put the behaviour into practice and maintained it. The responses measured how people deal with problems and what strategies they employed. The survey found that most CBS users/operators (73%) employed strategies for emptying, based on temporal cycles, proximity to emptying locations, including emptying whenever moving the boat or when passing Elsan points, or else determined by visitor numbers. The majority of respondents (67%) also had a plan for if the toilet failed to operate effectively.

Operators made multiple (22) references to behavioural determinants coded under ability factors such as "how-to-do" knowledge and ease of cleaning, emptying and practising handwashing behaviours (Table 7.4). The coded text highlighted operators' ability to follow sophisticated courses of action and organise the activities necessary for the adequate management of faecal matter. Operators also frequently discussed experimentation (8 references) and performance of specific behaviours, which was also an aspect of self-regulation behavioural determinant, as it dealt in part with problems and setbacks when cleaning, emptying or managing certain aspects of the toilet system. The emphasis on experimentation with processes reflects operators' ability to deal with unexpected setbacks, which may, in part, be explained by the context. From a sociocultural perspective, individuals living on canal boats are already choosing to follow alternative living arrangements to the normal housing stock available in London. Moreover, they manage all other waste streams produced on board the boat, which might explain the ability of operators to expertly manage CBS systems without formal training or expertise. Some of these sophisticated treatment arrangements and experimentation are captured by the following quotes:

So when there is three of those bags, they go in a bin, insulated inside a larger bin that sits next to engine. So the idea is when the engine is running that heat is used to treat the waste.

and

The composting … was too soggy and I realised … I got more cover and I made a nice layer in a second bucket and I tipped the first bucket into it. But yeah it took me a while, I had to work quite hard with the first bucket to get enough material to cover to get it sorted.

It is also noted that the source of the texts was a public “knowledge-sharing” platform, and therefore these responses may be biased to indicate a high level of how-to-do knowledge. However, references indicating an inability to carry out the activities and processes associated with CBS were far less frequent, which might be expected if this bias was a strong factor.

Norms

There was a difference in descriptive norms indicated by the responses from the survey. The survey found that 54% of respondents perceived a negative response from others with regard to the use and management of the toilet. Just less than half of the respondents perceived others’ approval of the toilet unit; more frequently it was respondents who owned compost type toilets who perceived positive descriptive norms. These norms are also captured above in the descriptions of weaknesses of certain CBS systems.

The role of social norms as a determinant of targeted behaviours appeared as a far smaller proportion of the coded text references (Table 7.2). However, these referenced text segments revealed important aspects of broader social norms influencing targeted sanitation behaviours. The operator interviews revealed a (perceived) lack of acceptance from regulatory bodies such as the Canal & River Trust and the wider community towards the use of CBS systems, suggesting certain social “injunctive” norms influencing behaviour. Specifically, these injunctive norms were around the disposal of urine. Operators cited how they would empty urine at night, or in remote rural locations, to avoid conflict with the general public, who might be concerned they were disposing of something more hazardous. Operators even suggested that the malodour of urine when disposed meant they chose “out-of-the-way” places. The contextual factors must also be recognised as a potential behavioural factor governing the (illegal) disposal of waste, since direct discharge or disposal of faecal matter or urine into rivers is illegal in the UK. Indeed, there was evidence that operators felt a sense of responsibility to adhere to these regulations, although some participants did cite the low occurrence of illegal dumping of waste, but it was not widespread. Although social norms influenced the targeted behaviours to some extent, the interviewees and forum users strongly believed in their own philosophy for carrying out the emptying and treatment of all waste streams, and this was a strong behavioural determinant in terms of how respondents managed waste processes in the CBS systems, borne out by this quote:

I think generally I feel it should be going back to the soil. That seems to be the right motivation for it. If you're talking about a full cycle, it makes more sense to me that it goes back and nourishes the soil.

Attitudes to CBS Systems

The words with the highest salience in terms of positive and negatives attitudes towards CBS systems on canal boats are shown in Table 7.4. The primary positive emotional attribute was autonomy (self-management). This was most frequently mentioned by respondents with a compost toilet, as compared to pump outs (lowest) and cassette toilets. Autonomy was not a positive attribute or attitude associated with the pump outs, presumably because these must be emptied by a third party. Other positive attributes of CBS systems implied cost/time benefits indicating convenience. Only respondents with compost type toilets referred to odour and physical attributes of the toilets positively.

It is also worthy of note that inconvenience was also highly salient as a negative attitude to all types of container-based toilets. More subjective assessments of the toilet included "smells" and "being able to see waste" as negative affective emotions associated with the toilets.

Table 7.4 Ranking of the most salient words referring to "strengths" and "weaknesses" of container-based systems

Ranking	Positive affective emotions expressed	Negative affective emotions
1	Autonomy	Odour
2	Convenient	Inconvenient
3	Cost	Proximity to waste
4	Environmental impact	Not popular with guests
5	Nothing	Lack of flush
6	Odour	Chemicals used
7	Physical attributes	

In general, a positive emotional attitude emerged frequently in the qualitative analysis as an important behavioural factor in safe handling practices (Table 7.2). The coded text identified frequent references (35) to confident, positive and joyous emotions, as well as indications of satisfaction in comparisons with other systems. Specifically, operators demonstrated positive emotional attitudes to the composting type system, when describing aspects of the faecal matter. They described faecal matter in the containers with words/phrases such as “naturalness”, “earthiness”, “beauty”, and “smells like a woodland walk in autumn”. Again, given the high baseline of targeted sanitation behaviours, it is not possible to associate the overall positive emotional attitudes to safe sanitation behaviours but it does not seem to contravene safe sanitation behaviour.

Self-regulation

A striking aspect of the analysis was the frequent references and expressions of confidence in overcoming barriers and a high resilience to problems arising during the practice of emptying containers and the treatment of faecal matter and urine. The coded text references were found to be frequently aligned to experimentation, trial and error, working hard and taking time (Table 7.4). Specifically, this was borne out in the interviews with operators by reference to self-regulation and continuous evaluation of behaviour and a high degree of commitment and obligation to perform behaviours, as well as the habitual references to handwashing “as a discipline”. The following quote illustrates this type of commitment and self-regulation:

So (I) did it this morning, it’s best done regularly, I try not to do leave it more than a couple for days.

7.4. Discussion of factors influencing behaviour and safe sanitation practices

Using the RANAS (risk, attitudes, norms, abilities, self-regulation) theoretical framework, the analysis identified the individual behavioural factors that facilitated, or opposed, the targeted behaviours. Among the key behavioural determinants was a high awareness and knowledge of risks, and a perceived low vulnerability to risk and severity of diarrhoeal disease. Also compelling in the analysis was the ability of operators and their positive emotional attitudes associated with targeted behaviours. The analysis explicitly addressed some of the contextual aspects in which the behavioural outcomes are embedded to avoid the limitations in the RANAS framework, which is criticised for not specifically highlighting contextual aspects of behaviour (Dreibelbis et al. 2013). However, the analysis does not go as far as specific socioecological frameworks, which recognise multiple levels of influence on behaviour and emphasise environmental and policy influences on behaviour (Elder et al. 2007), something the RANAS analytical framework cannot do. The focus here on the psychosocial determinants of behaviour was not intended to inform interventions beyond individual levels, but it is recognised that a deeper understanding of contextual and societal influences on behaviour (Davis et al. 2015) is an important area of further research for exposure risk management in CBS systems.

Some key assumptions are acknowledged before proceeding with discussion and interpretations of the analysis. The first assumption was that all survey respondents, interviewees and online forum participants were considered “operators” of the CBS system. The second assumption was that the various on-board toilet technologies (Table 7.1) represented types of CBS systems, and the behavioural determinants are thus relevant to the focus of the study.

The survey found that the targeted behaviours (emptying, cleaning and hand hygiene practices) were applied by the majority of operators responsible for CBS system management. The survey demonstrated that 100% of operators self-reported handwashing practices after handling faecal matter, although only 75% reported wearing gloves while handling faecal waste. These results were confirmed with triangulation from the qualitative analysis. The operators practised these safe sanitation behaviours while simultaneously perceiving a low risk of vulnerability to diarrhoeal diseases. Further, the operators were highly aware and knowledgeable about the health risks posed by hazardous pathogens in faecal matter and how diarrhoeal diseases may be spread. The awareness and knowledge of risks may have determined the behavioural activities operators engaged in, but it is widely recognised that awareness alone does not entirely motivate or generate desired behavioural responses (Michie et al. 2011). It is not clear whether this low perception of vulnerability to risk occurred as a result of the strong commitment to, or that it was a driver of, hand hygiene practices. What was implied, however, was that the wearing of gloves was associated with vulnerability to risk. The majority of respondents (75%) reported not wearing gloves when carrying out collection and emptying; however, wearing gloves was reported when handling other people’s faeces, or larger volumes of waste handling. One interpretation is that wearing gloves was driven by the increased level of perceived vulnerability when operators handled other people’s faecal matter. A plausible explanation may be that operators associated low frequency of personal enteric gut illness with the potential severity posed by the faecal matter. Since operators reported infrequent personal experience of diarrhoeal disease, it would have been logical for them to have assumed a low presence of harmful faecal pathogens in their own faecal matter. This aligns with previous research that considers that the risk of disease transmission resulting from inappropriate toilet use depends to a large extent to the health status of the user, and incidence rates of diarrhoeal disease are a major determinant of exposure risks (Peasey 2000; Schönning et al. 2007). However, the operators’ personal estimation of the low hazard level does not represent national health statistics. In the UK, there are

17 million cases of infectious intestinal diseases annually, equivalent to 25% of the population with a case of diarrhoea once per year (O'Brien 2011). Moreover, the lack of illness does not indicate lack of infection, as the person may be infected without presenting clinical symptoms (Julian 2016b). In such a case the faeces would contain a severe hazard without the operators' knowledge. Also, even when incidence rates are low, risks exist: one Danish study, which acknowledged ascariasis as a rare disease in the population, found the reuse of faeces from dry urine-diverting toilets as a garden fertiliser presented an unacceptable helminth risk, even after a storage period of 6–12 months (Schönning et al. 2007). Despite the actual potential of faecal pathogens being present in faecal matter, a low perception of vulnerability and severity to risk appeared to be a potentially important behavioural determinant of the target behaviours.

Ability factors, including how-to-do knowledge, experimentation and self-regulation, were strongly associated with the targeted behaviours, especially emptying and treatment of waste. The operators were performing relatively sophisticated activities in relation to the emptying and treatment of faecal matter generated in the CBS systems and, overwhelmingly, they found the behaviours simple and easy to do. The role of ability in determining behaviour is known in the occupational exposure literature as the "knowledge–application gap", which is described as "an inability to apply existing knowledge rather than the absence of appropriate knowledge" (Swuste and Eijkemans 2002). The preliminary evidence here suggests that interventions to drive safer sanitation management might employ tactics to increase operators' ability to carry out and perform certain behaviours, and confidence to experiment and deal with setbacks. Training to develop the capabilities of operators to perform key tasks is a recognised route to reduce the risk of infection and occupational exposure in a number of sectors, including sewage and waste (HSE 2011). The Work Improvement in Small Enterprises (WISE) approach aims to reduce occupational exposure and promotes the involvement of workers in developing responses and solutions to hazardous situations (Swuste and Eijkemans 2002). The WISE approach recognises the importance of ability in determining safe behaviours and promotes a training programme, including follow-up activities for workers.

The emotive and affective attitudinal factors present in operators' discourses surrounding targeted behaviours raised interesting perspectives for discussion. The analysis did not uncover strong negative emotions, instead, operators expressed positive affective emotions, such as joy, success and pleasant feelings. The most frequent negative emotional responses, odour, inconvenience and proximity to waste, were instrumental and less emotionally charged, which maybe reflects broader technical and operational contexts governing behaviour. The finding that certain negative emotions – in particular disgust – were not attached to targeted sanitation behaviours (such as the handwashing, cleaning or emptying frequencies) is important. This is in contrast to behavioural factors traditionally considered to drive sanitation behaviours. In the ecological-evolutionary paradigm, a sense of disgust is positioned as an evolved response against pathogen exposure and is used to motivate behaviour changes towards better sanitation practices (Curtis et al. 2011; Curtis 2011). Disgust, it is argued, is an adaptive behaviour mechanism that prevents people from contracting diseases, and that people with lower disgust sensitivities suffer more from infectious diseases (Curtis et al. 2011; Curtis 2011). This use of disgust as a behavioural change tool is not without its critics, who present negative side effects on individual wellbeing from its use as a behaviour change mechanism in sanitation interventions (Barrington et al. 2017; Brewis et al. 2019). Indeed, Brewis and colleagues (2019) conducted empirical research and their findings concluded that the use of disgust to promote sanitation behaviour resulted in a trade-off between public health gains from a collective reduction in open defecation or improved hygiene behaviours and the reduced mental wellbeing of individuals affected – in particular low social groups already vulnerable to negative exclusions. However, the findings presented here run contrary to the disgust paradigm, demonstrating that positive affective attitudes towards faecal matter were aligned with the practice of targeted behaviours. It is proposed that disgust may not always be an appropriate antecedent of safe sanitation behaviour. Given these preliminary findings, it is suggested that the influence of positive emotions as a behavioural facilitator of targeted behaviours requires further exploration and testing interventions that develop positive affective emotional responses to handling excreta matter to reduce subjective perceptions of vulnerability and stimulate safe sanitation behaviours. Presenting safe sanitation behaviours (cleaning and emptying of containers) as a joyful and positive experience may also mitigate the current social stigma associated with occupations involved in sanitation management (Yallew et al. 2012) in a global context. Indeed, while the emphasis on individual capabilities and motivations is necessary, the importance of such socioecological factors (Davis et al. 2015) must not be overlooked.

The specific behavioural determinants here are embedded in the broader social, technological and physical context of London, which are only lightly addressed in their influence with individual level behavioural factors. The analysis described how the level of education of respondents, access to handwashing facilities and the regulatory framework all contributed to determining the ability to carry out certain sanitation practices. Important interrelationships exist between contextual factors and behaviour (Dreibelbis et al. 2013), such as the highly informed and educated societal context of the Case Study, and these will have exerted a significant influence on the adoption of certain behaviours and, as such, may not be replicated in other contexts. In an occupational exposure setting, ecological frameworks that can reflect the governmental and organisational level determinants are important. Further analyses are important to determine if these behavioural determinants are unique for the canal boat CBS systems, or if they are replicated in other socioeconomic and cultural contexts.

The findings highlighted a question previously raised in the Cross Case analysis: to what extent has self-management of the CBS system, compared to serviced waste collection, influenced the perceived vulnerability to risks. As has been discussed earlier, operators perceived higher risks when they handled other people's faeces, or larger volumes, as opposed to smaller volumes of their own faecal waste. This implies that encouraging self-management of CBS systems would reduce collective risk. The elimination or substitution of this process logically reduces potential exposure risks or perceived vulnerability to exposure that results when handling larger volumes, or other people's faecal matter. There is very little research on perceived levels of vulnerability to exposure risks in related areas. However, similar risk assessments in the waste management sector concluded that the substitution or reduction of repetitive and risky process steps is an effective process control that reduces the likelihood of exposure to hazardous events (Bleck and Wettberg 2012). Additionally, the reduction of operator engagement would potentially have positive cost and time implications, making the collection process more efficient overall. Other studies point to the fact that the elimination and substitution of risk behaviour are more immediate than extensive exposure and health surveys (Swuste and Eijkemans 2002). These findings have potential implications in approaches for scaling up CBS systems and the appropriate behaviour changes required.

7.5. Strengths and Limitations

First, a key strength was the application of the RANAS model to measure the presence of key behavioural determinants of safe sanitation behaviours to improve the understanding and safety management in CBS systems. This is apparently the first study that applies this framework to an occupational exposure risk assessment and management context, thus comparison with previous studies is limited. Nonetheless, the study is an opportunity for further research on the control of occupational exposure risks in CBS systems to test interventions based on the findings of this formative analysis.

Second, it must be acknowledged that the high compliance with safe sanitation behaviours (hand hygiene behaviour) reported through the survey findings is a limitation in the subsequent interpretation of the results from the RANAS framework. The RANAS framework uses divergent target behaviours to identify emerging patterns in the behavioural factors associated with these divergent behaviours. Since 100% of operators practised safe hand hygiene behaviour, it was not possible to use comparative association with non-behaviour (hand hygiene) to compare the causal factors. Therefore, despite the differing perceptions of diarrhoeal disease, this cannot be correlated with handwashing practices.

Third, the number of interviews was small and may have compromised the findings of the analysis. Although the primary interview data was supplemented by a large volume of secondary data from online sources, the primary interview data ensured that respondents were from a selected area, whereas the identity of forum respondents was unknown. Bias was associated with non-random sampling and the use of social media data for analysis. Facebook was used for dissemination and only those on social media post information, resulting in a kind of social media bias, where data reflects the context of the people posting and is not an accurate or estimated depiction of all people.

7.6. Concluding Remarks

The findings highlighted specific perceptions that appear to facilitate behaviour and act as determinants of behaviour associated with effective risk management in a CBS system. The formative analysis identified positive emotional attitudes expressed as feelings of joy and success as well as ability factors at an individual level associated with targeted operator behaviours. The findings also suggest that disgust of excreta is not a key driver of behaviour related to sanitation management in this context, in contrast to typical sanitation management paradigms. However, there is no assertion that these determinants are appropriate to other contexts. The replicability of these finding to other contexts would require further testing of the theory in relevant settings. Despite the potential contextual differences at all levels – societal, communal, interpersonal, individual and habitual– the behavioural factors identified here have potential opportunity in different contexts.

The results from Case Study 2 appear to support the feasibility of scaling up self-managed CBS units, since the operators of these units had a low perception of vulnerability to exposure to faecal pathogens *when handling their own waste*. Perceived vulnerability was increased when handling another people's faecal waste. This finding could promote self-management and provides an interesting avenue for further work in understanding the feasibility of self-managed CBS as opposed to the operator collection currently pursued by the majority of CBS service providers.

More broadly, the study highlights the usefulness of psychosocial frameworks in decoding human behaviour and the importance of individual psychosocial aspects in managing behaviour and achieving behavioural interventions for effective risk management. The formal use of behavioural frameworks in sanitation interventions is widely used in "sanitation marketing", where it delivers a sound understanding of the specificities of demand for a product (Tremolet, Prat, and Monsour 2014).

However, there are limits to the frameworks in consideration of societal and environmental influences. Further work is recommended to test the theory based behavioural interventions. Second, further work should combine psychosocial and ecological frameworks to benefit from the synergistic effects on behavioural interventions. Overall, appropriate behaviour change techniques are sought to flip negative behaviours to positive behaviour practices and enhance the safety and efficiency of CBS systems in terms of occupational exposure risks (De Buck et al. 2016; Michie et al. 2011; Dreibelbis et al. 2013).

8. Safety Performance Indicator Framework

8.1. Introduction

The second objective of the study – to develop an appropriate framework for exposure risk along the entire sanitation chain – was addressed through (1) the practical application and adaption of the SSP for the Case Studies and associated field work and (2) a safety performance indicator (SPI) framework presented in this chapter that guides practitioners and risk managers to deliver safety outcomes.

The proposed framework complements the system assessments performed as part of the SSP (Sanitation Safety Planning) risk assessment and management framework, but is not intended to replace the day-to-day operational monitoring set out in the SSP. The SPI framework (Figure 26) illustrates how is expected to complement a risk management framework that measures and prioritises specific exposure risk at CCPs within the CBS system and informs an operational monitoring based on critical parameters at CCPs. Some of the performance indicators measure the desired outcomes of control measures and, in this sense, there is some cross-fertilisation between the development and monitoring of critical thresholds in risk assessment and management under the SSP framework. The performance indicators also assess external risk factors to indicate risk factors and help prioritise activities to reduce risks. The framework is developed as a structured way to collect data to give an impression of the overall health (in respect of exposure) of the organisation. In this sense, safety is an "emergent property" of the CBS system, controlled according to the interactions and behaviours of the system components.

Overall, the framework aims to contribute to SDG 6 and encompasses the need to support safely managed sanitation as a new and highest rung on the sanitation service ladder. In doing so, the framework fulfils the objective to address the lack of sector-wide assessment tools and indicators for sanitation service organisations to assess their safety performance.

