Opportunities and barriers to recovering value from faecal sludge in sub-Saharan Africa

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Statement of Originality

I hereby confirm that this PhD thesis is an original piece of work conducted independently by the undersigned and all work contained herein has not been submitted for any other degree. Where appropriate, I have acknowledged the nature and extent of work carried out in collaboration with others.

All research material has been duly acknowledged and cited, and ethical approval has been obtained for all research activities where necessary.

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Abstract

Pit latrines are the most common sanitation systems used in sub-Saharan African cities. The rapid expansion and densification of urban areas has led to an urgent need for sustainable management practices which safely remove and transport faecal sludge from pit latrines to treatment facilities. Transformation into compost or soil conditioner can add further value by recovering nutrients for agriculture. This thesis examines key opportunities and barriers to faecal sludge management and value recovery using the city of Blantyre (Malawi), as a case study. Socio-technical interactions and technological innovations are examined at three points in the 'faecal sludge value chain': removal of faecal sludge from pit latrines, treatment with novel composting systems, and public acceptability of the derived compost. Menstrual waste, which is commonly found in pit latrines, can obstruct pit emptying devices; the first objective was therefore to quantify menstrual waste entering pit latrines and identify its behavioural drivers. Surveys and interviews established that substantial quantities of cloth and pads are discarded in pit latrines, but socio-cultural sensitivities inhibit disposal elsewhere. Biological composting methods, such as use of black soldier fly larvae (BSFL) (*Hermetia illucens*), offer novel faecal sludge treatment strategies; the second objective was therefore to investigate the effectiveness of BSFL composting. Laboratory experiments examined the die-off of faecal indicator organisms in faecal sludge and vegetable waste in the presence of BSFL and found reductions in *Escherichia coli* but not in *Enterococcus faecalis*. Lack of public acceptability is regarded as a critical barrier to recovering agricultural nutrients from faecal sludge; the third objective was therefore to assess public acceptability and willingness to pay for human-excreta-derived fertiliser (HEDF). Surveys revealed that almost all people were willing to buy maize grown in HEDF, and buy HEDF to use on their farms, provided that they were able to view a sample of the product. The thesis highlights the importance of understanding cultural norms and behaviours of beneficiaries in order to design effective and sustainable interventions, and how the siloed nature of sanitation and solid waste management obscures their important interconnections. Overall, presence of solid waste in pit latrines remains one of the most significant and complex obstacles to economic and efficient recovery of faecal sludge, whilst public acceptability is often underestimated, and novel treatment solutions remain promising but require further investigation.

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List of Abbreviations

AEW	Agricultural extension worker
ANOVA	Analysis of variance
BSF	Black soldier flies
BSFL	Black soldier fly larvae
CFU	Colony forming units
EC	Electrical conductivity
FISP	Farm Inputs Subsidy Programme
FSM	Faecal sludge management
HEDF	Human excreta derived fertiliser
KI	Key informant
LB	Luria-Bertani
MHM	Menstrual hygiene management
MLGA	Membrane lactose glucuronide agar
MWK	Malawian kwacha
PBS	Phosphate buffered saline
QMRA	Quantitative microbial risk analysis
SSA	Sub-Saharan Africa
UDDT	Urine-diverting dry toilets
WASH	Water, sanitation, and health
WTP	Willingness to pay
WWTW	Wastewater treatment works

Chapter 1 | General introduction

1.1 Sanitation in sub-Saharan Africa

Around the world, an estimated 3.8 billion people use toilets connected to non-sewered sanitation systems, whereby their excreta are collected and stored in a pit or a tank rather than being channelled elsewhere by waterborne sewerage (World Health Organization, 2019). The region of sub-Saharan Africa (SSA) has one of the highest proportions of people reliant on non-sewered sanitation worldwide, used by an estimated 78% and 60% of urban and rural populations respectively (Berendes et al., 2017). Pit latrines are one of the most widely used non-sewered sanitation systems in SSA, and typically consist of a hole in the ground, into which excreta falls, covered by a superstructure which offers privacy to the user (Nakagiri et al., 2015a). The pit may be lined or unlined and this modification has an impact on the quality and quantity of the sludge and the feasibility of emptying it.

The lifetime management of a pit latrine ultimately determines its value to public health (Berendes et al., 2017). When pit latrines become full, they are typically either covered with earth and a new pit dug nearby, or else the faecal sludge is dug out and the pit reused (Thye et al., 2011; Nakagiri et al., 2015a). Poor burial of the pit or indiscriminate disposal of the contents can result in public exposure to untreated excreta and potentially cause faecal-oral disease transmission (Thye et al., 2011). Thus, use of a pit latrine is only the first step in a ‘chain’ of steps - called the ‘sanitation service chain’ - which are necessary to preserve public and environmental health (**Figure 1.1**). The term ‘faecal sludge management’ (FSM) refers to the safe transferral of excreta and other materials from on-site sanitation systems through the sanitation service chain (Strande, 2014a). In recent years, the importance of FSM to public health has been highlighted, notably through the development of ‘shit flow diagrams’ (of which a simplified version is presented in **Figure 1.2**), which evaluate amounts of excreta which are safely and unsafely disposed of in the urban and peri-urban environment (Peal et al., 2020).

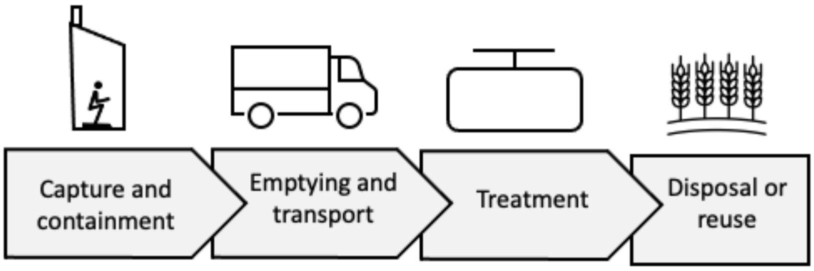

Figure 1.1. The sanitation service chain. Adapted from Strande (2014a).

The hazards of poorly managed pit latrines are particularly acute in densely populated urban areas, such as informal settlements, where latrines are often shared and fill quickly but there is limited space to dig new pits (Thye et al., 2011; Peal et al., 2014). SSA is home to the highest proportion of urban population living in informal settlements in the world, estimated at 55% of the urban population in 2018, and expected to grow further (UN-Habitat, 2020). As urban and peri-urban areas expand and densify, decision patterns in SSA households for emptying and abandoning pit latrines show signs of responding to the decrease in availability of land. For example, a survey of over 600 informal settlement households with pit latrines in Dar es Salaam, Tanzania, revealed that whilst only 36% of households had actually emptied their latrine in the past, 60% of households intended to empty their latrine in the future, indicating that demand for latrine emptying could be growing (Jenkins et al., 2015). However, the amount of sludge recovered at official disposal points does not always tally with the amount that is generated (Yesaya and Tilley, 2021). **Figure 1.2** shows collated data of the relative magnitude of different disposal pathways for excreta in 14 SSA cities, and unsafe disposal from non-sewered sanitation technologies is revealed as a substantial proportion of the total (Furlong, 2017).

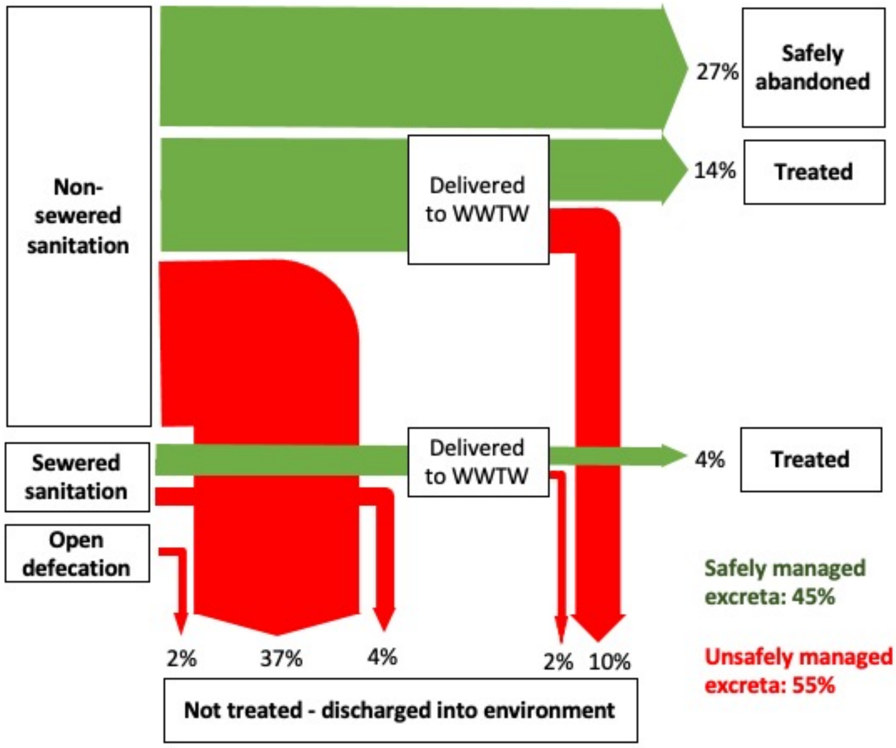

Figure 1.2. Simplified 'shit-flow diagram' showing excreta management across 14 African cities. Green arrows indicate excreta which is 'safely managed' and red arrows indicate excreta which is 'unsafely managed'. The size of the arrows is proportional to their flows. Adapted from Furlong (2017).

There are rare examples of local authorities providing households with free pit emptying services, such as eThekwini Municipality in South Africa (eThekwini Municipality, 2012; Sutherland, 2014), but the majority either charge for the service or do not provide it at all (Strande, 2014a). When pit latrines fill up, therefore, the sludge is often disposed into surrounding drainage channels or buried elsewhere on their property (Thye et al., 2011). Many households turn to emptying services from the informal private sector (i.e., buckets and spades), which are often cheaper, more easily accessed and have greater flexibility in technology type (thus potentially being able to cater for more kinds of pits) than more formalised services (i.e., vacuum trucks) (Thye et al. 2011). The cost of pit emptying is borne by the household, meaning that even though FSM systems do not require the users to purchase water for their operation, they nonetheless place a greater financial burden on the poor, whilst receiving fewer subsidies than sewerage (Dodane et al., 2012; Berendes et al., 2017).

In 2015, FSM was formally enshrined within the sanitation-related target of Sustainable Development Goal 6, which stipulates that excreta are not just ‘contained’ but also ‘safely disposed of’ (Mara and Evans, 2018). To that end, there is an urgent need to deliver widely accessible, affordable, and properly regulated pit emptying services and treatment facilities for the millions of people using non-sewered sanitation in SSA in order to meet the target by 2030 (Mara and Evans, 2018; Berendes et al., 2017). Furthermore, in the coming years, demand from agricultural industries for faecal sludge may increase due to the geopolitical risks associated with finite phosphorus rock supplies and the cost of producing nitrogen fertilisers through the energy-intensive Haber-Bosch process (Chowdhury et al. 2017; Iwaniec et al. 2016). As human excreta contain key elements required for healthy crop growth, pit latrines constitute a widely available but under-utilised source of agricultural nutrients (Peal et al 2020; Wielemaker et al., 2018). Reusing excreta in agriculture could potentially provide further impetus to the faecal sludge recovery process, whilst being particularly relevant for SSA due to the beneficial impacts on soil, which are often highly weathered and contain little organic matter (Ferguson, 2014; Eden et al., 2017; Oldfield et al., 2018).

In light of these global developments, now is the opportune moment to focus and accelerate progress in delivering sustainable FSM systems around the world. However, progress to date has been limited due to a range of technical, social, and economic obstacles. The fragmented nature of FSM, where roles, responsibilities, and incentives play out between very different stakeholders, has meant that these challenges have been difficult to tackle in a unified way (Water Research Commission, 2015). This thesis examines a range of opportunities and barriers to FSM delivery through the lens of the sanitation service chain in order to provide a holistic and interdisciplinary viewpoint.