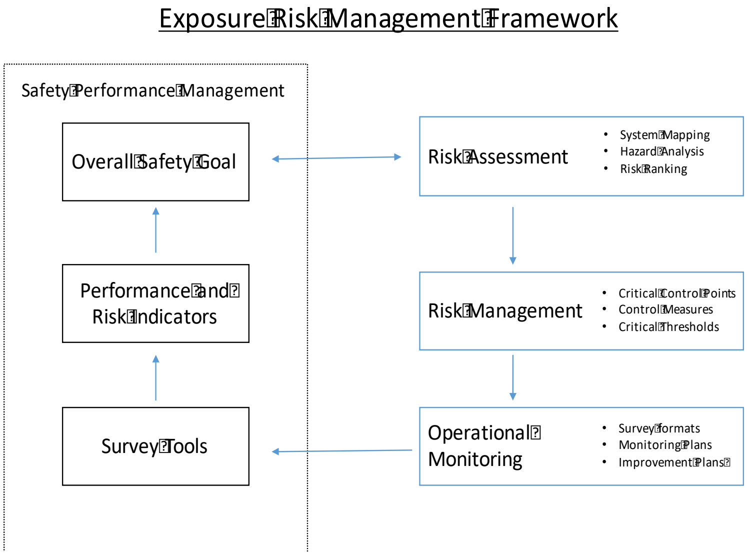


Figure 26 Relationship between the proposed safety performance management nested within the exposure risk assessment and management methodology

8.2. SPI Framework Development

Safety performance frameworks are widely used in the management and containment of hazardous materials (HSE 2006). The framework was developed according to a bottom-up examination of hazardous events and control measures derived from the empirical Case Studies and the literature review, which informed factors most pertinent to controlling exposure risks. The framework uses a system perspective to address the complexity of exposure and the interrelationships between social, environmental, technical and organisation scales that were recognised in the analysis of exposure risk across the Case Studies. The framework uses SPIs to measure aspects of the CBS system performance in terms of a range of "safety outcomes" (HSE 2006). The overall safety goal is measured by indicators (Atkins and Park 2011), and the safe performance and operation of CBS is enforced by developing, using and monitoring SPIs. A tiered approach is used in the framework development so that information can be collected at a range of levels (site, facility or organisation) (HSE 2006). The upper level indicators are intended to be generic and reflect common aspects of exposure management, while low level indicators are focused on collecting data from individual control measures specific for system performance.

The framework offers a set of interlocking indicators that align the concept of exposure across a range of technical, environmental, regulatory and behavioural factors in each category and compares risk across systems.[11] The framework is expected to undergo several iterations to establish those factors that contribute most to safety in containment and minimise exposure along the entire CBS chain. It is expected that site level indicators will be developed as appropriate on a case-by-case basis. The framework therefore conceptualises exposure at the level of the organisation, which other exposure risk assessments fail to achieve by working at city or national level (Robb 2015; Campos et al. 2015a; Acker et al. 2016). In trying to capture the inherent complexity and independencies that exist, there will always be a trade-off between too much and too little information, resulting in a framework either too cumbersome or unwieldy to be usable, or one that oversimplifies a complex system. There were potentially hundreds of sociocultural, behavioural, technical and environmental aspects that influenced exposure outcomes to pathogens at the household and community level; however, there were comparatively few directly related to occupational exposure risks during the operation of CBS systems. The indicators are arranged here to measure the actual progress in achieving a safely managed system for operators within CBS systems. Strategic performance indicators are defined to measure the performance of each operational safety attribute along the entire CBS system, thereby this provides a link between the control measures and the overall desired outcome is being achieved – that is, minimised exposure risks. The proposed framework is expected to undergo several iterations, in order to find the balance that delivers the benefits of KPIs, while not placing undue burdens on small enterprises that are not sufficiently resourced to carry out extensive internal monitoring programmes. Indeed, substitution or elimination of hazardous events is generally advised to be more effective in managing risks in certain contexts than exposure and risk surveys (Swuste and Eijkemans 2002b). Reducing the number of potential factors associated with exposure risk to a usable suite of indicators, which can justifiably measure exposure across a sanitation system for a range of operators and operational tasks, was not easy. The choice of factors was based on the fact that a) they are linked (correlate) with exposure management and b) can be observed or measured in CBS systems.

Figure 27 illustrates the 12 proposed immediate performance attributes relevant across all CBS system components.

[11] Adapted from Mayer's classification system used in disease risk analysis – environmental, socioeconomic, biological, cultural, behavioural.

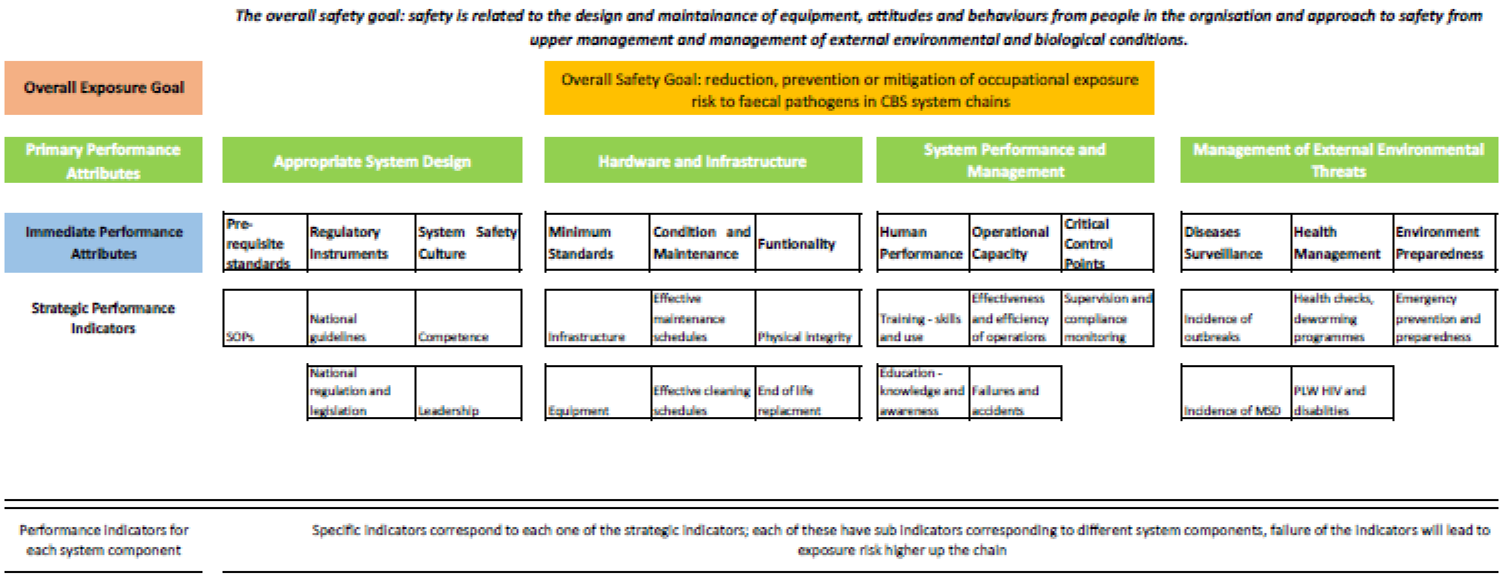


Figure 27 Safety performance framework for CBS systems (Eve Mackinnon)

8.3. Narrative of Safety Performance Attributes and Indicators

The purpose of the framework is to provide a structure for exposure risk management and an overall exposure goal that can be measured and managed. For the safety goal to be reached, a clear and logical linkage must exist through the framework, between the overall goal to the strategic performance indicators.

The operational attributes were developed in reference to the research findings. The strategic indicators that are provided are given presented as examples only and are given to demonstrate how the framework maybe operationalised.

8.3.1. Overall Goal

The overarching exposure safety goal is the "reduction, prevention or mitigation of occupational exposure risks in the CBS system". Achieving the overall goal depends upon many aspects that contribute to exposure safety: namely the hardware, equipment and infrastructure, individual behaviour as well as the broader approach from management and system safety culture, and, finally, the management of health vulnerability and disease outbreaks, flooding, or other environmental aspects. The framework aims to capture these aspects in a logical way to support management goals and determine the key indicators to ensure the overall safety goal. The framework's four primary operational attributes are 1) appropriate system design, 2) hardware and infrastructure, 3) correct system performance and management and 4) management of external environmental threats. These are discussed below with the indicators that support them.

8.3.2. Appropriate System Design

Appropriate system design refers to aspects of preventive management in the form of SOPs, monitoring and external regulations. It also encompasses the general attitudes to exposure risk at an individual and organisational level in the system safety culture. System design is captured by three immediate performance attributes, namely 1) prerequisite standards, 2) system safety culture and 3) regulatory instruments.

Prerequisite standards refer to GMPs and SOPs. This refers to both the existence and the application and effectiveness of SOPs to deal with exposure risks.

The system safety culture refers to internal culture and attitudes at an organisational level, which establishes that safety issues receive the attention warranted by their significance. Effective safety culture relies on the competence of leaders in risk management positions to manage safety issues. The frequency of worker consultation is also a valid indicator of system safety culture.

Regulations and legislation specific to faecal waste are important to exert pressure on service providers to manage waste and exposure. Strategic indicators may refer to the transport of waste, licences, permits and other aspects that prevent illegal dumping or mismanagement. A lack of institutional regulations and guidelines specific to faecal waste management reduces pressure on service providers to adequately deal with waste and poorly managed waste and increases those health risks associated with exposure to excreta-related pathogens (Medland et al. 2015).

8.3.3. Hardware and Technical Design

Appropriate technical design of equipment and infrastructure is critical for safe management. This includes design and maintenance related to operations and maintained to specifications. There are three immediate performance attributes under technical design, namely 1) hardware design, 2) condition and maintenance and 3) functionality.

The role of hardware and technical design (previously discussed in section 5.3) includes the structure (including size) and materials relating to the CBS hardware. Safety-guided design enhances both operational processes and performance and prevents technical failures and may refer to adherence to minimum design specifications (such as ISO standards). The application of minimum design standards for facilities addresses aspects of minimum design for treatment plants, transfer stations and other waste management involved in the CBS systems. Design criteria for vehicle and toilet hardware and collection containers address issues such as containment and isolation, usability, durability and cleanability of equipment to prevent pathogen transmission via multiple pathways.

Condition and maintenance ensures the physical integrity of the equipment. Indicators of the physical integrity of equipment include criteria such as watertight or airtight and physical condition or appearance. The collection of data of the end of life and maintenance programmes and schedules also indicates the successful delivery of maintenance. The cleanliness of equipment and hardware is also a key aspect of safety management under this performance indicator.

Functionality refers to technical performance and capability of the equipment to function to the desired specifications, such as the collection of data related to performance of equipment and functionality in meeting specified treatment parameters.

8.3.4. System Performance and Management

System performance and management refer to safety attributes that ensure the functionality and performance of hardware and software elements. The immediate performance attributes are 1) human performance and 2) operational capacity.

Human performance refers to the human elements (knowledge, skills and compliance) central to delivering system performance and the operation of CBS systems along the entire chain. The indicators that form the basis of human behaviours are the knowledge and awareness of individuals about hygiene and health, the level of compliance with protocols and the appropriate skills to perform the required activities.

Operating capacity covers the collection of data related to operational aspects such as the scheduling and collection of waste and treatment volumes.

8.3.5. Management of External Environmental Threats

This covers aspects of the public health environment that contribute to the overall safety goal as well as factors that reduce individual vulnerability to infection such as vaccinations. The primary environmental health aspects of most concern are preparedness for environmental emergency events, disease outbreaks and the susceptibility of exposed operators. These are reflected in the three immediate performance attributes, namely 1) environmental preparedness 2) health management and 3) disease surveillance.

Environmental preparedness includes scheduling exercises to respond to emergency scenarios in order to test response plans and adherence.

Indicators for health management include the assessment of staff health, since frontline staff are more vulnerable to exposure, given their close proximity and particular activities.

Lastly, disease surveillance indicates disease outbreaks and the subsequent pathogen loading in the system. Prevalence and incidence rates of faecal-oral diseases in the population can support risk management and obtain a useful metric on performance of this attribute. However, precise information on health data is hard to obtain; therefore a more useful metric is the demographic of users (see below). For example, a high concentration of under-five users (at schools, nurseries) should be considered a significant risk factor. Interviews with operators and users can also be used to determine the incidence of outbreaks. Secondary health data and literature review can be used for this indicator. The assumption of specific pathogens may be based on the acknowledgement that prevalence rates of diarrhoea as high as 50/1000 people are common in the global south.

8.3.6. Strategic Indicators

Hardware and Technical Design
(1) Percentage of equipment meeting minimum design standards for equipment and infrastructure including appropriate design of child features/urine diversion/surfaces: Determines the technical

performance of hardware posed physical structure, dimensions and materials are in accordance to minimum design specifications. Direct observation, prerequisite checks, organisation records and/or participatory/expert stakeholder assessment.
(2) Percentage of equipment and infrastructure failing maintenance checks: Equipment and infrastructure that have deteriorated are a direct indicator of technical functionality. May be verified through direct observation and/or participatory/expert stakeholder assessment and maintenance records.
(4) Percentage of equipment and infrastructure failing cleanliness checks: Proxy indicators for containment and cleanliness include an odour scale (no odour indicating good containment and isolation) and visual cleanliness. May be verified through direct observation and/or participatory/expert stakeholder assessment.
(5) Percentage of equipment and infrastructure on approved maintenance schedule: Proxy indicator of the condition of equipment and infrastructure. May be verified through maintenance records, direct observation, and/or participatory/expert stakeholder assessment to measure proportion of equipment and infrastructure on maintenance schedule.
Appropriate System Design
(1) Critical process SOPs in place: Proxy indicator for safety culture in terms of employee health management, hand hygiene and glove use protocols, PPE use and maintenance. Can be identified during routine key informant questions.
(2) Number of staff consultations in last six months: The number of staff feedback consultations in the last six months is an indicator that reflects effective leadership and correct attitudes at organisational level.
(3) Competence: Competence of the individuals assigned to manage risks is an indicator of effective management and internal organizational capacity.
(4) Existing governmental regulations and legislation: Guidelines for the collection, processing and reuse of faecally derived waste may be an indicator of the strength of external regulations. May be determined from interviews or landscape assessment.
(5) Number of sanctions enforced per annum: Sanctions against existing criteria, for example for the quality of post treatment faecally derived waste, are an indicator of the external regulatory environment.
(6) **Number of detections of regulatory failure per annum**: An indicator of regulatory control and enforcement.

System Performance and Management
(1) Sensitisation and awareness sessions in last six months: A proxy for knowledge level. Reports should be available from organisation records; if not available, then information sought through participatory/expert stakeholder opinion.
(2) Staff engaged in sensitisation and awareness sessions in last six months: A proxy for knowledge level. Reports should be available from organisation records; if not available, then information sought through participatory/expert stakeholder opinion.
(3) Individual attitudes and risk perception: Attitudes and risk perception influence the level of exposure risk. An attitude of risk awareness and precautions can be assessed using behavioural surveys.
(4) % of frontline staff received training in last six months: A proxy for compliance and skills level. It can be informed by training records.
(5) # of toilets serviced/in use per 1,000 users: Unreliable collection and conveyance resulting in missed service events increases exposure risks; proposed indicators are percentage of households digitally mapped and number of missed service events**.**
(6) % of solid faecal waste treated effectively and using proper procedures: System performance in terms of the volume of waste treated according to critical parameters (effective temperature, time etc.) is available from monitoring records, organisation records or participatory/expert stakeholder opinion.
(7) % of liquid faecal waste treated effectively and using proper procedures: Indicators of effective waste management proposed as the percentage of wastewater/urine managed through an effective soakaway with monitoring.
(8) # spillages/overflow reported: The number of spillages is an indicator of operational capacity captured through numbers of failures or accidents. Can be captured through routine operational monitoring.
External Environment Threats
(1) Surveillance of moderate to severe diarrhoea (MSD) and outbreaks of highly communicable diseases and MSD: The incidence of MSD is an indicator of the potential health risk of threat resulting from

	exposure to fecal waste accidentally.
(2)	**% of staff vaccinated; % of staff receiving regular health checks; % of staff with insurance:** This is an indicator of the vulnerability of the staff to health consequences post exposure. This information should be monitored internally or can be captured through staff surveys.
(3)	**# flood events in the last six months:** This information may be available from organisation records or regional government statistics; is an indicator for potential seasonal stresses.

8.4. Process Validation

Validation of the framework was conducted in Case Study 3 with staff employed by Wherever the Need India, a partner of Sanitation First. We ranked the performance of each indicator using a qualitative measurement as poor, satisfactory or good, standardised from 1 to 3 according to facial symbols. This risk scoring uses a participatory type methodology and is adapted from the PRASSA (Campos et al 2014). Each indicator can be scored, with 1 representing low exposure risks and 3 representing high exposure risks. The indicators used will undergo substantial iteration to guide useful metrics on exposure performance management for the CBS sector. Cumulative scores for each component represent the overall safety performance of the system component, while the performance of specific operational and performance attributes can be discerned from the linked strategic performance indicators.

Cumulative risk scores for each component were calculated and the lowest safety performance was affected in the waste treatment and reuse and disposal components. The framework indicated specific strategic indicators that were the main driver of poor safety performance; for example, the framework identified that hardware and toilet facilities were located in flood-prone areas and areas with poor solid waste management, which contributed to poor safety performance in relevant components. The lowest performance scores were associated with robust health management for staff, within all system components, indicating this is an important aspect contributing to the safety performance scores overall. The lowest performance scores were for perception of health risks and awareness of the wider community in the reuse and disposal of waste products.

8.5. Concluding Remarks

The framework and indicators are a practical tool to assess the performance of an organisation in managing exposure risk. The SPI framework complements the SSP frameworks and there will be some crossover between operational monitoring of CCPs in the SSP and the indicators in the SPI framework. The operational attributes and strategic indicators developed to assess and measure performance were suggested in section 0, but it would be expected that an organisation could develop alternative strategic indicators as required. The SPI framework offers many advantages, a key one being that it demonstrates to regulators and policy makers that performance management and exposure risk management are well attended to. Internally, the SPI framework, using lagging and leading indicators, offers advance warning of potential threats to the exposure safety management. The results and scores of the indicators presented here are not the focus of the enquiry, but set out how the framework can be applied, with specific strategic performance indicators that can either be quantitative or qualitative.

9. Overall Conclusions and Further Research

The research set out to describe and evaluate the occupational exposure management arising from exposure to faecal pathogens during operation of the CBS systems. The objectives generated from this were: (1) to evaluate the potential exposure risks to operators in the CBS systems studied; and (2) to develop risk management mechanisms and strategies to address these risks.

The study was situated within the current global sanitation crisis (Chapter 0), positioning CBS systems as an option to extend urban sanitation coverage and address the targets of safely managed sanitation under SDG 6.2. The literature review (Chapter 2) established a strong link between exposure to harmful faecal pathogens and adverse health impacts. Human excreta contains pathogens and is inherently difficult to manage and elimination of that exposure is virtually impossible. However, reducing opportunities for exposure will reduce the likelihood of exposure and subsequent infection. The evidence highlighted a range of factors, such as pathogen load and subsequent exposure driven by technical, cultural and social contexts, which exacerbate these mechanisms of exposure and infection. The evidence of occupational exposure risks and adverse health impacts arising from exposure to faecal pathogens in related waste management settings was supported by a number of meta-analyses (Giusti 2009; Pearson et al. 2015). The Health and Safety Executive (HSE) provided a relevant overview of health risks to sewage workers and how to protect them. Also, in LMICs, where the scale-up of onsite sanitation solutions is most relevant, there is evidence of occupational exposure in the relevant sewer and sanitary sectors (Tiwari 2008; Ambekar et al. 2004). There is, however, a notable lack of similar exposure assessments specific for CBS systems. Although it is possible that the review did not capture all relevant studies conducted, further investigation is clearly warranted, given the SDG agenda and focus on the provision of safe sustainable sanitation solutions that aim to separate excreta from human contact, *along the entire system chain*.

Three CBS systems were selected as Case Studies to investigate occupational exposures and develop a risk assessment and management framework. In each CBS system, an exposure risk assessment was performed, following guidance from SSP and HACCP risk assessment frameworks. Additional qualitative and quantitative data elements were embedded into the Case Studies. The rest of this chapter will discuss the main findings and conclusions in respect of objective one and objective two and conclude with a section on further work to be conducted to test the hypothesis and lessons learnt in this study.

9.1. Objective One: Exposure Risks and Causal Mechanisms

The main findings and contribution of this work to the first objective can be summarised as follows:

(1) For the first time, occupational exposures and risk outcomes in CBS systems, arising from contact with faecal pathogens, are set out at a level that has not been detailed in the literature till date.

(2) The Cross Case analysis (Chapter 5) resulted in two databases of potential HE associated with four primary causal mechanisms and associated typologies of control of exposure risk as: human behaviour, technical failures, system safety failures and physical/environmental failures and contributes to the formal implementation of future risk assessment (Table 5.2 and Table 5.3, respectively).

(3) An important finding was that hand contact with contaminated contact surfaces in CBS systems acted as a key transmission pathway of faecal pathogens, supporting he hypothesis that the highly physical and manual activities of the work, and high frequency of contacts with contaminated surfaces drove occupational exposure. Occupational exposure was minimised where operators did not have to enter individual households or empty individual's containers multiple times per day. Given that contact surfaces are not currently included in the WHO SSP exposure risk assessment the study yielded an important contribution to the conceptual model of occupational exposure to faecal pathogens in CBS systems.

(4) A short model-based simulation to highlight the role of faecally contaminated surfaces and hand contamination in occupational exposure was a novel approach used in Chapter 6. The modelling was carried out using measurements of FPV activity data and microbial FIB data collected in Case Study 1.

(5) The model outputs also implied that operators in CBS systems could act as vectors in a chain of infection spreading faecal pathogens via surface transmission, within and between households, if not appropriately managed. From a public health perspective, the potential health impact of a transfer of enteric pathogens within and between households is essential to consider, in particular during outbreak scenarios.