1.2 Studying the sanitation service chain

The safe and sustainable management of faecal sludge is an inherently socio-technical activity. Infrastructure rarely operates in isolation; people are responsible for using and maintaining it, and the functionality of the infrastructure is dependent on their actions (Kaminsky and Javernick-Will, 2014). Studying this socio-technical interface is particularly important when considering excreta and toilet use which are often imbued with complex cultural beliefs, restrictions, and taboos (Akpabio and Takura, 2014). **Figure 1.3** illustrates some of the social, technical, and economic processes that play into the sanitation service chain. This thesis has taken a holistic approach, whereby opportunities and barriers at three points in the sanitation service chain are examined, and the complex interplay of human behavioural and technological factors are considered. These three points of the sanitation chain are discussed in more detail below.

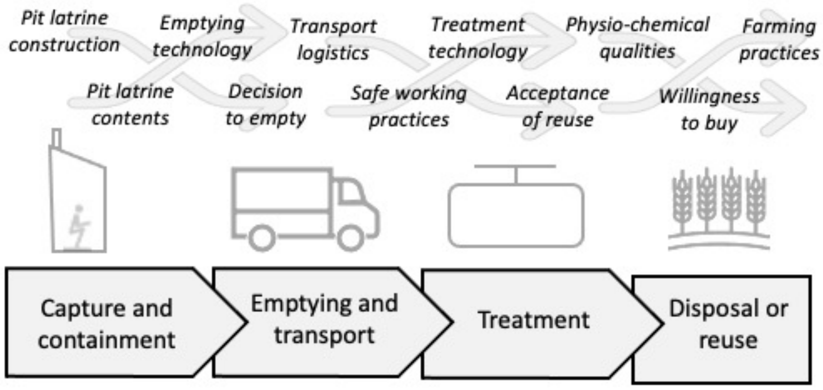

Figure 1.3. Social and technical processes and interactions in the sanitation value chain.

1.2.1 Capture: problematic pit latrine contents

At the beginning of the sanitation service chain, a person uses a toilet. However, human excreta are not the only material that is typically deposited in pit latrines (**Figure 1.4)**. Solid waste is one of the most common, and problematic, materials found in pit latrines (Sisco et al., 2017; Tembo et al., 2019), and baby nappies, anal cleansing materials, and menstrual hygiene materials in particular, are likely to be present (Nakagiri et al., 2015b). Habitually disposing of solid waste in a pit latrine can almost double the rate at which it fills up (Still and O'Riordan, 2012); however, many locations in SSA lack adequate solid waste management infrastructure and instead rely on open burning of rubbish in pits (Bundhoo, 2018). Therefore, many materials continue to be deposited in pit latrines regardless of the consequences, due to the relative discretion and privacy that the location offers (Still and O'Riordan, 2012).

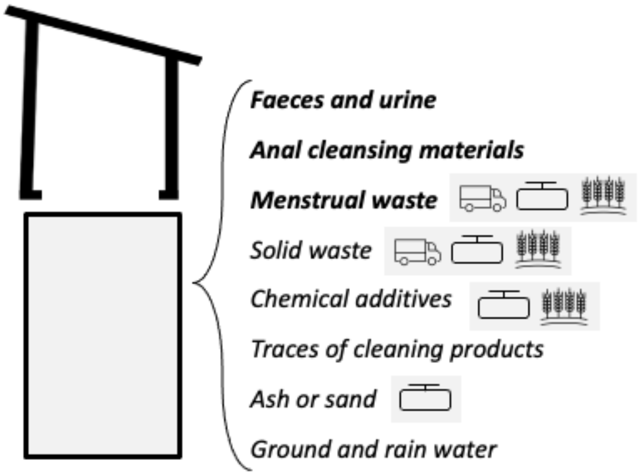

Figure 1.4. Typical pit latrine contents. Substances with particular socio-cultural sensitivities are in bold, and the technical challenges that they can potentially cause in the sanitation chain are indicated by the truck symbol (emptying/transport stage), tank symbol (treatment stage), and crop symbol (reuse stage) (Source: Author).

When a pit latrine contains solid waste, it becomes more difficult and time-consuming to empty the faecal sludge easily and safely (Holm et al., 2018; Tembo et al., 2019). This is because mechanical emptying devices are generally designed to pump fluids, but if waste (particularly textiles) becomes entangled in the propelling blades it can cause the pumps to malfunction, and so the waste must be manually removed first (Sisco et al., 2017). In recent years, efforts have been made to design pit emptying devices with powerful maceration capabilities so as to be able to pump waste-filled sludge without difficulty, but these are unlikely to be widely available or affordable to most small-scale pit emptying businesses (Chipeta et al., 2017). The presence of waste can furthermore have a detrimental effect on transport, treatment, and reuse in agriculture, by increasing the cost of these processes, affecting the efficiency of treatment, and downgrading the quality of compost produced (Niwagba et al., 2014; Tembo et al., 2019).

Menstrual waste is a particularly common type of solid waste found in pit latrines, as socio-cultural sensitivities necessitate private and discreet disposal (Scorgie et al., 2016). The intimate linkages between managing menses and access to adequate water and sanitation facilities have been highlighted in recent years, with studies of menstruation-related matters (often termed 'menstrual hygiene management' (MHM)) becoming more common in the water, sanitation and health (WASH) sector (Sommer et al., 2020). However, these studies are not often explicitly focussed on faecal sludge or sanitation (with the exception of Kjellén et al. (2011) and Sommer et al. (2013)), but rather tend to foreground the experiences and needs of women, and particularly, schoolgirls (e.g., Wall et al. (2018), Chinyama et al. (2019), MacRae et al. (2019), and MacLean et al. (2020)). Therefore, while significant and important insights into the socio-cultural constraints of menstruation have been found, linkages to the types of menstrual waste generated in the urban environment, menstrual waste disposal, and the resultant interactions between menstrual waste and sanitation and solid waste infrastructure remain poorly understood in quantitative terms. For instance, the volumes of menstrual waste generated annually, and the pathways and destinations of menstrual waste in the urban environment, have not been studied in depth at all.

Socio-cultural studies have revealed that, whilst the shame and stigma surrounding menstrual blood is almost universal, the status of menstruation can affect participation in public life in various ways. For instance, in some cultures, menstruating women might be expected to avoid crowded places or isolate themselves, and refrain from carrying out household chores such as cooking or washing (Morrison et al., 2018; Mohamed et al., 2018; Shah et al., 2019). Notable in parts of the world (particularly South Asia) is a strong religious and spiritual component to menstrual restrictions (Baumann et al., 2020), whilst in SSA, widespread views that menstrual blood can be used to perform dangerous witchcraft rituals are reported (Scorgie et al., 2016; Chinyama et al., 2019). Therefore, whilst the sight of menstrual blood is almost universally viewed as shameful, there are many local variations and nuances in beliefs and practices which can potentially affect women's usage and disposal of menstrual absorbents (Mohamed et al., 2018).

There is a need to combine insights from the social sciences and engineering in order to sensitively address menstrual waste management, so that women can have access to sustainably managed infrastructure and the products that suit their needs (Tilley et al., 2013). Whilst the ubiquitous presence of menstrual waste in pit latrines pose challenges to the development of economic and sustainable faecal sludge management, powerful and invisible processes drive these waste flows, and these are not likely to be quickly or easily adapted (Niwagba et al., 2014; Scorgie et al., 2016). In order to better understand and frame the interactions between menstrual waste and sanitation infrastructure, it would be helpful to gain a broader picture of the different ways in which menstrual waste are disposed and their relative prevalence and behavioural drivers, in order to fully assess the possibilities of diverting menstrual waste from pit latrines into other disposal pathways.

1.2.2 Treatment: the rise of biotechnology

In the middle of the sanitation chain, faecal sludge is treated to reduce concentrations of pathogenic organisms and odorous compounds (Niwagba et al., 2014). Whilst treatment of faecal sludge has traditionally relied upon processes such as composting, entrenchment, or anaerobic digestion, innovative biological waste processing techniques have gained prominence in recent years (Ronteltap et al., 2014). Controlled use of biological agents such as worms or fly larvae can achieve much faster degradation of organic matter than traditional methods (Čičková et al., 2015), leading to speculation as to whether these waste processing techniques could be used for the significant task of treating faecal sludge from low-income country cities (Banks et al., 2014).

One of the most exciting species to have emerged in recent years are black soldier fly larvae (BSFL; *Hermetia illucens*), which have gained worldwide recognition for their powerful waste management capabilities and have become one of the most studied fly species for the purpose of organic waste treatment (Čičková et al., 2015). BSFL are the most efficient organic waste convertors of any known fly species due to the great diversity of digestive enzymes in their gut and saliva (Kim et al., 2011). The production of useful by-products (larvae/prepupae for livestock feed or biofuel, and the insect frass as fertiliser) and reduction of odorous compounds adds further value to the process and makes them a particularly interesting candidate for faecal sludge treatment (Ronteltap et al., 2014; Beskin et al., 2018).

Black soldier flies (BSF) are typically found in tropical regions and develop through five life stages: eggs, larvae, prepupae, pupae, and adult flies (**Figure 1.5**). BSF require temperatures between 24°C - 30°C to thrive (Dortmans et al., 2017; Tomberlin et al., 2009), but they can also survive at colder temperatures, being hardiest at pupal stage (Spranghers et al., 2017). The larval stage is spent consuming decomposing organic matter and BSFL have naturally evolved a robust immune system to inhabit this environment, displaying some of the largest diversity of antimicrobial peptides of any insect (Zdybicka-Barabas et al., 2017; Vogel et al., 2018). Once the prepupal phase is reached, the prepupa empties its gut and leaves the food substrate to seek a dry and dark place to pupate. Pupation generally takes 2-3 weeks, and the adult fly lives for about 7 days (Dortmans et al., 2017), during which time it does not tend to interact with humans and does not behave as a disease vector. There are indications that the presence of BSF can suppress the oviposition of other fly species, particularly house flies (Bradley and Sheppard, 1984), meaning that their presence could actually inhibit the presence of other flies which act as disease vectors.

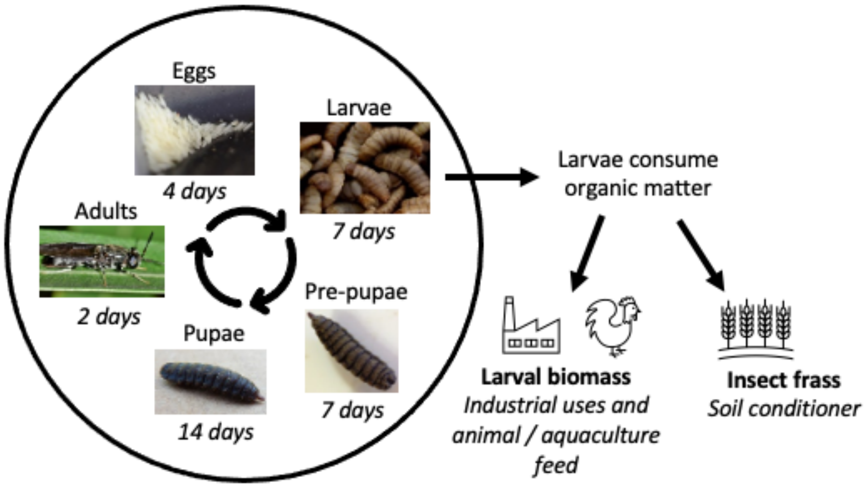

Figure 1.5. Lifecycle of the black soldier fly larvae and organic waste treatment procedure.