(6) An important contribution of this study is the FPV activity data that quantified the frequency of human–environment interactions of operators during CBS activities. Within the sanitation sector there is limited knowledge of human-environment interactions. The data highlighted frequent contacts made with potentially contaminated surfaces, particularly for those operators involved in cleaning and servicing at a household level. The data could support organisations to make efficiencies in their work stream, and can be used to identify types of activities which pose higher risks of exposure.

(7) The behavioural survey data revealed that operator behaviours linked to the safe handling of faecal waste were associated with positive emotional attitudes, expressed as feelings of joy and success; operators did not express feelings of disgust or negative emotions related to the handling of their own faecal waste; however, feelings of disgust were noted when operators had to manage other people's faeces.

(8) These findings suggest that operator behaviour could be changed through interventions that target their positive emotions and ability factors. Moreover, the absence of disgust suggests that it may not be an appropriate motivator of safer sanitation behaviours.

9.2. Objective Two: Developing a Risk Management Framework

The main findings and contribution of this work to the second objective can be summarised as follows:

(1) The study is a novel application of SSP (WHO 2016) to CBS systems and the findings have contributed to the comprehensive development of SSP for exposure risk management. The study findings were used to update the WHO SSP training manual and the study has thus contributed in a meaningful way to the measurement of sustainable and safe sanitation, targets associated with SDG 6.

(2) The use of participatory workshops in combination with quantitative and qualitative data collection tools present an effective framework for risk assessment that can be adapted for other CBS contexts and minimise some of the limitations of the participatory workshops. The use of participatory workshops to assess occupational exposures is recommended but efforts to avoid potential power dimensions and biases that arise are required.

(3) The use of sanitary surveys or in-depth interviews enhanced the exposure risk assessment to strengthen and avoid the potential biases and limitations of participatory risk.

(4) For the first time, a safety performance framework (Chapter 8) captured the casual mechanisms of exposure in a logical and innovative way to support management goals and determined the key indicators to ensure the overall safety goal.

(5) The framework specifically reduces the reliance on user and operator behaviour through appropriate system design, since a heavy reliance on compliance with safety protocols to manage occupational exposure risk, was associated with higher exposure risks due to the likelihood of non-compliance.

9.3. Further Work

Based on the present work, a number of topics have been identified for further research and are listed below:

(1) The occupational exposure risks (Chapter 4 and 5) highlighted exposure due to work-related activities in CBS in three Case Studies. Further work is recommended to broaden the scope of the enquiry to other decentralised sanitation systems to encompass comparisons between the CBS systems and alternative sanitation systems along the entire value chain. In particular, the exposure risks associated with manual pit desludging would benchmark exposure risks in CBS against other known technologies already promoted.

(2) Such work is important in making evidence-based decisions when promoting the use of CBS systems to meet the SDG 6 of universal sanitation. The portfolio report from the African Water Facility (2014) highlights the need for innovation boundaries to be extended in order to enable CBS and other serviced sanitation approaches to be advanced as an option for urban sanitation programmes.

(3) The Cross Case analysis highlighted the role of technical control measures for effective risk management in CBS. Further work is suggested to evaluate the minimum design standards for CBS system components developed (and set out in Appendix 15) that consider aspects of appropriate design, cleanability, durability, usability, isolation and containment (SFW), isolation and containment (LFW), minimum dispersal through air and appropriate risk signage and communication. The verification process may apply safety-guided design, which integrates the design and risk analysis processes to eliminate exposure risk from the initial design (see Leveson et al. 2012). Such research would contribute to relevant policy and practical research on standards and enforcement of sanitation facilities (SNV 2014).

(4) The study applied visual sanitary surveys associated with exposure risks that were triangulated with findings from the participatory workshops. Further work is recommended to explore which indicators have a statistical relevance to FIB when analysed with logical regression. The intended role of sanitary indicators would be in the context of risk assessment as a risk tool to support the SSP framework, rather than a diagnostic tool. The work of Snoad et al. (2017) is an interesting starting point for this research.

(5) The microbial data highlighted the presence of FIB on contaminated fomites and the role of fomites as exposure points. Further evaluation and study of fomite contamination are required to reduce operator (and user) exposure to faecal pathogens involved in CBS work-related activities. At present, fomites (surfaces) are not included as an exposure route in the guidance notes of SSP

and this limits the ability to fully manage risks. The use of Colilert for the detection of *E. coli* is a relatively simple method for identifying risks posed by surface transmission as in previous work in CBS by Berendes et al. (2015). Surface swabbing and Colilert could be used by sanitation services to monitor cleanliness and ensure control measures are adequate.

(6) The model-based simulations in Chapter 6 highlighted the nature of hand contamination and subsequent transmission in light of the potential “chains of infection” in CBS systems. The use of gloves and handwashing should be fully evaluated, since although beneficial, their use is imperfect. The work of Fuller et al. (2011) offers useful information regarding glove use and hand hygiene and compliance.

(7) The model highlighted that the frequency of interactions with contaminated objects drives microbial hand contamination, although initial contacts with highly contaminated objects appear most important. Control measures should consider the workflow and substitution of hazardous contacts to ensure the protection of frontline sanitation workers. These research suggestions are consistent with previous exposure risk assessments, which highlighted extensive manual handling in waste management (Bleck and Wettberg 2012b).

(8) The study identified that SSP implementation represents a significant time investment. It is suggested that the CBS sector should primarily focus on ensuring that fundamental risk management structures are in place, such as good management practices (GMPs) and standard operation protocols (SOPs), before more ambitious risk management plans are attempted (WHO 2003). If not, SSP might be attempted in a piecemeal fashion, which would prohibit the ability to identify important system interlinkages critical to reliable and accurate risk assessment.

(9) An interesting outcome from the behavioural analysis in Case Study 2 hinted at behavioural determinants that appeared to contradict popular paradigms in sanitation management and behaviour change and highlighted positive emotional attitudes and ability factors associated with the safe management and hand hygiene practices possessed by operators of self-managed CBS. A larger study is recommended in a target population of CBS users and operators to measure behavioural determinants of targeted behaviours and provide robust statistical analysis. The work of Mosler and Contzen (2012) provides a theoretical framework for the potential behaviour-influencing factors determining a specific target behaviour.

(10) In order to reduce operator exposure, modification to workflow by giving the responsibility of emptying household containers to the householders is suggested for further evaluation. The feasibility of self-managed CBS units (Case Study 2) in different population cohorts would focus on psychological factors and changing perceptions of users to handle and manage their own waste and potential behavioural determinants and subsequent behavioural interventions required to

adopt self-management. The work of Mosler (2012) provides a systemic approach for this type of investigation.

(11) The time implications from a business/cost perspective make self-management attractive. Alongside the behavioural evaluation, a technical evaluation would consider the implications of the self-management of CBS units in terms of cost, time and effectiveness. The FPV method used in the study demonstrates how the approaches may be compared and evaluated.

(12) The SPI framework developed in this study is a novel approach to measure and assess the exposure risk and is an important policy contribution to the CBS and broader sanitation sector to support performance-based assessment and monitoring of performance in achieving the targets for SDG 6. Verification and iteration of the SPI framework in consultation with the principal CBS service providers or CBSA are recommended for further work (that was outside the timeframe of this thesis). The consultation would focus on establishing safety performance goals and indicators that are general enough to represent the interests of a broad range of CBS service providers.

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11. Appendices

Appendix 1: Research Approval – Sanivation

SanitationasaService

Title: Reducing Risk of Disease Transmission in CBS Systems

Date: 12th of May 2016

Dear Eve MacKinnon,

On behalf of Sanivation, I grant you approval to carry out research in Karagita, a community outside of Naivasha, Kenya. I have reviewed the following documents and approve of the proposed research:

- Theoretical Conceptual Frameworks of Research
- Design Detail for Field Research – Phase 1

We will work closely with you to ensure that the research is carried out in a rigorous and methodical manner. We will offer in-country support with field and laboratory capacity. Sanivation has permission from the local chief to conduct research in the community. After a brief introduction with the chief, you too will be able to collect data from community members.

Please do not hesitate to contact us if you have any further questions.

Best,

[redacted]

Kate Bohnert, MPH

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Appendix 2: MoU – Sanitation First

Memorandum of Understanding for collaborative research with Sanitation First & Wherever The Need India Services

This Memorandum of Understanding "MoU" is dated 16th February 2018 and is between:

SANITATION FIRST (hereinafter referred to as "SF"), a charity registered in the UK, having its registered office at Limpley Mill, Lower Stoke, Bath, BA2 7FJ, bearing registration no. 1070826, represented by its Chief Executive Ms Louise Kirby-Garton;

WHEREVER THE NEED INDIA SERVICES (hereinafter referred to as "WTNIS"), a not-for-profit company, registered under Section 8 (formerly Section 25) of the Companies Act, 1956, having its registered office at 109 M, II Floor, Jaya Vilas Complex, Cuddalore Road, Mudaliarpet, Puducherry 605 004 bearing CIN U85190PY2009NPL002266 and represented by its Country Director, Dr S Paramasivan,

With

EVE MACKINNON, (hereinafter referred to as "Eve") a PhD researcher in safe sanitation at University College London residing at 88, Cadogan Terrace, London, E9 5HP.

Collectively referred to as "The Parties" and individually referred to as mentioned above.

WHEREAS

- SF has funded the implementation of the Container Based Sanitation Project by WTNIS in Cuddalore district of Tamil Nadu and Puducherry Union Territory, both in India, during 2009 and 2014 respectively.
- Eve has approached SF to visit these project, in order to assess and develop tools for handling exposure risk during implementation.
- The same has been discussed by SF with WTNIS and the dates and scope of work have been mutually agreed upon.
- The parties are entering into a collaborative relationship to conduct activities related to the assessment and management of exposure risk during collection, storage and treatment activities of 100 GroSan toilets in the locations mentioned above.
- The overall aim is to gain a better understanding and documentation regarding management of exposure risks during collection activities of GroSan, as well as to support the development of control measures to minimize exposure risks. More specifically, the objectives and activities are:

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1. An initial scoping visit to WTNIS GroSan operations in Pondicherry and Cuddalore, India.
2. Support a SSP risk assessment of GroSan activities.
3. To develop and pilot methodological tools to contribute to exposure risk assessment and management plan.
4. Characterise specific exposure risks during the collection and treatment processes.

Duration of the agreement

The agreement will be in effect for the entire duration of Eve's visit to India – 17th February to 8th March 2018 (both days inclusive)

Communications

- Eve Mackinnon and T S Padmapriya from WTNIS will be primary contacts for coordinating the scoping visit.
- Regular skype meetings should be initiated to follow up progress and notes of the same shared with all parties.
- All email communications during the period of visit must be copied to the signatories of this agreement as well as T S Padmapriya of WTNIS.

General Conditions

1. Eve shall exercise all reasonable skill, care and diligence in the discharge of duties under the Agreement. She will ensure she maintains full confidentiality of all information directly or indirectly acquired by her as part of her visit, both during and after the visit, unless it is required to be shared by the Government, the University or any other body, when she would do so after prior intimation to WTNIS and SF.

2. All the primary and secondary information collected during the visit shall be shared fully by Eve.

3. Eve will be culturally sensitive in approaching staff, stakeholders and community members as required in fulfilling the purpose of her visit.

4. Eve will obtain prior permission of WTNIS and SF before using the information collected during the visit in reports, articles, presentations or publications anywhere in the world, and ensure due credit in provided in the documents to both organisations.

5. The MOU is considered to have come into force immediately upon affixing of signature by all parties. Should circumstances arise which call for modification of the MoU these may be made by mutual consent given in writing.

6. During the currency of this agreement, it could be terminated by giving at least a week's notice by any party. The agreement may be terminated with immediate effect if Eve is not found to be adhering to the terms and conditions of this agreement.

7. Any dispute or difference arising out of the Agreement including those considered as such by only one of the parties, shall be settled by arbitration among the parties involved.

8. In event of any natural calamities, riots, Government regulations, strikes and other acts of God, owing to which the objectives under the agreement cannot be pursued, no party may be held responsible for continuation of the agreement, and it may either be suspended for the duration of disruption or cancelled based on mutual consent.

5. Evaluate control measures to manage specific exposure risks.

This MoU sets out the principles by which the parties intend to collaborate:

Responsibilities of the parties:

Eve Mackinnon

- To organise and submit all necessary ethical applications, including local (India) and UCL ethical review procedures. To ensure all data collected is in accordance with ethical procedures.
- To get the detailed study design agreed by WTNIS and SF
- To develop a hand hygiene observation tool (HHOT) for verification and compliance monitoring tools for hand hygiene practices and collect data on hand hygiene compliance.
- To develop the attitude survey for behavioural analysis of operators in regards hand hygiene practices and compliance.
- To collect data on pathogen die off and holding times of solid and liquid wastes.
- To provide support and technical assistance during Sanitation Safety Planning (SSP) activities, including results and analysis on microbial contamination and compliance data.
- To write a 2-page summary report with initial results and observations within the 2 weeks following the visit.
- To share all documents to be used in the study including consent forms in advance for approval before administering them to staff and community
- To share all documentation with test data.
- To document and publish the results of the SSP process in collaboration with SF and WTNIS after detailed discussion and approval
- To ensure adequate safeguards for health and safety are undertaken,
- To possess adequate and necessary insurance for health and accident while in India.

WTNIS and SF will not be liable for any loss, damage, injury, disability or death during Eve's stay in India as well as participation in research activities in the WTNIS project sites or travel to and from Pondicherry to Chennai or other sites within India.

Wherever The Need India Services

- To orientate and provide access for data collection during GroSan operations.
- To support and assist the testing of compliance monitoring tools for hand hygiene practices.
- To lead and arrange the SSP workshop activities.
- To work in collaboration with Eve Mackinnon to document and publish the SSP results.
- To provide translation assistance for forms where required.
- To review and approve any documents that are to be used during the study

Sanitation First

- To provide oversight to the visit and ensure legal, and compliance requirements of both the organisations are not compromised.
- To keep WTNIS in the loop on any agreements and decisions taken with regard to the study and resultant documentation.

This MoU is being entered into for purely academic reasons and no party will be liable to pay any other party for any expenses incurred as part of this collaborative research study.

Agreed and signed on this 16th day of February 2018

Signed[redacted] Date: 16.02.2018

(Eve Mackinnon, Researcher)

Signed:-[redacted]---------Date: 16.02.2018

(Dr S Paramasivan, Country Director, WTNIS)

Signed[redacted] Date: 22.02.18

(Louise Kirby-Garton, CEO, SF)

Appendix 3: Hazardous Event Definition sheet

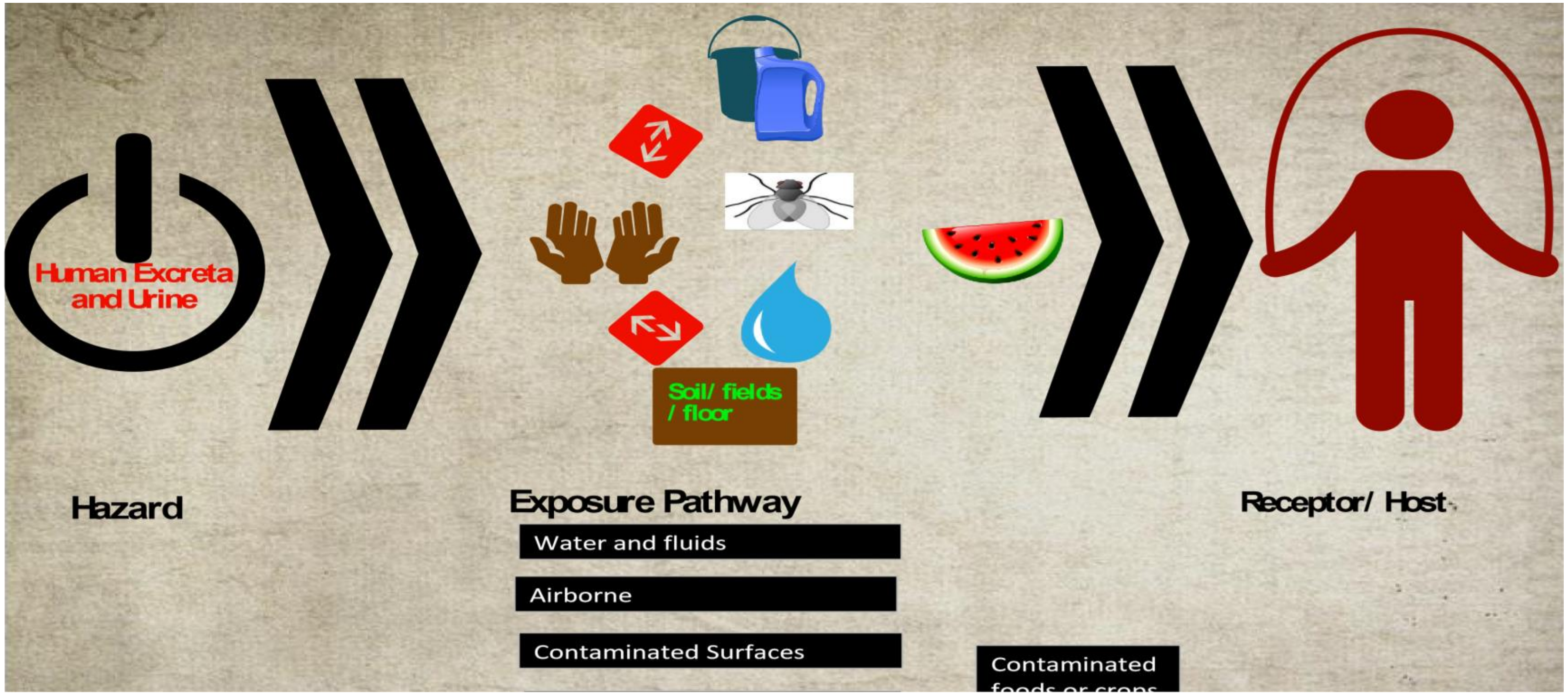
1: Hazardous Event Definition Form

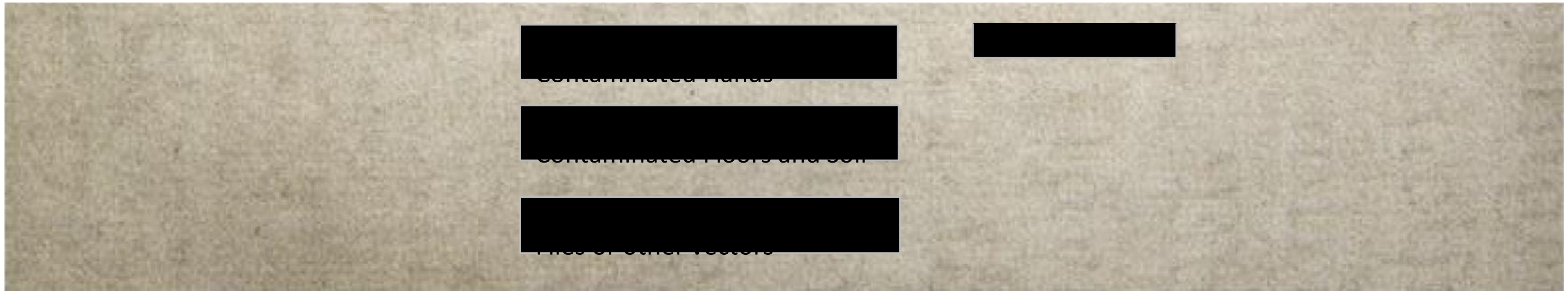
Flows of Waste - Household Generation to Final Disposal/Re-Use

Waste Flows:

Containment			Collection			Conveyance			Treatment			Re-use/Disposal		
Hazardous Event	Pathway	Receptor	Hazardous Event	Pathway	Receptor	Hazardous Event	Pathway	Receptor	Hazardous Event	Pathway	Receptor	Hazardous Event	Pathway	Receptor
Eg: Spillages of urine			Handling fecal material without gloves Illegal dumping			Leaking during transport			Incomplete treatment			Community might be exposed to poorly dispose Blocking of Elsan's not designed for solid waste Waterways polluted with urine		

Appendix 4: Transmission Pathways Definition sheet





Appendix 5: Control measures Definition sheet

System Components	Control Measures		
	Social *(controls related to personal behaviours and activiies that mitigate risks. Also related to education, perspective and awareness around risk mitigation)*	**Technical** *(controls measures related to physical design, processes and tools to mitigate risks, or environmental measures which mitigate risks)*	**Managerial** *(controls related to regulatory and institutional factors that mitigate risks. Also related to risk communication and signage)*
Containment			
Emptying and Transport			
Treatment			
Re-use/Disposal			

Appendix 6: Exposure Scenario notes CS 3

Field during observations of Containment/Collection and Conveyance of GroSan Units 22/23 February 2018

Description of hazardous events and transmission pathways noted	Risk factor concerns
Description of specific activities: Cleaning – wears gloves, sweeps out of the toilet floor. removes blockages from the urine diversion, splashing disinfectant onto the floors, surfaces Disposal of cleaning water Operators open up back and remove first box with tools, transport box to vehicle with handling tools Rotation of boxes inside GroSan unit Replacement of empty unit in GroSan box Urine collection – urine pumped from container into truck Transport back to treatment facility Hazardous Events Blockages in urine diversion and direct contact with faecal matter (and/or cover material) Walls not cleaned, dirt on walls Cleaning water contaminated disposed of in public space Splashing from removal Cleaners not wearing PPE Overflow from first unit – contact with raw fecal material	Gloves very new; appearance they are being worn for the purposes of being observed and far too big for the cleaner to be able to have any level of dexterity Many children and elderly people General cleanliness of toilets quite good The environmental sanitation/area around the toilets is quite low General level of poverty/low access to WASH = prevalence of disease in the area expected to be quite high Not monthly/scheduled regular collections due to the vehicle not being in good condition Poor maintenance of Grosan units No collection is a PH hazard Difficult to empty urine containers PPE wearing not monitored No protocols observed on urine collection Cleaning staff indicated health issues suspected to link to exposure to dirty toilets (fever)

Boxes in poor condition - breaking during removal Some containers with no lids potential spillages from containers Urine pipe directly into open drainage channel/urine pipe disconnected Spillages during pumping Handling of contaminated containers/pipes	

Exposure Risk to Ingestion of Faecal Pathogens at Waste treatment facility Site (24 February 2018)

Description of Hazardous Events and Transmission pathways noted	Risk Factors Concerns
Description of Specific Activities: Crate stored in blocks for 90 days (3 months) per batch After 90 days boxes are emptied into the windrows Washing of buckets Turning of windrows (and addition of water) Wheelbarrows "solids" across the yard Addition of sugarcane press Sieving to remove unwanted materials Sampling procedures for testing Hazardous Events Data labels erased – no box ID Covers missing, reduced physical integrity of box Strong odour from boxes Heavy – spillage (high stacks) Handling of contaminated waste Not wearing masks Cross-contamination with older compost Breakages and spillages due to disintegration of boxes during moving Splashing of contaminated water Water drains into public area/shallow GW Handling of contaminated waste Inhalation of spores/pathogens – not wearing masks correctly, inadequate mask	No recording system of the batches/dates/numbers No recording system of batched (volume/date) No temperature monitoring No handwashing signs/reminders/safety notices No specific handwashing hardware on site No zoning on site No drying areas Soakaway not well maintained, blockages Very manual process, very intensive and proximate handling Little awareness of potential hazardous of inhalation Use of hired labour, not trained and staff with health management- exploitation possible Unwanted debris not deposed of in a safe manner, dumped outside the site Sample results are not obtained prior to bagging. No process for samples which do not achieve adequate log reduction No systematic sampling of batches Unknown pathogen reduction of manure added after treatment process. Potential recontamination is highly likely

Appendix 7: Interview Transcripts A

<u>Transcript 1 CS 1 – 05/07/2016</u>

Please may you describe how long you have been working in the sanitation sector?