Examples of pilot trials using BSFL to process organic matter are abundant (Sheppard et al., 1994; Newton et al., 2005; Hem et al., 2008; Zurbrügg et al., 2017), and exploitation on an industrial and commercial scale is rapidly increasing (Li et al., 2019). However, as with any mass-produced livestock, rearing BSF requires a certain degree of specialist skill and experience (Lohri et al., 2017). Semi-decentralised BSFL treatment plants, whereby larvae are reared in a centralised hatchery and then distributed to decentralised waste processing sites, have therefore been suggested as the most suitable model for municipalities looking to utilise BSFL treatment for their waste (Lohri et al., 2017). A semi-decentralised system is advantageous in that it allows centralisation of specialist expertise and resources on the delicate task of fly rearing, whilst keeping satellite processing sites located close to where the waste material is being produced (Diener et al., 2015a). This could be particularly useful where climatic conditions mean that additional heat and light sources are required to rear flies, and where sources of waste are unevenly distributed across a large area. It also provides the opportunity to centralise more technical equipment for converting larvae/prepupae into meal, biodiesel, and chitin, as grown larvae can be returned from the waste treatment sites to the centralised site for processing (Lohri et al., 2017).

BSFL have been shown to thrive on human faeces as a feed substrate (Lalander et al., 2013), and a study of South African pit latrines found that the pH, moisture content, and chemical oxygen demand were all within a range suitable for BSFL development (Banks, 2014). However, the deepest (and therefore oldest) layers of faecal sludge in certain latrines were noted to be less suitable for the larvae (Banks, 2014). Total organic solids in pit latrines decrease proportionally with depth, reducing from 80% at the top layer to a levelling-off around 35% at the bottom layer (Nwaneri et al., 2008), which means a reduction in nutritional value to BSFL, and suggests that shallower pits, or those that are emptied regularly, may provide the best substrates. A variety of substrate moisture contents are found to support BSFL, ranging from 50% (Vogel et al., 2018) to 85% (Banks, 2014).

One reason why BSFL is of particular relevance to faecal sludge treatment is their ability to reduce concentrations of certain pathogenic organisms in the substrate (Gold et al., 2018). However, some pathogens show greater reductions than others and some do not appear to be reduced at all. Pathogens such as *Escherichia coli*, various strains of *Salmonella*, and viruses (including types of Reovirus, Adenovirus, and Enterovirus) can be reduced considerably under BSFL feeding activity in human faecal substrates, often falling below detection limits within days or weeks (Lalander et al., 2013; Lalander et al., 2015a; Lalander et al., 2015b). Others, such as *Enterococcus faecalis* and Bacteriophage ΦX174 show no substantial reductions compared to control treatments that do not contain larvae, suggesting that the mechanism by which pathogen destruction is achieved is not effective for reducing concentrations of these organisms (Lalander et al., 2013; Lalander et al., 2015a). It is not yet clear whether BSFL feeding activity might be able to supress, rather than reduce, concentrations of these pathogens, preventing their proliferation in the material (Lalander et al., 2015a).

The *Ascaris* worm is one of the most prevalent human helminths and its eggs (which are excreted in the faeces of infected people) are extremely persistent in the environment, surviving in faecal sludge for months or even years (Asaolu and Ofoezie, 2018). Experiments investigating the effect of BSFL feeding activity on the viability of *Ascaris suum* ova in faeces demonstrated reductions of less than 1 $\log_{10}$, which is short of the necessary reductions recommended by the World Health Organisation for the use of faecal sludge in agriculture in *Ascaris* endemic areas (Navarro and Jiménez, 2011; Lalander et al., 2015a). Nonetheless, any post-treatment steps to inactivate *Ascaris* ova in faecal sludge would be simplified by the considerable reduction in material mass as a result of BSFL feeding (Lalander et al., 2013). When concentration and viability of *Ascaris* ova were monitored in a continuous flow BSFL treatment system for a month, no significant reduction in concentration or viability were observed; however, none of the *Ascaris* eggs developed into pre-larvae (Lalander et al., 2015a). Once removed and kept at 28°C, 79% of the eggs developed into prelarvae within a month, indicating that development of the eggs was inhibited whilst inside the BSFL processing system (Lalander et al., 2015a). This may be due to the elevated concentrations of total ammonium nitrogen resulting from the BSFL feeding process, as ammonia has has been shown to inactivate *Ascaris* eggs (Fidjeland et al., 2015). If this is the case, the longer retention time in the BSFL system could potentially lead to inactivation.

BSFL feeding activity does not only affect concentrations of pathogenic organisms in their feed substrate, but can also affect concentrations of certain metals, pharmaceuticals, and pesticides. Substances including carbamazepine (CAS 298-46-4), roxithromycin (CAS 80214-83-1), trimethoprim (CAS 738-70-5), azoxystrobin (CAS 131860-33-8), and propiconazole (CAS 60207-90-1) have been found to significantly degrade after BSFL processing, with no accumulation noted in the larvae (Lalander et al., 2016). Cadmium can accumulate in the larvae with a bio-accumulation factor between 2.32 and 2.94, whereas lead was not found to accumulate in the larvae (Diener et al., 2015b). The bio-accumulation factor of zinc decreased as zinc concentration in the feed increased, indicating that zinc is actively regulated within the body of the larvae (Diener et al., 2015b). Whilst heavy metal concentrations are generally low in faecal sludge of domestic origin, such treatment effects could nonetheless potentially be beneficial for faecal sludge treatment, as the deposition of solid waste in pit latrines can cause small amounts of heavy metals to be present (Niwagba et al., 2014).

Whilst BSFL feeding activity has been clearly demonstrated to destroy certain pathogens and affect the characteristics of the feed substrate, the mechanisms by which this occurs are still poorly understood (Gold et al., 2018). Gaining greater insights into these processes could potentially allow them to be manipulated, and improve the efficiency and quality of treatment. In particular, the low nutritional value in certain pit latrine sludge layers raises questions as to whether co-processing of faecal sludge with other waste streams, e.g., organic waste, could provide a more optimal diet for the larvae, and improve treatment system operation and by-product processing accordingly. As such, there is substantial scope for further research to explore how this innovative bio-technology treatment method can be used in FSM.

1.2.3 Reuse in agriculture: overcoming the disgust instinct

At the end of the sanitation service chain, treated human excreta is either discarded or recycled for agriculture or energy generation purposes. In common with other organic amendments, human excreta have been shown to improve soil health and water retention capacity which increases productivity and resistance to dry conditions, making agricultural reuse of excreta particularly relevant for SSA (Eden et al., 2017; Oldfield et al., 2018). As global phosphorus rock supplies are finite, finding alternative sources of phosphorus for agriculture such as human excreta-derived fertilisers (HEDF) will become increasingly important. However, due to a psychological system evolved to protect us against infectious disease, almost all people instinctively avoid human faeces (Curtis et al., 2011), and the idea of using it to grow food can be particularly difficult to accept. The marketing and use of HEDF therefore faces a difficult challenge: overcoming an in-built reaction of disgust.

Despite this instinct, re-use of human excreta in agriculture has a long history. It is well documented that ancient civilisations in the Amazon (Factura et al., 2010) and China (Genpan, 2008) regularly returned various forms of excreta to agricultural fields in order to maintain soil fertility, and this practice continues in rural China to this day (Ying et al., 2014). Historical use of HEDF has also been documented in Pakistan and Tanzania (Rugalema et al., 1994; Drangert and Nawab, 2011; Khalid, 2017). In more recent times, there are reports of faecal sludge and wastewater reuse in agriculture occurring in Ghana, Mali, Benin, Nigeria, China, and Vietnam (Dreschel et al., 2010; Cofie et al., 2005; Cofie et al., 2010; Buit and Jansen, 2016; Knudsen et al., 2008; Jensen et al., 2008), and the global prevalence of urban wastewater reuse has been estimated at 2.9 million hectares of croplands (Thebo et al., 2017). As such, HEDF use is clearly a global phenomenon rather than being confined to any particular region or culture.

Various anthropological studies over the last few decades have presented a detailed picture of how human excreta is used in agriculture by societies around the world, and certain commonalities can be identified. As shown in the following examples, dried or stabilised faecal sludge (i.e., stored for a period of time) are consistently preferred to fresh faecal sludge as fertiliser, and the odour and appearance of faeces are repeatedly highlighted as important indicators of whether the material was considered suitable to use. In Vietnam, the duration needed for composting human faeces is thought to be sufficient when the material no longer has a strong odour and is dry and dark in colour (Knudsen et al., 2008), whilst in Ghana, farmers identify septic tank waste (which they prefer over fresh faecal sludge from public toilets) by the black colour of the material (Cofie et al., 2010). In Pakistan, fresh excreta are avoided by farmers, but outflows from septic tanks or latrine pits are considered acceptable to use due to their different colour and smell (Drangert and Nawab, 2011). In general, as fresh excreta become diminished in odour and darker in colour, people appear to change their opinions and behaviour towards it and are no longer disgusted by it (Khalid, 2017). This attitude was rationalised through the transformative effects of sunlight killing germs and drying the material (Khalid, 2017).

The odour of excreta is often identified as an indicator of danger, and even a direct cause of infection. In Pakistan, when participants were asked to rank various forms of faecal matter and urine according to health risk, the rankings appeared to indicate a general increase in perception of risk with increased strength of odour (Drangert and Nawab, 2011; Khalid, 2017). Fear of bad odour also emerged from participants as a central research theme in anthropological studies with farmers using excreta in Vietnam (Knudsen et al., 2008; Mackie Jensen et al., 2008). Participants explained that 'smelly' air contained germs, which could enter the human body through the lungs and cause disease to the respiratory and digestive systems (Knudsen et al., 2008; Mackie Jensen et al., 2008). By contrast, faecal matter with no smell was considered harmless; many of the Vietnamese farmers interviewed considered protective measures to be unnecessary when applying odourless faecal matter to the fields. Similarly, in Ghana, farmers specifically linked the foul smell of excreta to damaging environmental effects (Cofie et al., 2010).

Interviews with farmers and consumers about using faecal sludge as a fertiliser revealed preferences for only using it with certain crop types. Cereal crops, such as maize, sorghum and millet, are more widely acceptable for fertilising with faecal sludge, whilst vegetables tended to have lower acceptability due to a higher likelihood of being eaten uncooked and are therefore rightly perceived as having a higher risk of pathogen transfer (Cofie et al., 2010; Khalid, 2017; Rashid et al., 2017). Non-food crops, such as flowers, are also regarded as more acceptable for fertilisation with faecal sludge (Ekane et al., 2016). A similar pattern of opinion emerges from studies of wastewater irrigation in developed countries, with the degree of public support public depending on the crop being irrigated and the perceived level of contact with the wastewater (Friedler and Lahav, 2006; Smith et al., 2018).

Despite these commonalities, it is still difficult to interpret the willingness of farmers and the general public to accept HEDF use (Gwara et al., 2020). It is unclear why people hold the opinions and values that they do, and what might provide an incentive to change them. However, as the public acceptability of HEDF is closely linked to its economic value (Buit and Jansen, 2016), it is important to understand both the willingness of farmers to use HEDF, and their willingness to pay for it, in order to understand if the production and marketing of HEDF at scale is viable. For instance, whilst farmers might express disgust at HEDF, they are also sometimes willing to buy and use it if certain conditions were met, e.g., sufficiently low cost and adequate appearance (Buit and Jansen, 2016). There can therefore be a trade-off between price and acceptability, i.e., it is only acceptable if it is sufficiently cheap, with appearance acting as a modifying factor. Changing the appearance of faeces is a vitally important process to redefine it from a bodily excretion to a useful resource, and certain processing procedures, such as drying, packaging and labelling, can help to achieve a meaningful transformation for the consumer (Buit and Jansen, 2016; Gwara et al., 2020). Establishing locally accurate price points and the degree of post-treatment processing required to produce an 'acceptable' product are therefore an important part of determining the viability of HEDF.

1.3 Managing faecal sludge in Malawi

Safe management of faecal sludge is a pressing challenge throughout the world, but especially in SSA, where non-sewered sanitation technologies such as pit latrines are predominant (Berendes et al., 2017). Within SSA, the southern eastern country of Malawi presents a particularly interesting case study for all of the challenges and opportunities so far discussed.