He is okay working with Sanivation and has found no problem working within Sanivation. 2 years working with Sanivation, previously doing collection with the motorbike to the homesteads. But after having an accident he is based in the site.

What do you consider as hazards that exist during your role as a waste handler?

He says that when he is emptying the poop, he wears the PPE. The most important for the PPE is the cuts in finger or hands, and this prevents openings from germs getting into you. The mask also prevents the smell from respiratory problems.

To understand a bit better your daily interaction with the toilet and waste itself? Explain a typical day what aspects of the device or service you operate in relation to service?

Waits for Thomas, offloads the poop, after cleaning he takes them back to the store.

What problems or issues do you face related to your role?

No

Do you ever get exposed to the solid or liquid waste in the toilet?

No

Have you (or anybody else) ever been physically exposed to solid or liquid waste following an extraordinary or abnormal situations?

No

Who do you think is most exposed to solid or liquid waste?

Not possible to be exposed, because before you get to the red zone there is no way that any person can become contaminated with the waste.

Which routes shown do you think are most significant in transfer of pathogens from the toilet to a person during your daily activities?

Flies, hands are also very significant touching things and containers, and drinking water with containers means that hands might be involved and therefore handwashing is very important.

Is it easy to follow PPE and other procedures?

Simple and it is a must.

Is this currently being done?

Yes

Thinking of people who might come into contact with waste (*users, TSR or the community*) who do you think is more likely to suffer negative health consequences?

The collector is the one who is more at risk with collecting the poop, who is at more reaching the households not only once or twice, but a lot of risk.

What personal factors make a person more likely to be impacted negative health consequences?

The other factor is if he does not wear PPE he will be more at risk.

How important do you think handwashing is?

After mingling with people, after working and going back home it is important to go back home because you do not know where the germs are.

Do you feel like you are well informed about the health risks?

The first training that he got – he follows day after day

Is diarrhoea a health issue they experience for you and your family?

Previously 2 weeks, a problem with stomach but when he went it was about ulcers.

What other diseases that she is more concerned about other than diarrhoea?

Due to weather the only problem is the cold and cholera. There is cholera two weeks ago, outbreak a few weeks ago. That time it was combined with diarrhoea but affected more the children than the big people.

Last comments:

About the smell, can the company afford something to kill the smell? Can the company provide milk to reduce the smell from the poop that gets in you, even if you wear the mask?

Last comments:

After every two weeks, or every certain short training to have a re-training about the risks.

Transcript 2 CS 1 – 04/07/2016

Please may you describe how long you have been working in the sanitation sector?

6 months

What do you consider as hazards that exist during your role as a waste handler?

She don't see any problem because of the PPE –

Explain more the PPE –

Gloves, masks, overall

Which hazards does this protect from?

Overall protects from poop on water from splashing on personal clothing, gumboots protect from poop from splashing on feet.

What are the main health consequences that might result from exposure to these hazards?

It can bring diseases like cholera, smell, poop, if you get water on your skin, skin reaction or scratching.

To understand a bit better your daily interaction with the toilet and waste itself?

Explain a typical day what aspects of the device or service you operate in relation to service?

First things is to wash the site toilets, once buckets off-loaded, weighed and then cleaning and washing the buckets.

What problems or issues do you face related to your role?

No problems

Do you ever get exposed to the solid or liquid waste in the toilet?

Never experienced such a thing, every-time she is in the red zone she is completely covered.

Have you (or anybody else) ever been physically exposed to solid or liquid waste following an extraordinary or abnormal situations?

Never, only she is in the red zone. All visitors wear PPE and do not touch anything.

Whereabouts do these events take place?

Who do you think is most exposed to solid or liquid waste?

During which activities are you most concerned about exposure occurring?

For the period she has been working she is ok, she may contact the diseases if not wearing the PPE.

Which routes shown do you think are most significant in transfer of pathogens from the toilet to a person during your daily activities?

Flies is the most important route and if not handwashing this is an important route.

What factors may reduce the likelihood of other routes?

Flies: closing the buckets, lids on buckets would reduce the transmission of flies. The sun increases the amount of flies

Which ways does she block the pathways to faecal matter or urine waste?

Consistent wearing of PPE which blocks as all the dirt sticks onto the PPE- flies land on PPE not on the body. Gloves assist her picking buckets which are contaminated. PPE protect the wastewater from sprinkling. Gloves are not 100% protective – when removing then, you wash your hands for protection like when going to the toilet.

Is it easy to carry out handwashing?

Simple to do.

Is this currently being done?

Does everyone do them?

Everybody does them

Have you had any health issues related to the work?

No

Thinking of people who might come into contact with waste (*users, TSR or the community*) who do you think is more likely to suffer negative health consequences?

The person who is disposing the bucket to containers, it is very risky disposing the waste it is very risky – if he doesn't wear all the PPE he will be exposed to the waste.

The person who does the servicing – the collection of poop from the community is most at risk.

What personal factors make a person more likely to be impacted negative health consequences?

The collector is not covered therefore the collector must cover it first, protecting it from being uncovered. The other thing the box might be dirty. He has to clean the box, and has a lot of exposure *to it. If it is dirty he has to take responsibility to clean it and if he doesn't clean it in a protective way to himself he is more exposed to those pathogens.*

What can reduce the impact on these groups/people?

To make sure he uses the work items to wear the protective items.

Are these measures in place to reduce exposure to these risks?

According to her all the work items are in place and to make sure that all the work items are in place.

How important do you think handwashing is?

Washing hands is a must- to protect where you have touched, you touch everywhere to prevent them from getting to you

When are the most important times to do handwashing in a day?

If she is working she closes water tap, she washes hands, the other thing is when she gets to storage container, she doing something with tag tying, tag ties are contaminated – after sorting them out she makes sure she washes her hands.

Do you feel like you are well informed about the health risks?

Yes she feels well informed.

Where did you receive your knowledge about health risks?

From her boss.

Has this additional information changed her behaviour?

Before she was taught she knew nothing about the health risks so she benefitted everything from the teaching.

Is diarrhoea is health issue they experience for you and your family?

No

What other diseases that she is more concerned about other than diarrhoea?

Diarrhoea is the only disease she gets, and colds.

Transcript 3 CS 1 - 04/07/2016

Can you please describe what were you using before the toilet?

Pit latrine

Roughly how long you have been using the blue box?

Since last year

Who in your household uses the blue box?

Everyone, 4 people using, three children and mum.

How often do you use it?

Everyday.

What are the best about using the blue box?

The best things, it's clean because no insects or flies compared to pit latrine. It is best for night – instead of going to pit latrine you go to blue box. There is an inside and outside one.

Do you prefer a blue box to the other?

One is plastic, one is wooden, and I prefer both. It is good because it doesn't not stay for long, and will be collected like twice a week. Which is good because you stay clean.

Is there anything you do not like about using the blue box?

No there is nothing it is fine.

When you first used the box was it difficult?

No it was the same as now.

When you are using the toilet do you ever come into contact with the poop or urine? Smell, touch, and see the poop.

It has no smell, you see it then you put the ash.

13. Who does the cleaning?

Done by everyone, you use wet material to wipe the upper side.

15. This is human poop and ways they get into contact with a human? (Water, fingers, flies, soil) Which of these are important in your households?

There is no flies, since we put the ash, no smell, comes out so no flies come out. After using the toilet you wash your hands, and everyone is washing their hands.

Is it easy to wash your hands?

It is easy, everyone is washing their hands. The little one – you have to tell them to go back and wash their hands. Also the toilet is more up, so she has to struggle, to sit on it, always he has to miss, because he poops in the urine barrel instead of – even the hole is bigger than him, but I go and clean it. He is five years.

24. How often do you, and your family get diarrhoea, is it frequent?

No, maybe we food, not with the poop. It is rare though, and for even my brothers. In the community it is rare, because I have never had serious cases of it.

28. Do you think diarrhoea is a severe diseases or risk for your family? Do you think diarrhoea is bad?

It is worse compared to what caused it. Typhoid, is bad. Like typhoid, the waterborne diseases are worse.

Even cholera, is worse than diarrhoea.

Who is most at risk from getting diarrhoea?

Those who are not hygienic

Which people are not hygiene?

The people who come out of the toilet and do not wash their hands, and put ash. The ignorant.

Any group can be ignorant. There are some people who think it is not important.

People say hygiene is for the doctors: now if you assume it you will have the infections.

Who says hygiene is for the doctors?

Many people – many people are ignorant. Many people do not want to follow the instructions.

34. Do you feel like you are well informed about the diarrhoea and how you prevent ad get it?

Yeah it is good to be informed. I am well informed.

35. Where did you receive your knowledge about diarrhoea?

From school.

Transcript 4 – CS 1 04/07/2016

Community Health Worker

Roughly how long you have been using the blue box?

About one year,

Who in your household uses the blue box?

We use all sometimes. We are five. I have three children, me and their mother. The last child is 11 years.

How often do you use it?

We use all the time, sometimes in school, when comeback they use, we are not always here, when we use we are here.

What are the best about using the blue box?

The blue box is good, because when I was using the usual toilet, it is better because they collect. If they use the new one, it is come to be full up. It is bringing a lot of smelling. Now they provide another method. The charcoal one, we put inside usually and no smell.

Other good ways?

In myself, I am a community h worker, I saw the way it is used, and how they collect, two times a week it is good, you cannot see the smell because they collect at the right time.

Is there anything issues/ you do not like about using the blue box? When you first used the box was it difficult?

The first one, but I complained, the hole was too small. You cannot see any faeces, and all the product goes down to the right place.

When you are using the toilet do you ever come into contact with the poop or urine? Smell, touch, and see the poop.

No. Never.

How often do you see or smell the waste?

In my blue box, because the collect at the right time, you cannot see the smell, because they work what is needed.

Is there any risk of touching?

Because I have shown my children, how to using, after using wash their hands, so no problem with that. We use the right cloth to clean the top.

How common for people to wash their hands in the community?

Many people do this, I follow, and I do the follow up.

Why teaching the handwashing?

After the toilet you are supposed to wash your hands, after teaching them they do – after teaching them they hear and see the danger and wash their hands.

15. This is human poop and ways they get into contact with a human? (Water, fingers, flies, soil) Which of these are important in your household?

This is what I teach the people, after the flies take the faeces from the toilet, they flies come to your food contaminated with germs and you can have diarrhoea.

People fear the diarrhoea.

Which is an important pathway?

The most important is to wash the hands. And flies is the most dangerous, it goes down and touch the faeces. When it come to the food, it takes germs. If you wash your toilet, you cannot see the flies. And wash your hands, we usually tell them to wash their hands. Because if you go to the toilet you can forget to wash your hands, it is very dangerous. You can see your friends and touch and come contaminated.

Is h/w common?

After my follow up, my work is to make the h/w facility in the outside, so that's what I do. We are using the tap, but after my investigation, the tap is dangerous: after the toilet you open and close the tap, after h/w you touch the tap, so you are not washing your hands.

What makes these pathways more possible?

I tell the children: When you use the blue box, immediately you close. So the fly cannot go inside when closed, the box might be open.

Does the age user affect the use of the blue box?

So that's what I say, I teach the children, I teach the children after using they close and wash the hands. So not possible the flies go inside.

Do you target children?

Yes, we share the people about the house. In a group, in a dispensary.

You take the group.

If I inform the mother, the mother will teach the child.

24. How often do you, and your family get diarrhoea, is it frequent?

There is no diarrhoea.

In the community?

No messages of diarrhoea

28. Do you think diarrhoea is a severe diseases or risk for your family? Do you think diarrhoea is bad?

Diarrhoea is normal. I hear about the other diseases, but not diarrhoea. I hear about the kind of diarrhoea, it’s like diarrhoea which gets the medicine, it okay. But diarrhoea like the cholera is very dangerous. I think diarrhoea is dangerous.

Transcript 5 – CS1 04/07/2016

User

Can you please describe what were you using before the toilet?

Before I was using the latrine a normal latrine, I started using the blue box in Feb 2015.

Roughly how long you have been using the blue box?

Who in your household uses the blue box?

The children use the blue box, 4 kids, only from 18 years – 8 years. The blue box my son, in the garden he has some disabilities – mental one, using the outside one I am not comfortable, he falls like epilepsy but not epilepsy… he falls like hysteria.

He grows slowly, so using the outside latrine is not safe for him. So when I heard about the blue box from CHW I saw how it works and thought it was good for my son. For the young child find it very comfortable, because the outside latrines the holes are big. And all of them they loved it so much. So I put it into their bedroom at night. During the day, when they close the school they use it very often. So when they bang the door get inside, very noisy, so I put it in the outside, they use it there. In the evening I put it in the bedroom.

What are the best and worst things about using the blue box?

What are some of the worst things: no complaints from the children about it?

OK, the girls when they are adolescent in periods, they find it uncomfortable they have to use the outside one.

How often do you and your family use the toilet on a normal day?

Moving the box is very comfortable because of the handles.

We use charcoal, better than ash.

When you move it does it shift?

It has never shifted and its 1.5 years now.

Are all days similar to this one you have described?

When you are using the toilet do you ever come into contact with the poop or urine?

Once you apply the ash, there is no more smell.

Its make does not allow that type of contact. The urine goes in there, but on top if a child has urinated, it goes on top I give it a clean. I have shown the children how to use it, they never put their hands inside. When they use it, they must look it after using. We have someone who stays at home, a sho sho, who stay with the children when I am at work. Once they use the toilet she is very considerate to see how they have used, if they have not applied enough ash, or if there is anything on top she wipes. She cleans and also we have shown them how to do it.

What do you use for cleaning after poop?

Toilet paper, or the gazette, magazines. Newspaper.

Are they available?

It is available, but they do not sell it but the tissue is best, but when the month is at the corner we do not have money that time that is when we can use that one.

After defecating, do they do handwashing?

Yes you have to wash your hands after every visit to the toilet. We have trained them after using the latrine they have to wash their hands.

Is there anyone in your family who is at risk from the touching poop or urine?

If you have the small children, you have to support them when they are going there. But since mine are big they are ok.

This is human poop and ways they get into contact with a human? (Water, fingers, flies, soil) Which of these are important in your households?

Insects get once we have not applied the ash as well. But since we apply there are normal insects that come. Once you put the ash, you put it nicely, the flies go away.

Any other routes?

For the old people, a very old sho, who use it, I think applying the ashes they do not know how to apply the ashes. So might has pooped a little one, you might find it smelling a bit. Old sho sho, like 95. Okay she cannot also balance it. That's why I was saying

She needs a stair on the blue box, so once she is sitting she can balance herself with that stair. Once they sit they are old, they come quick, they are losing the bladder, so now when it's going there, and it's already out. She cannot always wipe, she might close it without ash.

If there was a supporter or a balance, it would be better.

Is there ever poop on the floor with the older people?

Not on the floor. But once they sit, they will make sure they have entered that whatever (hole), but it might not be balanced. Some might fall inside and others here, at the step of the urine, if you are not there quick there is a smell in the household.

Do you think hands or surfaces are important when your children use the toilets- do they hands transfer poop?

Once you use it nicely, there is no problem with the flies, and you have also shown them how to wash their hands after using, so no risk of getting it.

How often do you, and your family get diarrhoea, is it frequent?

No, I do not find it here, it might be that you have eaten a lot of fat, but we do not have it.

Do you think diarrhoea is a severe diseases or risk for your family?

It is a very big stress… it can kill. I had another child. Today she would be in class 8 if she was alive today. I had to take her to nursery every morning and there was a lot of mishandling of the children. So there was not a good place where I would have to drop have dropped my child. So I used to drop her there, and the place was dirty, and the lady did not know how to feed the children. So the child started diarrhoea. When I took her to hospital she had gotten pneumonia because the place was also very cold. Most of the places here, the nursery schools, do not know how to take care of the children. There is a lot of death for the children in the nursery schools here. Once you go round. So my child got diarrhoea. At the hospital they told me she had eaten dirty food and whatever. And she also had pneumonia because of the cold. But I suffered, I had to stay in the ward with child - later on she died out of diarrhoea. She diarrhoea, she diarrhoeal, we put water, but by then she did not make it. So I really fear diarrhoea. Even these ones every time, I usually tell them every time, before they eat fruit, every time. I do not like the diarrhoea.

Do you feel like you are well informed about the diarrhoea and how you prevent ad get it?

You know most of the time, diarrhoea comes out of dirtiness, it might be cholera, some stagnant water, where insects are coming from, even the latrine, the flies at the latrine, and the foods the children are eating.

Where did you receive your knowledge about diarrhoea?

I have worked for 17 years as a community health worker.

Within the community how frequent a diseases is diarrhoea?

It is very normal here, and a very major one. And especially the young children, they really suffer. Once the women delivery after 3 months, they work back at the flower farms they leave the children at the nursery, those day cares are dirty people don't care. The children end up with diarrhoea, most of them end up with diarrhoeal and dying.

How severe do you think the community thinks diarrhoea is?

I think 'they doesn't care even, others doesn't know the effect of diarrhoea, you might see the child is sick, and then you might see the place you are taking the child is very dirty. But some of think it is curse or witches, they don't believe it is dirtiness... So they need a lot of awareness.

Do you think they are concerned of other diseases?

Yes the Salaries are very low, so feeding of the children, the children are feeding with porridge with black tea, and not a balanced diet. Most of the children they are good looking but not healthy.

In the community in terms of h/w, is it widely practiced?

A great improvement, since I remember the staff of the blue box last year and we had a training with them about the hygiene and whatever. So people are coming in this community, and since I have about 8 chammas… We discuss what is in the community, they showed us how to wash their hands, so we started them showing how we wash their hands. Some people have improved.

Any problems with access to water/soap?

Right now we have water. Now whatever, let me say diarrhoea or typhoid, because typhoid is very high in this place. Even my children, I took them to the hospital. Two of my children had typhoid. Typhoid is very high here, but it is from the water.

Yeah, the water we get is salty, and does not have the chlorine, so when the children drink direct, they get sick. And not everyone can buy the waterguard. So for myself I just put it, and not everyone can buy the waterguard. They just drink it like that and typhoid is very high here. But this water, if you start drinking it, you will get sick. And many people here cannot boil the water. In a single house, they cannot buy the charcoal, one small bag of charcoal. And might be wanting to cook with it for three days.