Malawi is a landlocked country covering an area of 118, 484 km^2 and containing a population of approximately 18.6 million people (The World Bank Group, 2018a). It is one of the poorest countries in the world, with a high proportion (70%) of the population living on less than $1.90 per day (United Nations Development Programme, 2020). Malawi is heavily reliant on subsistence agriculture (National Statistical Office, 2020), but a combination of population pressure and low land availability creates risks to food security (Giertz et al., 2015). Compared to its neighbours, Zambia, Tanzania, and Mozambique, Malawi has a very high population density of 192 people per km^2 (The World Bank Group, 2018b), whilst only a small proportion of land is suitable for growing crops (Li et al., 2017). Constraints on land availability make it challenging for smallholder farmers to rotate crops, or allow land to lie fallow, in order to maintain and protect soil fertility (Li et al., 2017). Soil rehabilitation through sustainable agricultural practices, such as HEDF use, are therefore urgently required.

Two severe periods of food insecurity and hunger in the growing seasons of 2001/2 and 2004/5 led to food security and agricultural subsidies becoming a prominent and politically charged issue (Chinsinga, 2012). As a result, the Farm Inputs Subsidy Programme (FISP), which has existed in some form since the late 1990s, was significantly scaled up, with the government subsidising and distributing synthetic fertiliser to large numbers of resource-poor smallholder farmers. FISP has continued to operate to the present day (Basurto et al., 2020), and general consensus suggests that the FISP has succeeded in improving food security among the poor and increasing agricultural productivity (Chinsinga, 2012; Basurto et al., 2020). However, the heavy promotion and subsidisation of chemical fertiliser has resulted in a diminished use of organic alternatives, such as compost (Cai et al., 2019; Ndambi et al., 2019). As subsidies for farm inputs are scaled down (Nkhoma, 2018), interest in organic alternatives to synthetic fertiliser are likely to increase in the near future. Malawi therefore presents a timely opportunity to investigate whether there is willingness to accept and pay for HEDF among smallholder farmers.

Pit latrines are the most common form of sanitation in Malawi, used by 88% of rural households and 86% of urban households (National Statistical Office, 2020). As such, there is no shortage of faecal sludge available in proximity to farmland. Pit latrines are traditionally abandoned and replaced when full, but as urban areas increase in population size and density, pit latrine emptying is expected to become more prevalent in the coming years (Chunga et al., 2016). Currently, pit emptying businesses in Blantyre (the second largest city and commercial capital of Malawi) (**Figure 1.6**) are legally required to discharge faecal sludge at two wastewater treatment plants, located in the south west and south east of the city (Yesaya and Tilley, 2021). However, the amount of sludge being received at these treatment plants falls significantly short of what is expected given the prevalence of pit latrines across the city, suggesting that substantial volumes are being illegally dumped, despite discharge at the treatment plants being free (Yesaya and Tilley, 2021).

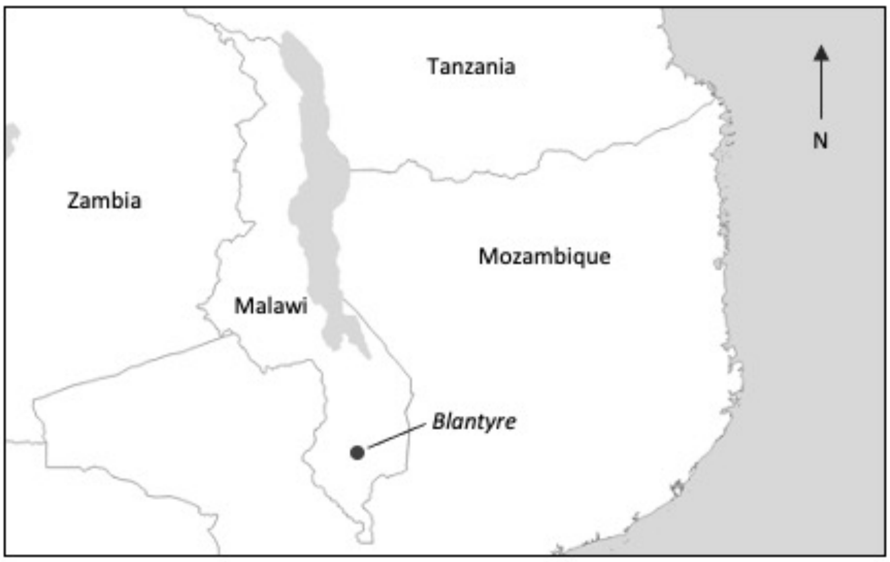

Figure 1.6. Location of Blantyre within Malawi.

In common with most other parts of the world, little is known about how menstrual waste interacts with sanitation infrastructure in Malawi. Whilst menstruation is typically regarded as something to be kept secret, its onset is also an important life event which marks the commencement of adulthood and many traditional rituals surround this important milestone (Piper Pillitteri, 2011; Perianes and Ndaferankhande, 2020). At the time that this project commenced, no studies had examined the experiences of menstruation in the context of urban areas or waste management; instead, existing literature primarily focussed on the experiences of rural schoolgirls and absenteeism (Piper Pillitteri, 2011; Grant et al., 2013). The literature has subsequently expanded to explore urban settings and menstrual absorbent preferences (Kambala et al., 2020; Mchenga et al., 2020); the discoveries of these recent studies are discussed alongside the thesis results in Chapter 7.

1.4 Aim and objectives of thesis

Systems to safely remove, treat, and dispose of faecal sludge from pit latrines are urgently required across urban SSA, particularly in densely populated informal settlements, in order to protect public and environmental health. Such systems have potential for wide-ranging benefits, such as using treated faecal sludge as an organic fertiliser particularly where it is being generated in proximity to intensively used farmland, and can take advantage of recent developments in novel biological treatment technologies. However, the interconnectedness of waste management streams in urban SSA means that separating faecal sludge from other inorganic waste streams at source may be complex, and the public acceptability of faeces-derived products is unclear.

The overarching aim of this study was to ***identify key opportunities and barriers to implementing faecal sludge management systems and value recovery in urban sub-Saharan Africa***, using the city of Blantyre, Malawi, as a case study. The three specific research objectives are described below.