And once you educate them about boiling the water, they tell you where I would get the charcoal to boil the water. Let them drink even the rest are drinking. But it is very risky. To drink from the tap. The doctor said I must boil the water or put waterguard.

Thanks.

End///

Appendix 8: Interview Transcripts B

Transcript 1 20th April 2017

The first question is about the type of toilet your using and how long you've been using it for

I started using it in January 2014 I had come to London by boat the previous Oct. Been on a mooring and when I came to be moving and on the tow path I found I was more concerned about the um where I am going to empty the loo than any other the other complicated issues like finding a mooring or security

so I started investigating it and there was not group then to talk to, I was just on my own, found some of the commercial like airhead and things and I was quite reluctant to spend that amount of money without knowing whether it was going to work or not.

So I did a lot of reading of humanure by Jenkins and one of the things I realised that although all of the systems around seemed to be about separating – I found the um airhead and um and the separett and I think the good loo at that time, martin was making his version, um, reading humanure, because his is an all in one system was that separating wasn't the be all and end it is a convenient way to managing the bulk because if you have an all one you need a lot of sawdust and a big compost heaps, so I thought the world won't end if some wee gets in with poo. In fact it might even help!

So you did a lot of research?

Yes I did a lot of research.

How long did you spend, when you first looked into it?

Probably About six weeks. *I read humanure all the way through about 3 times, um I thought*

Did you know anyone with a toilet?

Oh I had met one boat a year to two before who had a rather bulky environment which they swore by, but they weren't live aboard, but extensive travelling, so would last 6 weeks of cruising, and then they would leave it and when they came back it was ready to empty.

So you didn't know anyone

But at that stage they wasn't anybody doing anything much, it was only once Colin started a group there was more interest in it.

Ok so you want to know my system.

Very simple, my shower is quite deep, so I thought I can perch on the edge of that. So I bought myself from a hydroponics supplier out in Tottenham, I bought 3 x 25 l buckets and 1 x 10l buckets

The 25 l bucket I placed them in the shower, with a layer off... one of the my early mistakes was that I used that stuff they use in parks quite rough chippings, - because I thought that would be good, that would have more oxygen, more airspaces.

And that was at the base of the containers? Yes

Um that was a mistake, I realised what you need at the bottom is a really absorbent sponge layer, then perhaps some chipping for air, but actually it was a mistake to have those, the fist bucket was far too wet

What was the problem with it being too wet?

Well my thing was that it didn't matter, and I was right, it didn't; matter if I had some mixed wee but what you do need is enough cover to properly soak it up. I hadn't you know…And until u have used it for a little while.

Why was it being wet, was it that a problem to latter compost, what was the problem?

Oh well, what happened because it was a bit too wet, once it was full and I was composting it was too soggy and I realised that one day I have a little hand fork and I was forking it over and so what I did was I got more cover and I made a nice layer in a second bucket and I tipped the first bucket into it. But yeah it took me a while, I had to work quite hard with the first bucket to get enough material to cover to get it sort

So it will sit there and do nothing?

Well it was just a bit to soggy, then of course what you'll get is anaerobic breakdown instead of aerobic. Um, I get a feeling that is quite a common problem the first time round. People haven't quite got used to it, if they've got a separator they get a bit of spillage over the back of it you know, I think it does take a little while.

So the composting, once you've taken it out- what do you do with the container once it is full?

Well now of course: I work it over regularly while it is in use, I have one of those spiral dog walking things that Tony Sulman popularised, I looked for ages for a suitable compost turner, but of course they are all *built for very big compost piles, not for 25 l buckets, um so, now I work it over regularly while it is in situ, because, um it starts the composting off*

Ok

And I realised one thing that is it's a lot easier to breakdown poo and mix it up with the cover composting with your cover while it is still soft, once it has sat there, the moisture starts to be pulled out of it by the cover and it all goes a bit hard

How long does it take you, one person to fill that?

Well another reason I found for working it over is that it shrinks the bulk, interestingly , I tend to leave it until it is half full, otherwise you have nothing to work on really, but once it is about 2/3 full and give it give a going over and it will go down to half. And I do it regularly. That bucket, that is in there at the moment, which is full, I keep thinking its full and then using it again, has been on the go since the middle of Nov, and it is now middle of April.

Wow so nearly 4 months

Yeah, I mean generally, I was saying 8-10 weeks but I mean, admittedly some of the time I am out at work and going away, but you could probably take, it definitely done 10 weeks.

How often do you use it? Every day?

Yeah, I would say. I do and have the high fibre diet.

Wow so that is amazing

Yeah well I think it because I am working it down

So you have a 25 l container for the poo. And for the 10l …?

For the wee and an old mixing jug that I use to separate when I having a poo.

And how often are you emptying that?

Here on a mooring with a sluice, about 15 feet away, I do it about every 3 days. My crucial thing when it comes to drying the bucket. I find that if you rinse it out and dry it doesn't smell. Out on the towpath and cruising, I will empty it out every night before I go to bed. I will get a jug and I will add canal water, dilute it and water a tree, give it a good rinse and leave it to dry over night

And this smell, is it a problem to you?

Well if it get smelly, it is mildly unpleasant, so I empty and wash it, and dry it. What you do find, is you do get, one of the reasons I have stuck with my bucket is that you do get some scale after a while.

Right yeah

And so err from time to time, try to do it once a week, but in reality it doesn't really happen, if I am cruising, for example, when I am near an Elsan point, then I might use something a bit more ferocious in the cleaning line, that I wouldn't tip in the canal. Generally I try to be eco about it I probably do that about once a quarter, the descaler you use for kettles

Yee, that's interesting

Yes you do get scale up. Yes that's one of the issues that scale ups the urine diverters

When you are using the urine diverter, or the bucket, do you get spillages of urine?

No never. It's a very wide bucket, roughly the same size as my bottom, so I can pee directly into it. That's one of things that makes it so simple really

Ok great

When you're turning the waste – the contents of the solid the poo, are there any time that you have contacted you're of when you're doing that?

Not really, there's a handle on the top and but you know yes, as you move it around, you might get a bit, but I always wash my hands thoroughly afterwards

Ok- and you have a sink, soap, water on the toilet

Yes

Any other challenges that arrive when you're emptying

It's best done regular, I try not to do leave it more than a couple of days. It's a fairly sturdy bucket but it starts to feel a bit fragile, if it gets to nearly 10 (l) it is actually quite heavy starts to feel quite heavy and I have lost the lid

Ok

If I could find the lid, then I could clip the lid on to take it, but I 'm always a bit conscious that I might spill some when I am with that. And well the other one, it depends obviously. Generally I was saying It weighs only about 18kg when I come to empty it, but now I am doing this and the bucket is lasting longer, I think it is more, so yeah, when it comes to empty that it will probably be 20-22kg down to that

It probably be 22kg, but generally I only need to take it from the bathroom there, to the bank thought he side hatch. So the weight of that could be a thing, I think when I have a more permanent one built, I will probably go for smaller buckets. That seemed quite important when I started a biggish bucket so it would last – now I realise that its more about the whole system, it's the whole system capacity, not the bucket that is in the bathroom.

Yea

Yea I got three 25 l buckets, so if I had a 15 l one in the bathroom, by the time I emptied that into one of the 25 and that broke down, It's about the capacity of the whole lot, not just about what you have in the bathroom

Could you get a 100 50 l bucket for the secondary composting?

If I have somewhere to put it yes

So it is space

Yea, 25l I put one in the engine room and one under the bough one if necessary on the roof without anyone particularly noticing. Tends to be warmer, that's doing secondary, one up on the cratch at front, at one of the roof. I have wondered about all sorts of other kinds, possibly a 40l square one

And do you just take the whole container and swop it over?

Yes, I never empty a container into anything else. The only time I had to do that was the first time when it was a bit soggy and I had to sort of tip it over, mix it in and tip it back again but generally speaking no. It goes in the bathroom, I fill it up

So before you remove that one you have to empty a composting one?

How do you use the compost?

Well I aim for about a year, but I have eight months, it tends to be well broken down and nothing recognisable and I take it down to a friend's garden I can put it in. One of the temporary moorings I've used there is an area of garden I've used – dug under a tree.

Not put on pots on-board?

No, but that's not because don't want to use it or think it is dangerous, it because long ago gave up trying to grow anything. I quite like gardening.

Have you thought about fuel bricks?

No, that one I haven't

Any reason?

Mostly I hadn't thought about, hadn't come across it really. I don't know much about it. I could be inserted in it. I think generally I feel it should be going back to the soil. That seems to be the right motivation for it. If you're talking about a full cycle, it makes more sense to me that it goes back and nourishes the soil.

Yea, but if it could replace a fuel brick- you use a soil fuel?

Yes to some extent – if it was replacing fossil fuels, there would be element of sense. The other thing about that is that is my circumstances at the moment that would be problematic here because it is a smokeless zone and we have quite sensitive neighbours, it is very built up around this basin, and it very noticeable since they did the last bit of building, which is the school at the end which means, there is no longer a decent flow of air around the basin, they are more complaints. So we have to be careful about what we burn.

Are there any smokeless fuel?

Yes, even those you have to be a little careful about which you use, while they are all smokeless, some are more fumes, than others so that is quite a sensitive one.

But in terms of various options, the more options the better really, because, there is quite a lot of variety amongst boaters, how many people on the boat, how often, what they're circumstances are for composting, processing and the size of the boat and me. Two of you on a 45 ft. boat is a bit different, is different yea

Coming back to the idea of it being a system- any improvements or things that you think (if you were going to design) to make things easier what would be top three improvement?

I think In terms of containers, the 25 has been very good for me, means I can compost all the way through, and in terms of sitting in the shower it is the right size. I think going for a err, something that looks more like a toilet, I might go for a smaller container, I might have

Is it easy to pick up and handle?

The 25 l heavy, is quite heavy but I only do it once every 3 months. I think if starting from scratch, - Ident like a lot of clutter on my roof, I like to stand at the back of my roof and see where I am going. I don't want too much on the roof. But I do have ladder, - I have looked 40l square boxes, which I think might be better- 15 l in the loo, 25l in the engine room, first stage where nice and warm and then something on the roof to finish it off. But in a way that's one of things I like about the whole things and why I am forever banging on about systems, is it gives you quite a lot of flexibility in terms of how you do it. You don't carry big weights then have little buckets in the loo, for some people it works well to have bigger buckets, square ones or round ones.

Cleaning maintenance and units itself?

Well, I haven't really got a unit, when I am emptying the bucket or having a shower, I give the shower a clean,

Ok

I do now keep the bucket, one difference is now, and I use to have the 25 l bucket sitting there. And ow I have the bucket sitting on a folded towel. Because I realised that it was sitting on a towel, the showers is plastic, it spreads the weight and also

What is the towel for?

Well and also, even though I don't really get any spillages, um, just a black plastic bucket sitting on a white plastic shower will mark it.

Ok cosmetic,

Does it mop up potential spillages?

Well it is quite difficult to spill anything, it is a 10l bucket with a diameter of 12-14 Inc. – I don't have to work hard to aim into it, it would be difficult to miss, If I did miss it would land. Well actually it probably has happened once or twice, I dash in there, in a bit of a hurry, with the angle. Yeah, all that happens then is a bit of wee ends up on the lid of the solid buckets – I'd have to be absolutely busting to get to do more than you know, so yea, so once or twice I have found vie managed to get ever so slightly …

Do you get any condensation or, from the containers

A little bit, not on the bathroom, on the lid of the solids containers, I do get a bit, but I don't seal it. But the lid sits on it to provide a surface for the 12 litre one but um, it only sits loose, another device I used before the sulminator, I would simply put, because the hydroponics buckets the lids seals, what I used to do at one point, before the screw thing, I would fit the lid on really tightly turn the whole thing upside down and leave the whole thing upside down for 24hrs, 48 hrs until I got round to it and then I would roll it, so that is quite good thing, if you don't want to touch it thing

With the sulminator- do you keep it in the bucket?

Well I do remove it because I only have the one- but as soon as I come across a pet shop I'm going to buy another one.

Ok – why do you want multiple ones?

So one can sit in there and one can sit in the engine room. It's just easier than taking them out and err… yeah if I am going to take it to another one then I'm probably going to put gloves on, and get tissue roll and clean it off and take because I don't want to really carry it through the boat, potentially dripping bits of compost. Um, so I just quite like the idea of one in the engine room that's second and one in the bathroom which is first stage and when its last stage it gets left to its own devices, and if I did want to turn them over, that's all outside, I could just line them outside and you know do the mixing, it's really having one in the bathroom and having one outside that is important.

Transcript 2 - 05/04/2017

Information about the research so it will be used, I will transcribe it and analyse the content, regarding some of the issues we shall talk about, so if you can say you're happy for the information to be sued and you consent.

I am happy for you to use this information and I consent.

E: So just some background when did you first get this compost toilet you have here and how many people are using?

M: *Do you mean how long have you been composting or how long have you been using this one?*

E: Yeah well how long since you started?

M: well, this is our third iteration

F: *We started with morning star and that was about 2013 thereabouts, we have had gaps since then where we weren't composting*

M: *yeah there has been points where we shifted to a cassette = back and forth and changing but probably 3 years, but it was when we moved onto this boat we have been composting mostly, so that's about 2.5 years.*

E: How did you first come across using the compost toilet?

F: *When I first moved onto a boat and was researching I came across the toilet – Wasn't really familiar with the idea of compost toilets, but moving onto the boat for the first time made me realise that this might be an option for me and at the time I didn't have – nothing like that on the boat, so I had to create a rudimentary compost toilet*

E: So what kind of toilet was on the boat?

F: *there was a cassette in very small wet room, so I had to rip about the sink and remove the cassette, just about had room to make a box with a seat and a bucket, and that was when we were bagging and binning, was not really equipped to compost and we were disposing of urine in Elsan points but it was still preferable to cassettes*,

E: So how was it better when you changed?

F: *For me less smelly, easier to carry- a cassette toilet can weight 20kg plus, with separated waste I wouldn't have to carry more than a 10l bottle of urine at any time and more manageable in that sense – I didn't have to rely on getting Elsan chemicals to*

M: *Yeah we weren't adding horrible chemicals into the system, cassettes are just disgusting, essentially they smell really bad, and whenever you open it the smell fills the room that you're in.*

E: They smell worse? What do they smell like?

M: *Like sewers*

F: *sulphur rot*

M: *sulphur – yeah the chemical you add doesn't really do a lot for the smell and if you add more eco-friendly chemicals it doesn't do a lot for the smell, it's basically gases sitting inside a chamber, and then when you open it comes up*

E: so before you had a compost toilet, how familiar with the managing toilet waste? Emptying and so forth?

F: *I'd had it for about a year, and that meant emptying about every 2 weeks at the time.*

E: How did you empty?

F: *So either by boat or by trolley to an Elsan point and it's quite a grimy job emptying an Elsan point, in that the contents of the tank might have tissue, or all sorts, so sometimes it doesn't empty out very easily and then you have to rinse it out to get out any residues that would make the smell worse*

M: *the Elsan points themselves are not well managed – other users do not clean up after themselves, so you might start by cleaning up someone else's mess and it's not a very pleasant experience, and some of them are inside so the smells don't come out, your just in small room and no lights,*

F: *or they might not have a flush, so they smell will still be there.*

E: do you still use Elsan points now?

F: *If we are moored in town – somewhere without a lot of green space then we would empty our urine in an Elsan point. Just because there is nowhere else polite to empty 10-40l of urine in the city, so we will still use an Elsan point just in those situations.*

E: and do you have to pay a fee?

F: *no, it's part of your licence*

M: *there's not that many of them, we're kind of fortunate that in urban environments there is quite a lot of them , but when you get out of London there are very few of them, but then there are lots of green spaces where people don't go walking and you can dispose of it there.*

E: do you dilute the urine before you dispose of it?

M: *it's kind of diluted a little bit just by cleaning, but*

F: *possible we will do it on a rainy day*

E: so where is the closest Elsan point to here?

F: *oh it's really close –*

M: *10minute walk – Victoria Park*

E: and here we are surrounded by quite a lot of green space – would you just dispose of it here?

M: *probably wouldn't do it here, it's a green space, but it is a well-used green space. I'm careful about this ammonia smell, although it is quite short lived, its' not necessarily pleasant for people who are just going walking, and it doesn't necessarily also look very good, its looks like your disposing of a horrible chemical. You have a container, and you're just emptying it, that would potentially look like chemical dumping to some people*

E: I see

F: *Somewhere a bit wild, or less managed, a bit less busy, I'd be absolutely fine to dispose of urine in the tens of litres. Somewhere in the town, a busy park, I'm not quite as comfortable to empty it, environmentally I don't think it does any harm, but socially, I don't think it does any favours for our reputation.*

E: Have you seen other people emptying it like you describe?

M: *Other people we talk to don't do it like we do it, we basically fill up to capacity and then empty it whereas they will everyday take what they have on board and pour it.*

E: do you think they do it in a les restricted way?

M: *Definitely, they'll probably just go over there and pour it, I don't know, what've talked to people*.

E: How do other boaters see that behaviours?

M: *I don't think they have a problem with it, most boaters, male boaters won't pee on board, in their boat, and they will go on the tow path.*

F: *some people pee in their sink.*

M: *into the canal, the thing with the cassette, if you use a cassette and open it to have a piss, your boat will just stink of shit basically,*

F: *and it will fill up quicker, and they will have to empty it more, so people like to avoid weeing into anything with a limited amount capacity, they will happily wee outside and some people will pour there wee into the water*.

E: Do you think the community around, if they saw doing that how would you feel?

M: *Not with boaters- general people they won't know its piss but I worry they think we are fly tipping chemical waste,*

F: or *that they think it's disgusting and they will be less happy with having boaters around.*

E: so the way you manage it do you think that the best way?

M: *it's not the best*,

F: *its suits us*

M: *I prefer it to pouring it down the Elsan, because that has to clean. When I pour it into the forest, I know those nutrients are going to be used and there isn't like a big infrastructure to clean it. And less impact, I'm kind of aware it doesn't scale up very well, you can't have everyone doing it. But in the meantime, I feel like it is the best way for us.*

E: So it is convenient.

M: *I mean I have no problem, I have a bike trailer and would take the liquids to an Elsan, here I pop it in the trailer, cycle there , clean it and wash it and bring it back,*

E: So have you done that in the last couple of days?

M: *We haven't had to empty since we moved*

F: *When we moved*.

M: It *was when we mobbed- Monday,*

E: So where did you empty it then?

M: *That was near the east way,*

F: *Into Wick woods,*

E: So a natural environment

M: *Although this one, I did it, it was a bit of an unusual one, I wouldn't have normally done it, because we were feeling up with water, so I took them, it was near Here East, between Here East and Eastway, there was a plant garden a manmade plant bed, quite large, like maybe 4-5 times the size of this boat and I went round the back of it and poured them out into the wood chips there.*

E: And do you feel stealth when you do it!?

M: *I mean, I have got better at not worrying too much*

E: How did you feel originally, has it taken a while?

M: *I think each time I care less, one time in Broxbourne, I looked up and there was a rail track worker, just standing there, right next to me, I was just like hello. I thought I completely on my own, and a man in bright orange jump suit it standing there, smiling at me.*

F: *It's quite self-conscious, it's not something I want to be seen doing.*

M: *Yeah, we generally try not to do it during the day or kind of aware it is a little but embarrassing, and not also very nice for other people*

F: *Because of the smell.*

M: *Yes ha and they don't know what it is. If they smell it they know what it is*

F: *It's gone in a few hours*

M: *and also the smell depend on how long you have held onto it. The newest ones don't really smell at all, but the oldest ones smell.*

M: *we were having you fill up 4, but now we fill up 3 – what Kate was saying, she lets them dry out, we never let them dry out, we never let them dry out, so now we let them dry out, and any bacteria can reduce.*

E: So that's your urine system – and so can you tell me about the poo system?

M: *so it is the separett. A bin inside it, lined with a bag, heavy duty bag, when that get full that gets cover material added to it, a variety of coffee grinds that are dried out, cocoa coir, and sawdust. We tried bran*

E: how did you find that?

M; *if it got added to anything damp, it was very quick to grow fungi, but we don't know if that was the bran or just like damp coffee grinds. Ones that hasn't fully dried out. But we couldn't find its carbon content. But we haven't found out*. *so that's gets added, and when that gets full.*

E; do you ever have a problem with not getting any?

M: *Well we drink enough coffee that there is always at least coffee grinds. And we – I go into a hydroponics shop and get a bag of coco coir and that will 6 months at least, it's been about a year since I got that other one*

F: *plus there is about that sells groceries that's sells fairly cheap wood shavings that are a by-product from heat logs. SO even if I don't have access to a pet shop, I can still get some wood shavings.*

M: *Yeah the worst if you run out you just go to a pet shop and get some sawdust. Never been that much of a problem, so that goes into the engine bay, so when there is a 3 of those bags, they go in a bin, insulated inside a larger bin. Which has a lid that sits next to engine. So the idea is when the engine is running that heat is used um, when that is full- it use to go into 25l coal bags, but these boxes, are the first version of two that is a nicer looking version of that, that raises the solar panels of the metal work to make use of that space. It wasn't the nicest looking thing having these bags- no-one thought it was compost, part of it was thought it was coal- if someone tried to steal your coal they would get a bit of a shock- bags of old poo*

E: Who was doing the manual, work, transferring.

M: *Sharing it*

Flo: *I'd do half or more of transferring it from the toilet to the engine space but I did find it quite heavy to take it from the engine to the roof, so max tended to do all that. I find that too much.*

E: How do you feel about the handling of poo?

M: *Not a problem with it. Initially,*

F: *We rarely come into direct contact with it.*

M: *Its only really, compared to some of the nasty shit that happened with cassette toilets, it is so easy and not that gross and very quickly changes states to be almost unrecognisable. It is quite easy in my head to just switch off and be like it's not shit, its jus already, its breakdown and has a different smell. It's quite easy to think it's just a material.*

E: Do you think that has changed as you got more experienced doing it?

M: *Yeah, I certainly got a lot better, it's a bit like going to the dentist, nope, and I'll go to my happy place.*

F: *Also the contact is quite minimal, we are mostly transferring the contents of one container into another container maybe a bit of stirring, we are having to get that close up, until it is already quite well rotted so in the first few stages, it really is just transferring the contents from one container to another. Bit the time it has reached about 3 months, we have maybe handled it twice, it is much less unpleasant to look at and doesn't smell bad. Stirring it by that stage isn't really too unpleasant.*

E: I see, so similar to what you were saying about the urine, not wanting to do it in front of other people how do think boaters perceive how you do ?

M: *Most other boaters, seem to have an idea that compost toilets are … everyone hates cassette toilets. It's gross and pump outs take up loads of space, the facilities don't work most of the time and just eat up all your money – and they leak, they don't really like them. And compost toilets are like this mythical thing that are supposedly amazing, they generally seem to be interested in it and ask to have a look at mine.*

F: *There is a bit of curiosity. They seem to be viewed fairly positively. I think a non-boater would have no idea what we were doing?*

M: *Oh yeah totally, I've had conversations while I am doing it, and I say it is compost like food waste. They see me jump of the boat, go grab some leaves and grind it, and make it diverse as possible. And they will be like are what are you doing. Like in Springfield Park the amount of Jewish orthodox talking to me while I am doing it and they have absolutely no idea what I am doing. They just chit chat. I just say I am composting… What I don't want to say is I have a big old spade that is covered in my shit, that's what I'm doing. I don't want to have to deal with that.*

E: so you mentioned about the comparison about what you were suing before – do you feel this is a safer way to be handling it.

M: I *dunno about safety, I'm not really concerned too much about the safety elements of composting. I think … The cross over between not wanting to get shit on my hands and the safety elements seem pretty close, just. It's generally just good hygiene. Generally I would wear disposal gloves while doing a big job. Like when I did a big transfer I recently emptied that toilet, changed everything over to that bin filled up the whole thing that was done with disposal gloves, I knew I was going to wash myself afterwards and I knew stuff would get onto my clothes just by doing it, but I knew I wasn't going to wear those clothes out afterwards, those were dirty clothes and were going to go into a washing basket.*

F: *I don't feel particularly safe hygiene wise when emptying a cassette at an Elsan point. If you had seen the Elsan points at Tottenham hale, so Cambridge lock, I mean that's so discussing, and it's really hard to avoid touching any surfaces, I would feel as unsafe handling that* as *I would any our own waste*

M: *Yeah the hygiene levels are so poor in Elsan points*

F: *I do some wonder:*

E: How much do you know about the potential; do you consider there is a risk.

F: *I think it is mostly contact based, and the things we touch, we can use gloves as a barrier or we can wash our hands to minimise those risks. I sometimes wonder about the risks from moulds, we could stir up into the air, that we could breathe in, but that's more than about not knowing than an actually perceiving a problem*

M: *Yeah the risk, like we are growing plants out of that stuff, and some of those plants are food, courgettes, and I'm not really concerned about that.*

F: *Yeah we don't really use the humanure on the surface of the pots, so I don't think there is a risk that the food we grow ourselves is touching the humanure, and the humanure is already very well-rotted, it would almost be a year old by that point. Um*

M: *the statistically chances – I don't know what it is – but a pathogen surviving that whole process – I think they kind of deserve to do me in, if they manage to do that they are insanely hardy – I don't see how they make it through my guts, through that whole process, through the growing process and back to me into me. I probably just wash the vegetables.*

M: *I'm not worried 0 I might give the courgette an extra risks than I might do normally.*

E: If you were sick – would you take any other precautions?

M: *Since using a compost toilet, before you put the covering on, you see what you have done, you have become more familiar. I have had real problems, I've become much more aware of the stool chart – the Bristol stool chart – with flo being a dietician.*

E: well 6-7 is diarrhoea isn't it – I'm often on a six! How often would you consider it being six?

F: *Well I'm an IBS sufferer, and I was long before I used a compost toilet, I don't think my IBS is anyone worse since using the compost toilet and I don't see what it should be?*

E: Do you handle the contents differently since when you had a bout?

F: *Because it's IBS I don't consider it to be infective, all that means I add extra cover material, adjust for the moisture. I don't consider it to be infective, I've never had diarrhoea in the time I was using the compost, toilet, of course, I can't be 100% certain it wasn't infective, but I didn't believe it was, so all I've ever done is compensate with dry matter.*

M: *The only diarrhoea I've had is over indulgence- like I ate a load of cheese – and drank a few nights before, and there you, and take a probiotic to rebalance things*.

M: *Well the health concerns, I am aware usually after the act I've just don't that job and realised I have cuts on my hands., but the health side of it has never really bothered me.*

F*: But maybe we could get sick and then we would have to change our practices*.

M: *Yeah*

F: *I'm not sure what I would do differently. If I had a stomach bug I haven't thought about how I would process it differently, but I suppose I would need to keep it separate – give it more time, maybe try an encourage a higher temperature, but I might also not bother*.

M: *Also it's like, you've got the plastic bags, there dry on the outside, you tie them up and put them in the engine bay, there's three of them and especially now we've got the roof we pour it in with a spade, take each bag turn it upside down an empty it out. And then that bag gets thrown away. There is not point that you handle it. There might be some spillage, but or onto your arm, and it while you're doing it make sure you don't touch other things, use elbows not to touch other, things and then take of my disposal gloves, wash my arms and then you know I always assume that the clothes have had things on them and I will check them over, if they look ok I'll keep on wearing them, but if they have stuff on them I'll take them of* *put them into to be washed. So it's doesn't seem like swimming about it. Just general hygiene covers most safety.*

E: Well you've clearly got a high awareness of safety

F: *Well your workshop made me think about it more. And made me aware, previously it was like just don't get it on me, but was lot of cross over, but then after the workshop, thinking about what are the safety implications and became a bit more aware of it. It's not like oh I don't want it to get on me, it more like I want to make sure I'm not getting something and touching something else, and then later putting that on to my face.*

E: Do you think your assessment will change with a baby?

F: *It might yeah, um, I can't make the same assumptions that the baby will be as resilient the baby probably won't empty the toilet! I mean that said, I don't; expect the baby to make any contact with the toilet until it is potty trained, by which point, it will have a bit of a stronger metabolism*.

M: *I'm of the belief that children should be dirty.*

Thanks. End//

Transcript 3 CS 2: 15th April 2017

I just have to need to explain the contents of the research and then if you can confirm verbally if you happy to give your information and for me to use it in my research. I'm just having a chat with you and then transcribing the data. So if you happy with that

Yes

E: So first, tell me a bit about your system – when you first got your toilet

J: *I first started using waterless toilet systems when I grew up in the Far East ok so I just have had masses of years – I'm now in my late fifties – composting and now working*. *So yeah I've tried everything from long drops to compost bins to small bins and compost system. I was head gardener at a place where we just used humanure for that and added pig manure and cow manure growing food.So for personal use on the boat*

E: So yeah you have a lot of experience

Thinking back to when you installed it on your boat? How long ago was that?

J: *The first one I ever used was in 1983/84*

E: And can you remember how it.

J: *A separator system. Urine goes direct onto the flower bed, no treatment and everyone remarks how many flower we can grow on the beds, oh that's very strange and the solids go into a compost bin which that gets composted down and used in different places*

E: Into details on those processes – thinking back to the last time you emptied the container - typical day can you describe these emptying?

J: *Yeah it's a very easy system, I've got a lid, take the lid off, take the bin, um, mulch it round and put it in the compost bin, and either put some green compost or straw on top of it. It's not complicated*

E; It not know- what you're wearing?

J: *What now: I don't have many clothes. Not wearing any gloves*

E: Are you wearing any protective things like gloves:

J: *No*

E: Are you taking precautions to avoid contacting the waste?

No, it's just my wife and me and she is just as filthy as. I am so that's fine. Interestingly she is involved in health and social care so she has a much bigger interest in social health and well-being as it were. The only thing we do, is make sure are hands are thoroughly cleaned afterwards

E: right ok – so you do that with soap, so how do you do that

J: *well depending on where I am what I am going to do next, it's either with one of those dry cleansers, or a tea tree based soap, a natural soap*

E: and why you use dry cloth

J: *oh it's not a dry cloth it like an anti-bacterial gel*

Oh like a sanitiser:

J: *Yes*

E: Where do the contents go, after you have emptied?

J: *just go into an ordinary compost bin and onto the garden*

E: are there any challenges with the season, is there any challenges

J: *in the winter it's a bit slower, but it soon starts to pick up again*

What would you describe about anything more to say? Anything difficult that you find

J: *Nothing. Just practise: what we find with people used to a flushing toilet is that it's just a psychological thing, to get this idea over using gallons and gallons of water to wash away your own waste*. *That is so inbred in people and that's what we have to do and that's the healthy thing. Until you start looking at what's around the toilet bowl and the top of it*

E: so do you now look at another

J: *yes in Britain I think there is more health issues with people with these flush toilets I think because if you're running a compost system your running a clean natural system so as long as you keep your hands clean,. You contact you don't put your hands on your mouth, and you don't scratch your nose while you're doing it*

E; where did you pick this up this information- how much has your knowledge changed?

J: *how much has my knowledge changed?*

E: Can you think back to how you were managing it 20 years ago?>

J: *yeah not really, sounds a bit arrogant but I spend most of my time telling other people how to do it and building compost toilets for projects so it's not a big issue. I think out in the far east, people did it straight into paddy fields, and I remember the issue – I remember as a child not having any toilet paper, that was a shock having toilet paper, um, we just burn that – yeah so we burn the toilet paper, we run a gas free boat so our stove is always on, which is purely fed on wood. So yeah that's one things and then obviously I grew up in a monastery with an earth closet, so washing and defecation was a part of the thing.*

J: *It's very rare to – with compost toilets there's never been a D and V situation*. *If you're using a compost toilet and not being careful, and not washing hands – could lead to D and V, but in all my experience I've not had an incident of that, and I've never been witness to that*

I think that's down to discipline of washing your hands

J: *In a big community where I was a gardener we had two of turning twice a month, sometime people didn't want to do that, if we had a group in, we doing a teaching, because we didn't know what they were eating we would use rubber gloves to empty to remove the waste from the dustbin,*

E: do you take special considerations if you're unsure of where it has come from?

J: *Sure*

E: Do you think handling your own waste to others?

Yes

E: If you know you're sick?

J: *It doesn't really occur*. *We went to remove the dustbin from would use rubber gloves to remove it. The poo was done in the dustbin, we had it in the dustbin, so when we removed the dustbin from the building we would take it out with rubber gloves and empty it with rubber gloves and use rubber gloves to dig it up – we also had a compost system with a settlement tank*

Appendix 9: User Interface Sanitary Survey Format

	Sanitary Survey at the User Interface				
	Use a Single Sheet per HH				
	Unit number:				
	NAME OF ENUMERATOR				
	TIME AND DATE OF SURVEY				
	NOTE WEATHER				
	LAST RAIN EVENT				
A: Installation Information					
	1	Number of toilet units		__	Number
	2	What % of users are adults?		__	Number
	3	What % of users are children < 5?		__	Number
	4	Type of Walling (surrounding the toilet unit)	A	__	Concrete
			B	__	Plastic (PVC)
			C	__	Aluminum (APC)
			D	__	Corrugated sheet
			B	__	Bricks
			E	__	Other
	5	Type of Roofing (installed on the toilet unit)	A	__	Corrugated sheet (aluminum)
			B	__	Corrugated sheet (iron)
			C	__	Tiled (ceramic)
			D	__	Plastic (PVC)
			E	__	None
	6	Type of Flooring (inside the toilet unit)	A	__	Earth/Mud/Bare
			B	__	Concrete
			C	__	Tiled
			D	__	Plastic (PVC)
			E	__	Other
B: Environmental Risk Factors					
	7	Has the community reported any outbreaks/cases of diarrheal diseases	A	□	High
			B	□	Medium
			C	□	Low
			D	□	Unknown
	8	Are there highly vulnerable individuals served by the toilet units (tick those that apply)	A	□	Pregnant women
			B	□	Children <5
			C	□	Elderly > 60
			D	□	People living with HIV/disabilities
			E	□	Unknown
	9	Is the area in a flood risk / prone to flooding?	A	□	Frequently floods
			B	□	Sometimes floods
			C	□	Rarely / never floods
			D	□	Unknown
C: System Performance					

	10	Is there access to a hand washing facility for handwashing after defecation around the toilet?	A	□	No handwashing facility is available
			B	□	Handwashing available in the toilet
			C	□	Handwashing available in the household
			D	□	Handwashing available outside the toilet
			E	□	Not possible to observe/Unknown
	11	Is there soap or liquid soap available to users for handwashing after defecation around the toilet?	A	□	Yes soap is observed
			B	□	Yes soap is not observed but is reported to be available
			C	□	No soap is observed or reported to be available
			D	□	Not possible to observe/Unknown
	12	Do people practice handwashing after going to the toilet?	A	□	Yes
			B	□	No
			C	□	Not known
	12	Is handwashing observed or reported?	A	□	Observed
			B	□	Reported
			C	□	Not known
	13	Distance to the nearest water point from the toilet?		___	meters
	14	Are anal cleansing materials available for use after defecation (check bin for evidence of use)	A	□	None present
			B	□	Water observed
			C	□	Toilet paper observed
			D	□	Not possible to observe
	15	Cover material available for use after defecation (Sawdust, ash, coconut coir, etc.)	A	□	Plenty next to the toilet
			B	□	A small amount, close to toilet
			C	□	None observed
	16	What is the physical condition of the unit: sides and surfaces of toilet	A	□	Deteriorated: Cracks, corrosion, holes (water tightness compromised)
			B	□	Fair condition: A few minor cracks, scuffs, other marks on surfaces
			C	□	Brand new: Toilet appears in good physical condition
			D	□	Not possible to observe
	17	What is the physical condition of the lids, seats, sealing mechanism of the toilet	A	□	Deteriorated: Cracks, corrosion, holes (airtightness compromised)
			B	□	Fair condition: A few minor cracks, scuffs, other marks on surfaces
			C	□	Brand new: Toilet appears in good physical condition
			D	□	Not possible to observe
	18		A	□	Urine Diversion is blocked

		Is there any blockages in the urine diversion (mis-use, build-up of salts)	B	□	Some fecal matter or other material in Urine Diversion
			C	□	No fecal matter dirt visible
			D	□	Not possible to observe
	19	What is the status of the toilet service?	A	□	Toilet has overflowed
			B	□	Toilet is full
			C	□	Toilet is regularly serviced
			D	□	Not possible to observe
	20	Is the toilet unit clean, free of fecal smudges (not mud/dirt)	A	□	Very Clean
			B	□	Sufficient
			C	□	Inadequate
			D	□	Not possible to observe
	21	Is the floor surfaces around the toilet area clean and free of fecal smudges?	A	□	Very Clean
			B	□	Sufficient
			C	□	Inadequate
			D	□	Not possible to observe
	22	When the toilet was last cleaned?	A	□	Today
			B	□	Yesterday
			C	□	Last Week
			D	□	Unknown
	23	Is the urine/waste water collected or disposed of on site?	A	□	Collected
			B	□	Disposed of on site
			C	□	Not possible to observe
	24	Is the urine soakaway in good condition	A	□	Yes, no visible blockages and no standing water
			B	□	No, visible blockages and standing water
			C	□	No soakaway constructed
			D	□	Not possible to observe
	25	Is the area around the liquid collection container dry without pools or standing water	A	□	Yes, no leakages and no standing water
			B	□	No, some leakages and standing water
			C	□	Not possible to observe
	26	Is there any odor / smell apparent nearby the toilet unit?	A	□	No smell, well ventilated
			B	□	Acceptable
			C	□	Unacceptable smell
			D	□	A very offensive smell
	27	Number of flies observed around the toilet area?	A	□	None
			B	□	Some (1-9)
			D	□	A lot (>10 or more)
	28	Is there visible risk information or communication to inform and remind users to follow best practices?	A	□	In the toilet unit
			B	□	Outside the toilet unit
			C	□	Not observed
	29	Typically, how frequently are the users sensitised about good practices?	A	□	Daily
			B	□	Weekly
			C	□	Monthly
			D	□	< 6 months
			E	□	> 6 months
			F	□	Not Known

	30	Typically, what methods are typically used for sensitization?	A	□	House to house
			B	□	Groups meetings
			C	□	Other
	31	Generally how well informed are users about the use and maintenance of the toilet unit?	A	□	Very well informed
			B	□	Well informed
			C	□	Quite well informed
			D	□	Not so well informed
			E	□	Not informed at all
			F	□	Not Known

Appendix 10: Collection and Conveyance Sanitary Survey Format

	Sanitary Survey at the Collection and Conveyance				
	Use a Single Sheet per HH				
	Unit ID				
	NAME OF ENUMERATOR				
	TIME AND DATE OF SURVEY				
	NOTE WEATHER				
	LAST RAIN EVENT				
A: Environmental Risk Factors					
3	What is the state of the road condition used for route collection? (Deteriorated, potholes, or uneven road surfaces)	A	□	Good condition and dry	
		B	□	Good condition and wet	
		C	□	Deteriorated and dry	
		D	□	Deteriorated and wet	
		E	□	Unknown	
4	What is the condition of the collection vehicle?	A	□	Very good (brand new)	
		B	□	Fair Condition	
		C	□	Deteriorated	
		D	□	Unknown	
23	Does the vehicle have risk information signs to indicate hazardous material being transported?	A	□	Yes	
		B	□	No	
		D	□	Don't know	
System Performance					
1	What is the condition and state of the collection containers - water-tightness?				
	Urine	A	□	Deteriorated: cracks, breakages and/or major cracks	
		B	□	Fair condition: minor cracks, scuffs, other marks on surfaces	
		C	□	Brand New	
		D	□	Not possible to observe	
	Solids	A	□	Deteriorated: cracks, breakages and/or major cracks	
		B	□	Fair condition: minor cracks, scuffs, other marks on surfaces	
		C	□	Brand New	
		D	□	Not possible to observe	
2	What is the condition of seals/fittings/lids/caps of collection containers - air-tightness?				
	Urine	A	□	Deteriorated: lids missing, ill fitting	
		B	□	Fair condition: wear and tear	
		C	□	Brand New	
		D	□	Not possible to observe	
	Solids	A	□	Deteriorated: lids missing, ill fitting	
		B	□	Fair condition: wear and tear	

			C	□	Brand New
			D	□	Not possible to observe
	5	What overall condition is the PPE in?	A	□	Very Good (brand new)
			B	□	Satisfactory
			D	□	Deteriorated
			E	□	None observed
	6	How are containers secured to prevent being displaced while transported?	A	□	Containers are not secured
			B	□	Secured with physical restraints
			C	□	Not known
	7	Note the cleanliness of the floor in the vehicle	A	□	Visibly clean
			B	□	Sufficient
			C	□	Inadequate (fecal smudges)
	8	Cleanliness of the fecal collection containers? (Select a sample of 10%)	A	□	Visibly clean
			B	□	Sufficient
			C	□	Inadequate (fecal smudges)
	9	Is there a spillage disinfection kit on board the collection vehicle?	A	□	Visibly clean
			B	□	Sufficient
			C	□	Inadequate (fecal smudges)
	10	How many collections from units are made per day?	A	□	Low levels (10-20 toilets/day)
			B	□	Medium (20-30 toilets/day)
			C	□	High (30 + toilets/day)
			D	□	Not known
	11	Observation of spillages or accidents	A	□	Zero
			B	□	1
			C	□	2 or more
			D	□	Unknown
	12	Are there flies observed around the vehicle?	A	□	None
			B	□	Some (1 or more)
			C	□	A lot (>10 or more)
Operational Capacity					
	13	Which items of PPE are available for operators during collection and conveyance?	A	□	Latex (medical) gloves
			B	□	PVC (work wear) gloves
			C	□	Mask
			D	□	Overalls
			E	□	Safety Helmet
	14	What vaccinations have staff received?	B	□	Tetanus
			C	□	Hepatitis A and B
			D	□	Polio
			E	□	Cholera
			F	□	Rota Virus

Appendix 11: Waste Treatment Facility Sanitary Survey Format

Sanitary Survey at the Waste Transfer and/or Transfer Stations					
Use a Single Sheet per site visit					
Unit ID					
NAME					
TIME AND DATE OF SURVEY					
NOTE WEATHER					
LAST RAIN EVENT					
CONDITION OF HARDWARE					
	1	Physical integrity of storage containers - consider air and watertightness?			
	i	Urine storage containers	A	□	Deteriorated: cracks, breakage and/or major cracks
			B	□	Fair condition: minor cracks, scuffs, other marks on surfaces
			C	□	Brand New
			D	□	Not possible to observe
			E	□	Other ____
	ii	Solids	A	□	Deteriorated: cracks, breakage and/or major cracks
			B	□	Fair condition: minor cracks, scuffs, other marks on surfaces
			C	□	Brand New
			D	□	Not possible to observe
			E	□	Other ____
	2	Condition of treatment equipment - if applicable?			
	i	Urine treatment equipment	A	□	Deteriorated: lids missing, ill fitting
			B	□	Fair condition: wear and tear
			C	□	Brand New
			D	□	Not possible to observe
	ii	Solids treatment equipment	A	□	Deteriorated: lids missing, ill fitting
			B	□	Fair condition: wear and tear
			C	□	Brand New
			D	□	Not possible to observe
	3		A	□	100%

		What proportion of treatment equipment and machines is on a regular maintenance schedule?	B	□	>90%
			C	□	>50%
			D	□	n/a
	4	What proportion of treatment equipment and machines is on a regular cleaning schedule?	A	□	100%
			B	□	>90%
			C	□	>50%
			D	□	Unknown
	5	What is the cleanliness in high risk areas?	A	□	Good
			B	□	Fair
			C	□	Inadequate
			E	□	Unknown
	6	What is the cleanliness in low risk areas?	A	□	Good
			B	□	Fair
			C	□	Inadequate
			E	□	Unknown
OPERATIONAL CAPACITY AT TREATMENT FACILITY					
	7	Which items of PPE are available for operators during collection and conveyance?	A	□	Latex (medical) gloves
			B	□	PVC (workwear) gloves
			C	□	Mask
			D	□	Overalls
			E	□	Safety Helmet
			F	□	Googles
			G	□	Torch
			H	□	Boots
			I	□	Not possible to observe
	8	What overall condition is the PPE in?	A	□	Very Good
			B	□	Satisfactory
			C	□	Poor
			D	□	Very Poor
			E	□	None observed
	9	Functionality of handwashing/hygiene device for operators?	A	□	Soap and water available
			B	□	Alcohol hand rub available
			C	□	No soap and water available
			D	□	Not possible to observe
	10	How many spillage disinfection kits on site?	A	___	number
	11	How is waste transferred from collection containers to treatment containers?	A	□	Mechanised process
			B	□	Partially mechanised/manual
			C	□	Manually (low number of steps <5)
			D	□	Manually (high number of steps >5)
	12	Is type of waste treatment is observed			
	13	Solids (fecal wastes)	A	□	pasteurisation >70 degrees Celsius
			B	□	thermophilic aerobic composting (windrows)

			C	□	thermophilic aerobic composting (in-vessel composting)
			D	□	mesophilic anaerobic composting
			E	□	Other ______________________________________
	14	Urine	A	□	direct disposal
			B	□	soakaway pit
			C	□	drainage field
			D	□	slow sand filtration
			E	□	Other ______________________________________
	15	Waste Water (black/contaminated from washing process)	A	□	direct disposal
			B	□	soakaway pit
			C	□	drainage field
			D		slow sand filtration
			E	□	Other ______________________________________
	16	Other solids (plastics)	A	□	incineration
			B	□	landfill
			C	□	municipal
			D	□	other ______________________________________
	17	How many failures in waste treatment in the last week? (pathogen reduction not achieved)	A	□	Zero
			B	□	<10
			C	□	>10
			D	□	Unknown
	18	Is movement of people controlled from high risk (red) areas well defined from low risk (green) areas in treatment facility?	A	□	Well maintained and defined high and low risk areas
			B	□	
			C	□	Poor definition between high and low risk areas
	19	Number of flies observed around the treatment site?	A	□	None
			B	□	Some (1 or more)
			C	□	A lot (>10 or more)
	20	Has there been any spillages or accidents reported in the last week?	A	□	Zero
			B	□	<10
			C	□	>10
			D	□	Unknown
	21	Is there an accident reporting format for operators	A	□	Yes
			B	□	No
			C	□	Not known
	22	Is there visible and appropriate risk information or communication to inform and remind operators to use hand hygiene?	A	□	Yes
			B	□	No
			C	□	Don't know
	23	Is there water available on site?	A	□	Yes
			B	□	No

			C	□	Not observed
HUMAN PERFORMANCE: HANDWASHING BEHAVIOUR AND USER BEHAVIOUR					
	24	When the operators were last trained in hand hygiene compliance and protocols?	A	□	> 6 months
			B	□	< 6 months
			C	□	Don't know
	25	Have the operators been sensitised in hand hygiene (in the last 6 months)?	A	□	> 6 months
			B	□	< 6 months
			C	□	Don't know
MANAGEMENT AND SAFETY CULTURE					
	26	When was the last emergency scenario scheduled carried out?	A	__	days
			B	__	weeks
			C	__	months
	27	Are SOPs available for the following:	A	□	Disinfection and Cleaning Protocols
			B	□	Glove Wearing and Hand Hygiene Protocols
			C	□	Hand Washing Protocols
			D	□	Loading Protocols
			E	□	Glove Wearing and Hand Hygiene Protocols
			F	□	Don't know
	28	Do operators have up-to-date vaccination records against the following diseases (tick which apply)	A	□	Typhoid
			B	□	Tetanus
			C	□	Hepatitis A and B
			D	□	Polio
			E	□	Cholera
			F	□	Rota Virus
	29	Are the treatment operators on de-wormed regularly?	A	□	Yes
			B	□	No
			D	□	Don't know
	30	Are the treatment operators given regular health checks?	A	□	Yes
			B	□	No
			D	□	Don't know

Appendix 12: Behavioural Survey

Compost Toilets in London Canal Boats

Section A
Location
Date
Do you agree to participate in the survey (y/n)
Generally, how would you describe your status as a canal boater?
❑ a. Constant Cruiser
❑ b. Residential Mooring
❑ c. Other (*please write below*)

How many people are on board?

What type of toilet are you currently using on board?
❑ a. Compost toilet
❑ b. Cassette toilet
❑ d. No toilet/won't say

Regarding your composting toilet: which specific type of compost toilet do you own?
❑ a. Kildwick
❑ b. Simploo
❑ c. Separett
❑ d. Envirolet
❑ e. Other
❑ c. Self-build

Typically, how do you dispose of or manage the solid waste?
❑ a. Bagging and binning
❑ b. Composting
❑ c. Burying
❑ d. Burning
❑ e. Doing something else
❑ c. Prefer not to say

Typically how frequently do you empty the toilet (mainly solids)?
❑ a. Once a week
❑ b. Fortnightly
❑ c. Monthly
❑ d. Twice a month
❑ e. Don't know

Typically how frequently do you clean the toilet surfaces?
❑ a. Daily or more
❑ b. Few time a weeks

❑ c. Once a week
❑ d. Fortnightly
❑ e. Monthly

Normally do you wear gloves when emptying of the contents of the containers waste?
❑ a. yes
❑ b. no
❑ c. don't participate in disposing of waste

Do you wash your hands after emptying contents of the containers?
❑ a. Yes
❑ b. No

Have you had any spillages when you empty it?
❑ a. Everytime you empty it
❑ b. A few time a years
❑ c. Once or twice per year
❑ d. Less than once a year
❑ e. Don't know

Risks
We wish to ask you some questions about the impact of human poop and wee on human health and the environment and to what extent you agree or disagree:

My toilet has not adversely affected my health:
❑ a. Strongly agree
❑ b. Generally agree
❑ c. Generally disagree
❑ d. Strongly disagree

If I touching or contact with raw faeces poop it may harm my health:
❑ a. Strongly agree
❑ b. Generally agree
❑ c. Generally disagree
❑ d. Strongly disagree

If raw or untreated sewage escapes it can harm the health of local environment:
❑ a. Strongly agree
❑ b. Generally agree
❑ c. Generally disagree
❑ d. Strongly disagree

What are the ways that illnesses like diarrhoea are transmitted to people?
❑ a. Drinking dirty or contaminated water
❑ b. Through bad, unhygienic food preparation
❑ c. By touching contaminated objects in the environment
❑ d. From ingesting dirty soil
❑ e. Through a lack of proper personal hygiene

How does untreated poop enter the local environment?
❑ a. Lack of proper collection (collective or individual) - illegal dumping of sewage
❑ b. Lack of proper treatment or disposal systems
❑ c. Not using a toilet
❑ d. Other

From my personal experience, the risk of catching diarrhoea is high?
❑ a. Strongly agree
❑ b. Generally agree
❑ c. Generally disagree
❑ d. Strongly disagree

Thinking back to a time I last had diarrhoea, the impact on my daily life was severe
❑ a. Strongly agree
❑ b. Generally agree
❑ c. Generally disagree
❑ d. Strongly disagree

Attitudes
This section is about how your attitude to your toilet in terms of the costs and benefits (i.e the time you spend managing with your toilet, your health, your financial resources, money etc

Using and managing my toilet (i.e. cleaning, emptying your toilet) takes up a lot of time?
❑ a. Strongly agree
❑ b. Generally agree
❑ c. Generally disagree
❑ d. Strongly disagree

Compared to other toilet facilities you may use – what is the best thing about your toilet?
❑ a. ____

Compared to other toilet facilities you may use – what is the worst thing about your toilet?
❑ a. ____

What was the cost of your toilet?
❑ a. >£1000
❑ b. £800- 1000
❑ c. £500 -799
❑ d. £200 - 399
❑ e. <£200
❑ f. prefer not to say

The cost of the toilet was the most important consideration when buying it
❑ Strongly agree
❑ Generally agree
❑ Generally disagree

❑ Strongly disagree

It is very important to me is that toilet waste is re-used
❑ a. Strongly agree
❑ b. Generally agree
❑ c. Generally disagree
❑ d. Strongly disagree

It is very important is to me that toilet waste is properly treated and contained from the aquatic environment
❑ a. Strongly agree
❑ b. Generally agree
❑ c. Generally disagree
❑ d. Strongly disagree

As far as you're aware: how many people in your community have the same type of toilet as you?
❑ a. (Almost) all of them (100%)
❑ b. Over half of them >50%
❑ d. Less than half <50%
❑ e. (Almost) nobody 0%

Visitors and guests like the toilet
❑ a. Strongly agree
❑ b. Generally agree
❑ c. Generally disagree
❑ d. Strongly disagree

I find it simple and easy to clean the toilet
❑ a. Strongly agree
❑ b. Generally agree
❑ c. Generally disagree
❑ d. Strongly disagree

I find it simple and easy to empty the toilet
❑ a. Strongly agree
❑ b. Generally agree
❑ c. Generally disagree
❑ d. Strongly disagree

I am confident in the performance of the toilet; especially in it being able to deal with issues like blockage and leakage?
❑ a. Strongly agree
❑ b. Generally agree
❑ c. Generally disagree
❑ d. Strongly disagree

I have a set of routines for emptying the toilet

❑ a. Strongly agree
❑ b. Generally agree
❑ c. Generally disagree
❑ d. Strongly disagree

I often forget to empty the toilet
❑ a. Strongly agree
❑ b. Generally agree
❑ c. Generally disagree
❑ d. Strongly disagree

I have strategies to remind me to empty the toilet
❑ a. Strongly agree
❑ b. Generally agree
❑ c. Generally disagree
❑ d. Strongly disagree

I have a plan for what to do if my toilet stops working?
❑ a. Strongly agree
❑ b. Generally agree
❑ c. Generally disagree
❑ d. Strongly disagree

Appendix 13: Colilert protocol and surface swabbing

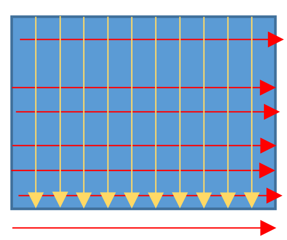
We will collect swabs from surfaces in the toilet/bathroom area to test for presence of *Escherichia coli* (abbreviated as *E. coli*) tested for as a faecal indicator bacteria (FIB). *E. coli* indicate presence of bacteria found in the environment, foods, and intestines of people and animals.

<u>Material Required</u>

PBS solution (15ml per swab to be collected) Sterile deionized water (90ml per sample) Sample vials – 15ml (one per swab) Sample bottles for preparing samples – 100ml (one per sample) Quanti-trays and Colilert powder Iron UV light

- Sterilise swabs are sterilised and keep sealed until ready for use in field
- Prepare enough PBS solution for sample collection (14ml for each swab)
- Mix one tablet of PBS with correct volume of distilled water (according to the size of the tablet)
- Sterilise PBS solution and distilled water
- Prepare sterile 15ml sample vials with 7ml of sterilised PBS solution
- Prepare data labels for sample vials
- Environmental Data collection
- Select areas to be swabbed
- Put on gloves
- Select a representative 10cm^2 surface area to be swabbed
- Take out swab and use the swabbing technique describe below to collect microbiological specimen

Swabbing technique: Using one side of the swab, move the swab one direction following the red arrows. Then flip the swab and move the swab following the yellows arrows



- After swabbing put the swab into the 15ml vial – use scissors to break the end and secure lid
- Label the collection vial with sample ID and date
- Put into cool box and transport back to lab
- Colilert Protocol
- Vortexed all sample vials for 30 secs

- Added another 7ml of PBS to vials (total 14ml in vials)
- Vortex for another 30 secs
- Leave until ready for processing
- Prepare 100ml sterile sample bottles
- Preparing a 1:10 dilution
- Added 90ml sterile distilled water in 100ml sterile sample bottle
- Added 10ml of sample elute from vial
- Add one sachet of Colilert powder as directed
- Shake for10 secs and allow reagent powder to dissolve >5 mins
- Label sample bottle with sample ID and dilution
- Preparing negative control
- Added 10ml PBS to 90ml sterile distilled water
- Prepare Quanti-tray
- Holding the tray open according to the directions in Quanti-tray information sheet, tip entire 100ml contents into Quanti-tray
- Seal the tray using the iron on a flat surface. Start at the base of the tray and move the iron up the tray to direct liquid into all the cells
- Check all the cells are filled
- Label the Quanti-tray with sample ID and time of entry into incubator
- Place in incubator cells facing up
- Incubated at 35 ^{0}C for 18–22 hours
- Count wells according to Colilert sample sheets

Appendix 14: First Person Videography protocol

Protocol for the First Person Videography (FPV) for Collection of Activity Data for Servicing and Emptying of Onsite Sanitation

Equipment needed

- Micro action camera (e.g. DRIFT Stealth 2) including SD card (16GB for storing camera data and accessories like batteries or charger for video camera
- Headband (Nike sports band or similar)
- Smartphone with app for real time viewing of the video (desirable)
- Linking App and Video Software (see user manual for further details)

Process

- Download camera software onto the smartphone (e.g. DRIFT APP)
- Update firmware for SD card if required
- Mounting the video camera for use (see user manual for further details)
- The micro action camera may come with fixtures to be mounted to a helmet.
- Remove mounting fixtures and attach to headband (or attach to a helmet)
- Mount the camera forwards and downwards, onto a headband around the head; to the side of the head
- Recording activity data
- Ensure all consent forms and information sheets have been signed and accepted
- Ensure the person is comfortable with the video recording experience and positioning
- Make any necessary physical adjustments to the headband to make sure it comfortable for the wearer
- Do 2–3 tests runs letting the person wear the camera and encourage the person to carry on their activities as normal
- Play back the video to the person (or share the real time view on smartphone) to share the activity data recorded on the camera
- Make any adjustments to the position of the camera to ensure it is capturing hand activity for both hands so that hand–mouth and hand–objects contacts can be viewed
- Ensure the battery is 100% and that the expected video data will not exceed battery length (approx. 2 hours)
- Ensure SD card has sufficient capacity
- Ensure the video camera is set to green for recording
- Turn off when finished recording
- When returned from field download the data onto a computer using the USB cable and save with date/time and location and any other information
- Back up the video data in a second location in case of loss of data on hard drive

Site Selection – Location and Number

1. If the emptying locations are varied and highly heterogeneous, for examples in terms of physical environment, housing density and toilet structures ensure the sample for data collection accounts for the spatial diversity.

2. The quantity of activity data collected should be large enough to be representative of the types of contacts and activity that occurs under normal conditions.

3. The length of each unique emptying event will determine the number of events that may be collected. A large enough sample of unique emptying events should be recorded to capture variability; about 10 emptying events. In general, a period of recording the activity data would be a minimum 2 hours - maximum 10 hours (the time limitation is due to micro-level data translation).

4. Unless there is concern of contact during transport, only the servicing or emptying event of the onsite sanitation system (container/septic tank) needs to be recorded.

5. Notes should be taken to record any additional data associated with cleanliness and risk factors.

Appendix 15: Minimum Design Standards for CBS Components

Minimum Design Standards			
Toilet hardware – front end, collection container			Source
1	Design	Toilet is accessible for people living with disability when appropriate (height, size, steps)	
2		Toilet is accessible for children (height, size, steps, smaller seat and/or drop hole (<25cm) for child use)	
3		Normal use of the toilet doesn't involve hands going near excreta (i.e. lifting covers or changing containers)	
4		The separator design prevents fecal deposits landing on separator and facilitates separation of urine and faeces	
5		The urine pipe should be wide enough to not block easily, due to build-up of salts in urea (recommended > 32mm minimum diameter)	
6	Cleanability	Contact surfaces are smooth and non-porous, e.g. prefabricated plastic, wood (painted), coated concrete,	SEI
7		Floors are non-absorbent, easy to clean and washable (non-porous concrete or PVC plastic or other non-porous material)	
8		Toilet surfaces are easily available for cleaning (cleaned without disassembly)	ISO
11	Material durability	Materials from which the unit is constructed should be durable to prevent rapid deterioration	
13	Isolation and containment (SFW and LFW)	Design ensures any spillages contained within toilet unit	Kildwick
14		A soak away is installed for wastewater/urine if not collected	
15		Soak away not installed on rock/flooded ground	
16	Minimum dispersal through air	Sealed containers when full or not in use prevents dispersion through air	SEI
17		Toilet installed >10 m from food preparation areas	
18	Risk signage and communication	Appropriate IEC when toilet is in use (visible, relevant)	ISO
Transport equipment			Source
1	Cleanability	Contact surfaces are smooth, non-porous and easy to clean, e.g. prefabricated plastic, wood (painted), PVC plastic	
2	Durability	Equipment used for collection and conveyance are highly durable, durable	
3		Equipment has a maintenance schedule	

4	Usability	Solids containers are appropriately sized to enable safe handling (max. lifting weight per person 25kg)	OSHA
5		Handles/straps on containers to facilitate lifting	
6		Handling tools to prevent direct manual handling when required	
7	Isolation and containment (SFW)	The collection vehicle is covered and sealed	
8	Isolation and containment (LFW)	The collection vehicle has a watertight vehicle floor	
9	Risk signage and communication	The collection vehicle if fitted with speed restriction device or similar	
10		Appropriate IEC: biological hazard (signs) to inform public of biohazard	
11		Emergency response kit (spillage disinfection kit) on board	
Treatment facility			Source
1	Design	Facility is not sited in rocky ground/ground liable to flooding	
2	Cleanability	Contact surfaces are smooth, non-porous and easy to clean e.g. prefabricated plastic, wood (painted), PVC plastic	
3		Floors in high risk areas are non-permeable and washable; (cement, coated concrete, vinyl, ceramic tiles)	
4		Drainage adequate to allow flow of water (no standing water)	
2	Durability	Equipment is included within a maintenance schedule	
5	Usability	Handwashing stations and disinfection points are available	
6		Contaminated and non-contaminated areas are separated into high- and low-risk areas	
7		Standards operating procedures exist for facility management	
8		Cleaning and disinfection process does not result in splashing and direct ingestion of wastewater	
9		“Close-contact” manipulation by frontline staff of the fecal and urine waste materials is minimised	
10	Isolation and containment (SFW)	A physical fly barrier or adequate steps are taken to prevent vector transmission from high risk areas (raw fecal sludge)	
11		Stored waste is kept in sealed containers, until final disposal	
12	Isolation and containment (LFW)	An appropriate soak-away area or drainage system is installed for grey/wastewater	
13	Minimum dispersal through air	Adequate ventilation when handling waste to prevent concentration of dangerous particles	
14		All staff areas and eating areas are physically separate with hygiene controls to prevent cross-contamination	

15		Compost facility >100–250m from populated areas to prevent dispersal of hazardous particles	
16	Risk signage and communication	Appropriate IEC to address potential hazards associated with equipment	
17		The facility is securely fenced to prevent access to the public	
Liquid waste disposal facility – soakaway pits, drainage fields			Source
1	Design	The soakaway area has a length to width ratio > 2:1 to allow solids to settle	
2		The soakaway is installed over >30m from a potable water point	
3		The depth to the groundwater is >3m from the bottom of the soakaway pit	
4		The soakaway has sufficient capacity for the input	
		Soakaway not installed on rock/flooded ground	
5	Durability	Construction materials are durable, no cracks in concrete, mortar durable	
6	Usability	Grease trap is accessible for maintenance	
7	Isolation and containment (SFW)	Sludge is managed at end of final disposal	
8	Isolation and containment (LFW)	The treatment system can accommodate increases in discharge inputs/discharge rate is controlled	
9	Minimum dispersal through air	There is no odour from the pit	
10	Risk signage and communication	Fence and public access barriers are erected around the soakaway pit	
Solid waste disposal facility – incinerator, landfill			Source
1	Design	Chimney height above 4-5m	
2		Waste destruction efficiency >90%	WHO
3		Incinerator has a roof (walls and ventilated)	
4	Durability	Construction materials are durable	
5	Usability	Protocols for disposal procedures exist	
6		Facility/equipment has a maintenance schedule	
7		Manual handling of waste by frontline staff of the fecal and urine waste materials is minimised	
8		Solid waste prior to disposal is securely stored (in a sealed container)	

9	Minimum dispersal through air	incinerator sited >100 - 250m from populated areas to prevent dispersal of hazardous particles	
10	Risk signage and communication	Fence and public access barriers are erected around the incinerator site	

Appendix 16: Critical SOPs

Critical process and SOPs in CBS system	
1	Containment SOPs
2	User and maintenance at HH SOPs
3	Cleaning and disinfection SOPs (at toilet level, at ECU)
4	Collection and conveyance SOPs
5	Treatment specific protocols
6	Composting SOPs (organic solid fecal waste)
7	Slow sand filtration SOPs
8	Spillage scenarios SOPs
9	Emergency scenarios SOPs (relevant emergencies)
Specific health and safety guidelines	
	Glove use guidelines
	Hand hygiene guidelines
	Reuse and crop application guidelines

Annexes

Annex 1

WHO Sanitation Safety Planning Workshop for CBS

Workshop Notes – T. Keatman

Trainers and participants

Overview

SSP is a practical, iterative and modular risk assessment process which can be used to systematically understand and mitigate health-related hazards for each link of the sanitation chain. The WHO SSP workshop (11–14 September 2017) for CBS providers took place over the course of 4 days; with each day dedicated to working through modules of the SSP process. All participants appeared engaged and interested in learning about the process and developing organisational Sanitation Safety Plans once "home".

The process is not complicated or technical – but does require time, ongoing engagement and potentially, pathogen/exposure risk data analysis at the local level. Once an SSP process has been completed and a plan agreed, it may also mean making incremental changes to improve CBS standard (technical) operating procedures and staff management practices.

- WHO is willing to continue supporting the workshop participants with some "small, doable and practical" actions to help maintain momentum. Ideas include:
- Helping facilitate discussions with government
- Linking each CBS group with one of their SSP trainers (e.g. Leonelha will be in Lima soon and may be able to visit X-Runner)
- Linking each CBS group (or everyone) with experts through webinars, through collating questions and responding, through research, etc.
- Jointly publishing a compendium of SSPs for CBS systems.
- The brief notes below follow the structure of the SSP process as outlined in the WHO SSP manual (2016) and as used during the workshop. UCL student, Eve (MacKinnon), whose PhD is focused on assessing and managing exposure risks along the CBS service chain, kindly provided examples for participants of how each step of the SSP process could be applied to the CBS-specific content

SSP modules and notes:

Participants all received the full WHO manual *Sanitation safety planning: manual for safe use and disposal of wastewater, greywater and excreta* (WHO 2016), PPT handouts, worksheets, and access to all reference/resource materials in a dedicated Dropbox (including an example full sanitation safety plan from The Philippines). These notes are only a brief snapshot of information shared during the training with some hints/tips from the trainers for CBS providers. The content below is drawn directly from the Manual and the teaching materials – please attribute WHO, 2016 and Eve (denoted Eve) if you reuse any of the content below!

Workshop objectives for CBS participants:

- Understand the SSP process, outputs and outcomes

- Gain confidence in applying SSP to your CBS system
- Know how to complete SSP for your system.

Purpose of SSP: To bring the health focus to the forefront of sanitation and reuse as well as identifying actual (as opposed to perceived) risks for health and safety across the sanitation system. (In this case, the CBS sanitation chain rather than, for example, a city-wide sanitation system.) SSP focuses on (hygiene and sanitation) behaviour change not just infrastructure.

SSP history: WHO's 2006 Guidelines for the safe use of wastewater, excreta and greywater are a "code of good practice for the safest possible use of wastes in agriculture and aquaculture, so that nutritional and household food security benefits can be shared widely" (Darryl's slides) – the SSP manual was developed to simplify the Guidelines for wider uptake and for use with other sectors also (e.g. FSM, public irrigation, CBS).

SSP structure: The SSP process includes two key phases: 1) a system assessment phase where disease pathways and affected people are identified and analysed for risks; 2) an operational monitoring and management phase where strategies are developed to reduce the highest risks and to incrementally address others.

SSP outcomes: Helps sanitation operators and the health sector to: target limited resources to the highest risks; develop a multi-sector team approach to identify and manage health of at-risk people; and, focus on simple operational monitoring and correction. The *process* of undertaking a multi-stakeholder SSP can also be helpful for local advocacy and raising the profile of sanitation/CBS with health sector colleagues.

SSP outputs: 1) a *prioritised*, *incremental* improvement plan; 2) an operational monitoring plan for regular monitoring and periodic verification.

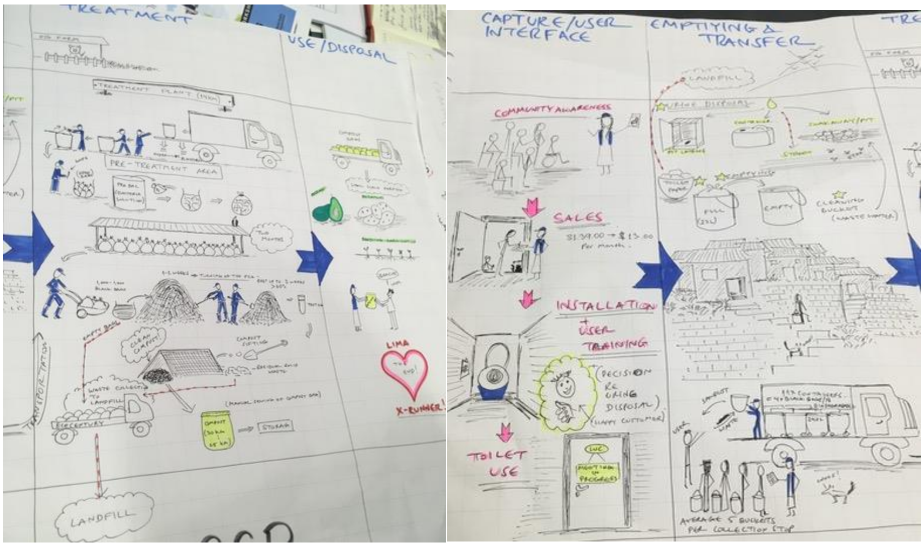
Module and intended outputs	Steps	CBS considerations for each step – hints and tips (not the whole process!)
Module 1: Prepare for SSP Outputs: Agreed priority areas, purpose, scope, boundaries and leadership for SSP	Establish priority areas or activities Set objectives (improved public health outcomes) Define the system boundary and lead organisation	Where to do SSP? Who to involve? **Priority areas** (i.e. activities that pose the greatest health risk) – for CBS, these are all the links in the sanitation chain, even if the CBS provider is not directly responsible for or operational in each. E.g. Clean Team work closely with Kumasi Metropolitan Assembly (KMA) and their local contractor on disposal/reuse. All relevant third parties should be included in the SSP process. Set up a Steering

A multidisciplinary team representing the sanitation chain for development and implementation of SSP	Assemble the team Consider a local, multi-stakeholder SSP meeting to kick things off, to gain buy-in and to maintain momentum	Committee if you need one to convene/manage the various actors. **SSP objectives** – Examples for CBS: to safeguard human health, promote the safety of workers and users, and enhance environmental protection; to promote local/national discussion and influencing for policy and regulatory changes; to demonstrate CBS as a viable alternative. **System boundary** – CBS is a concise boundary system, so the scope of the SSP would be to focus on the operations of the CBS provider. **Lead organisation** – The CBS providers will lead the SSP process (in each context). **The team** – 8–10 people? What's nimble and simple in your context? Conduct a stakeholder analysis to assess who should be involved (for each chain link) and invite those with expertise/influence in each chain segment to contribute. One person can be elected to lead on the analysis for each chain link (or have sub-teams for each link) – allocate roles and responsibilities clearly. Community representatives can offer perspectives of exposure groups. E.g. farmers who may be exposed to reuse risks. Ensure that appropriate permissions/protocols are followed as individuals' contributions may require time and other resources. Select a team leader with authority and good project management skills. **Management/financial considerations** – discuss and agree in-kind and actual resources required to develop the plan. E.g. if the SSP process takes 6 months, how many meetings will you need? Who can provide what? Does time need to be

		reimbursed? Can research agencies/universities assist with data collection? Should job descriptions be revised?
Module 2: Describe the sanitation system Outputs: A validated map and description of the system Potential exposure groups An understanding of the waste stream constituents and waste-related health hazards An understanding of the factors affecting the performance and vulnerability of the system A compilation of all other relevant technical, legal and regulatory information	2.1 Map the system 2.2 Characterise the waste fractions 2.3 Identify *potential* exposure groups 2.4 Gather compliance and contextual information 2.5 Validate the system description Module 2 needs a substantial time allocation. Take time to do it thoroughly! A system description could take at least 2–3 days for two people to complete Build in time for peer review of the system description. Use the same reviewer each time! Maybe a CBS colleague?	What is the system? Who's at risk? This module guides SSP planners on how to draw together sufficient information to support the risk assessments in module 3. Use the Guidance notes in the Manual! You may need to gather a lot of data for this step and it may take some time! **Map** – use system flow or process flow diagrams to show the interrelationships between sanitation chain links and describe it all through a narrative (include quantitative info about the quantity of waste streams, seasonal variations, chemicals, component capacities, different types of waste). Workshop participants mainly mapped the processes in each of their CBS cases for: capture/user interface; container emptying and transport; treatment; use and/or disposal. See an example below of X-Runner's (stunning!) map. The entire analysis can take time to complete fully, e.g. The Philippines case noted above split the work out over 2 months. **Waste fractions** – The map should show the path of *all* the solid and liquid waste fractions along each link of the sanitation chain – but keep/note the waste streams separately, e.g. highlight where each goes individually, such as urine, fecal sludge, blackwater used for container washing, toilet paper/anal cleansing materials, sanitary pads/rags, nappies, etc. **Identify and add *potential* exposure groups** (e.g. people affected or in contact with each waste stream) for each chain link, such as workers, users, local community members, product users, consumers (Eve – example CBS potential exposure groups). **Compliance/context info** – compile and summarize information about the context, such as local/national quality standards, demographics and land use patterns, seasonal conditions that may affect services, bacteriological data, KAP

		surveys, etc. You may need to work with health experts/ researchers to analyse each waste fraction and assess its associated *actual* health hazards (i.e. is it a biological, chemical or physical hazard?) **Validate as you go** – as information is gathered for the map and narrative, test your assumptions and data quality through focus group discussions with users and workers, field investigations and inspections, sample testing at labs, etc. In most cases, you probably won't need in-depth studies such as epidemiological surveys or environmental sampling.

X-runner System Maps



Module and intended outputs	Steps	CBS considerations for each step – hints and tips (not the whole process!)
Module 3: Identify hazardous events, assess existing control measures and exposure risks Outputs:	3.1 Identify hazards and hazardous events 3.2 Refine exposure groups and exposure routes	How significant are the risks? Module 3 ensure that efforts and investments in system monitoring and improvements respond to highest risks first. This is the risk assessment step. This step requires: desk-top analysis and field investigation; technical understanding; contamination pathway knowledge; inquisitiveness!

A risk assessment table which includes a comprehensive list of hazards, and summarises hazardous events, exposure groups and routes, existing control measures and their effectiveness A prioritised list of hazardous events to guide system improvements	3.3 Identify and assess existing control measures 3.4 Assess and prioritise the exposure risk Module 3 requires a lot of detailed work, but an intensive half-day workshop would be very useful – you could do each other step/module in smaller/shorter meetings with relevant people only	**Hazards** – the actual and identified biological, chemical and physical hazards. **Hazardous events –** the events/actions which expose people to hazards (the story). *A well-described hazardous event will include a brief comment on the circumstances or case under which the event occurs* – e.g. exposure to excreta during removal of a damaged container. Eve identified, for example, four categories of hazardous events in CBS systems: Person error – e.g. excreta or urine spills onto surfaces and floors due to overflow Equipment/technical failure – e.g. in an UDT, urine spills due to salt build-up of urea in urine diversion pipe Regulatory and system safety culture failure – e.g. individuals are exposed to urine/excreta due to redundant or ineffective personal protective equipment (PPE) protocols Physical/seasonal/environmental variables – e.g. wastewater/urine soakaways or other similar systems overflow due to extreme weather/flood events **Refine exposure groups** – identify in more detail who exactly may be at risk of exposure to the different hazards. Describe who is in which group in your plan – consider demographics, vulnerable groups, seasonal workers, informal settlements, etc. E.g. Workers = person engaged by the CBS entity who maintains, cleans, operates or empties the sanitation technology including treatment. (Eve) **Refine exposure routes** – describe the exposure and transmission routes that put specific groups of people into contact with the hazards that could affect their health. Routes include: ingestion; consumption (of contaminated produce); dermal contact; vector-borne; inhalation of particles. Eve provided several useful examples to draw on (these can be found in the Participants' Worksheets).

		Identify and assess existing control measures (i.e. an action / barrier that can prevent, reduce or eliminate the hazard) – note down what measures are in place already to determine how well the existing system protects those at risk. E.g. use of PPE, treatment processes, crop selection. *Sanitation systems should provide more than one barrier against the different types of pathogens* – i.e. consider multiple barriers. Eve suggested some CBS control measures in relation to each hazardous event category: Person error – e.g. good food preparation practices Equipment/technical failure – e.g. strong sealing mechanism (lid/cap/bag/fastening) on collection containers Regulatory and system safety culture failure – e.g. agreed spillage protocol Physical/seasonal/environmental variables – e.g. flood event scenario planning **Assessing control measure effectiveness** – WHO uses reductions in *E. coli* as an indicator for risks of viral, protozoa and bacterial infections (in agricultural reuse contexts) as it shows definitively that water/wastewater is contaminated with faecal matter. This indicator can also be adopted by CBS entities. For helminths, WHO uses actual counts of helminth eggs Consider how effective the existing control measure *could* be, assuming it works well at all times (known as CM validation), and how effective it is *in practice*, considering actual conditions, regulations, operating practices, etc. **Assess and prioritise exposure risk** – In this step, each hazardous event (and each of its different hazards) is categorised through a typical risk analysis model e.g. where *likelihood* of the event happening and the *severity* of impact are considered or through a traffic light grading. See pages 52–53 of the SSP manual for details of grading/prioritising. Decide which risk assessment method you will use upfront – make sure all the team is happy with it!

		Remember: also consider what the grade would be without any existing mitigation measure in place at all. Maybe you can already see which measures have more impact than others. Also, describe why each risk has been assessed in the way it has (i.e. your justification of the grade)… you may need to refer back to this info when you revise your plan!

CBS worker health and hygiene – news and views

CBS staff protection		Hygiene for SDGs
Most CBS providers already have a package of health protection measures for their workers. During the workshop, health experts (Samuel Fuhrimann and Mirko Winkler) from the Swiss Tropical and Public Health Institute at the University of Basel suggested at least the following (but check with health professionals in your context): Vaccinations/immunisations – hepatitis A and B, polio, tetanus, typhoid, rotavirus (if available and relevant), and cholera (only when there's been recent/acute cholera outbreaks or following a local, seasonal outbreak pattern – its short-term impact, low efficacy and cost make it rather pointless the rest of the time). Regular health checks – consider a health check when a new staff member joins and then have them checked every 6–12 months (and treat them with anti-helminth drugs such as praziquantel, albendazole, metronidazole). See the *Oxford Handbook of Tropical Medicine* for more information.		Without handwashing facilities and the evidence of hand-washing with soap, we won't reach SDG target 6.2[12] – what can CBS providers do to support this? Ideas include: Include hygiene and hand-washing messages in all customer communications, e.g. the value of using/making soap and non-rinse soap, use of ash (not SDG-compliant but useful in water scarce settings), safe toilet cleaning and appropriate usage, etc. Offer an optional 'gold' health and hygiene package to customers on top of their emptying service – e.g. include soap, anal cleansing materials, PPE, non-chemical/non-toxic toilet cleaners and disinfectants (grapefruit, vinegar, baking soda, laundry soap don't need a sales licence in most contexts!) Consider an additional menstrual hygiene management package with information on disposal and bulk pad purchase opportunities CBS providers could bulk-buy hygiene consumables and sell the products with a minimal/zero mark-up. Or link with local companies who may sponsor such add-ons as part of their corporate social responsibility plans. Or link with government health campaigns and offer to be a communication/supply channel to customers!

[12] Indicator 6.2.1 = Proportion of population using safely managed sanitation services, including a hand-washing facility with soap and water.

Also, what about this tricky problem of getting people to use PPE consistently and to use it effectively? Do you know the barriers for non-usage already? Can you use a carrot (positive incentive) rather than a stick (compliance order)? Do workers dip their gloves in disinfectant at the end of each shift and leave them to dry overnight?		Check out PPPHW for more info and ideas for celebrating Global Handwashing Day on October 15.

Module and intended outputs	Steps	CBS considerations for each step – hints and tips (not the whole process!)
Module 4: Develop and implement an incremental improvement plan Outputs: An implemented plan with incremental improvements which protects all exposure groups along the sanitation chain	4.1 Consider options to control identified risks 4.2 Use selected options to develop an incremental improvement plan 4.3 Implement the improvement plan	What needs to be improved? Module 3 identified priority risks; module 4 focuses on selecting new control measures or other improvements that address these risks at the most effective places in the system. This means that funding and effort can both target the highest risks with greatest urgency. **Consider options** – consider: short and long-term plans; treatment, non-treatment and behaviour change options; where along the chain the control measure would have most impact; multiple barrier approaches. Improvements might include changes to facilities/assets (capital works), operational practices, staff and user behaviours or any combination thereof. Types of control measures for CBS systems (Eve): Substitute the hazardous equipment, e.g. modify toilet to remove dead spaces Improve treatment controls, e.g. heat or chemical inactivation; pH shocks Improve non-treatment controls, e.g. change collection timings; fly/vector control

		Use standard operating procedures, e.g. change operating or working procedures **Improvement plan** – *Use a step-wise approach to get incremental improvements.* Consolidate the options into a clear plan of action and… Prioritise changes based on the highest risks Identify who takes action for implementation (and when, how, etc.) Assess the cost of making changes – affordable interim control measures may be fine until more expensive options are feasible.
Module 5: Monitor control measures and verify performance Outputs: An operational monitoring plan A verification monitoring plan Independent assessment	5.1 Define and implement operational monitoring 5.2 Verify system performance 5.3 Audit the system Control measures have to be integrated into your operational procedures; how long might that take? What's realistic?	Is the system operating as planned? **Implementing monitoring** – Describe how, where, when and by whom each control measure is monitored – make sure the data collection methods you choose (for monitoring) are practical, feasible and cost-effective for your context (e.g. simple, visual checks, sampling and testing, or collecting usage info in log books, etc.). This is routine, day-to-day monitoring to show you that all is working as expected. It generates evidence to show that existing operations are sufficient; and if not, shows where changes need to be made. **Verification and audit** – Periodically verify whether your monitoring system meets your intended performance outcomes (such as quality reuse products). E.g. use microbial testing, health monitoring or KAP surveys for exposure groups, satisfaction surveys, etc. Check out the technical checklists in the SSP manual! (Page 75) E.g. monitor for E. coli and helminth eggs every 3–6 months at exposure points.

		External agencies may also want to independently audit your plan and approach, such as relevant local government authorities. You could choose to engage these authorities in your SSP process from the start to get their buy-in and support.
Module 6: Develop supporting programmes and review plans Outputs: Supporting programmes and management procedures that improve implementation of the SSP outputs Up-to-date SSP outputs responding to internal and external changes	6.1 Identify and implement supporting programmes and management procedures 6.2 Periodically review and update the SSP outputs	How can we adapt to changes? Module 6 offers ideas on how to support the development of people's skills and knowledge and an organisation's ability and capacity to meet SSP commitments. Questions to ask: Do you need new staff training programmes? Do standard operating procedures need updating? Do you need new educational and informational materials for users? E.g. on the importance of handwashing with soap, the use of PPE when cleaning, correct toilet usage, etc. Should new health communications protocols be developed for staff and customers? Is there a gap in knowledge that requires some research/analysis? Should you shift attention onto more policy influencing and lobbying on CBS SSP needs? Do you have (adequate) emergency management procedures in place? **Plan review** – an annual review (and update) of your plan is recommended.