- Menstrual waste is one of the most common components of solid waste found in pit latrines and is also a highly socio-culturally sensitive material. The first objective is therefore to ***quantify the extent to which menstrual waste enters the sanitation service chain and identify the socio-cultural processes that drive and sustain this behaviour and how they might be adapted.***
- Novel biological treatment technologies for faecal sludge have gained attention in recent years, although their effectiveness in practice, and opportunities for synergies with other waste treatment streams, is still being established. The second objective is therefore to ***investigate the efficiency of a novel biological faecal sludge management technology - black soldier fly larvae - on removing faecal indicator microorganisms from faecal sludge with and without the addition of additional organic waste.***
- Lack of public acceptability is regarded as one of the most important barriers to the recovery of agricultural nutrients from faecal sludge. The third objective is therefore to ***assess public acceptability and willingness to pay for HEDF and identify potentially effective strategies for promoting HEDF usage.***

Chapter 2 | Power, danger, and secrecy: a socio-cultural examination of menstrual waste management in urban Malawi

This chapter has been published as:

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R.S. Quilliam, K. Hampshire, E.A. Tilley, and D.M. Oliver supervised the project. H. Roxburgh designed the data collection tools with support from all other authors. K. Kaliwo and H. Roxburgh carried out the fieldwork with support from E.A. Tilley. H. Roxburgh led data analysis and interpretation with support from K. Kaliwo. H. Roxburgh produced the manuscript, and all authors commented on draft versions.

2.1 Abstract

Menstrual blood is not just a physical substance; it is laden with symbolism and often powerfully stigmatised. It is important to understand local perceptions and attitudes towards menstrual blood, as well as the preferred practices of menstruating women, in order to design appropriate sanitation and solid waste systems to support menstruation. Failure to take account of socio-cultural factors can jeopardise the effectiveness of such infrastructure. This study, conducted in Blantyre, Malawi, is a qualitative socio-cultural examination of how women manage and view menstruation. Thirty-nine interviews, conducted with individuals and with small groups of friends, were carried out with thirty-one women using pit latrines, flush toilets, and urine-diverting dry toilets in early 2019. Menstruation in Blantyre was found to be shrouded in secrecy because it was viewed as 'dirty', and therefore remained concealed. There was widespread anxiety about menstrual blood being used in *ufiti* (witchcraft), which affected how women used and disposed of their menstrual absorbents. At the same time, menstrual blood was also viewed as a powerful healing substance with uses in traditional medicine. The type of infrastructure required by women to support their menstruation depended on the type of menstrual absorbent used. Those using reusable cloth generally preferred a private bathroom with

discreet drainage, whilst those using disposable pads needed a discreet and convenient disposal system. Increased preference for disposable pads over reusable cloth (particularly for younger women in education or employment) suggested that menstrual waste profiles of urban areas may be changing. Understanding these changing needs will be crucial for planning effective, sustainable waste disposal and sanitation infrastructure.

2.2 Introduction

Menstruation and menstrual blood are not just physiological or physical phenomena; they are steeped in symbolism and subjectivity (Tan et al., 2017; Buckley and Gottleib, 1988). Globally, there are substantial spatial and temporal variations in how menstruation is regarded and managed, and how menstruating women are expected to behave (Mohamed et al., 2018). For example, in particular contexts, menstruation can affect women's participation in religious life (Wall et al., 2018; Ussher, 2006) and can cause a degree of withdrawal from public life, ranging from the avoidance of crowded places (Shah et al., 2019) to total isolation (Sah et al., 2018). Some menstruating women may be expected to abstain from cooking, washing, or household chores (Mohamed et al., 2018; Sah et al., 2018), whilst others do not refrain from anything at all (Appell, 1988).

Some broad trends are associated with the social conceptualisation of menstruation across different contexts. One common framing is of a "dirty", "polluting" process (Mohamed et al., 2018; Sah et al., 2019), under which menstruation and menstrual blood are stigmatised (Johnston-Robledo and Chrisler, 2013). As a result of such stigmatisation, many women around the world feel obliged to keep their menstruation secret and conceal any visible signs of bleeding (Mohamed et al., 2018; Shah et al., 2019; Sah et al., 2018). Whilst this stigmatisation is challenged in some spaces and spheres (Mondragon and Txertudi, 2019), it remains common in many parts of the world.

Menstruation, and the associated term 'menstrual hygiene management' (MHM), have become increasingly recognised in the water, sanitation and hygiene (WASH) development sector as an important and gendered aspect of sanitation and health (Sommer et al., 2015; Mahon and Fernandes, 2010). Infrastructural services that provide waste disposal and/or privacy - including water supply, sanitation and bathroom facilities, and solid waste collection - all play into women's experiences and practices of menstruation (MacRae et al., 2019). However, as Sommer et al. (2013) and others have argued, this infrastructure must reflect local norms and preferences around menstruation, rather than being merely replicated in different contexts (Sommer et al., 2013; Schmitt et al., 2018; Tilley et al., 2013).

Failing to take account of locally-specific ways in which menstruation is understood and managed can fundamentally undermine the effectiveness of health and environmental interventions. For instance, trials of a HIV-prevention vaginal ring in southern and central Africa showed that women preferred to remove their rings during menses, because of concern that the rings would impede the flow of blood and affect bodily hygiene; this compromised effectiveness of protection against HIV (Duby et al., 2020). Similarly, a preference towards disposal of menstrual waste in pit latrines can hamper the economic viability of the pit emptying sector, and impede the recovery of value from faecal sludge in the form of agricultural nutrients or energy (Sommer et al., 2013; Elledge et al., 2018; Kjellén et al., 2011).

The objective of this study was to examine, qualitatively, practices, preferences, and socio-cultural norms surrounding menstruation among women using three types of sanitation facility in Blantyre, Malawi – pit latrines, flush toilets, and urine-diverting dry toilets (UDDTs). Pit latrines are the most common type of toilet facility in Blantyre, used by 78% of the population, followed by flush toilets (21%) (National Statistical Office, 2017). UDDTs are relatively uncommon, used by less than 1% of the population, but are promoted in Blantyre and more widely across Africa by advocates of ecological sanitation. These are a type of resource-recovery toilet that separates urine and faeces at the point of use by diverting urine into a tank or into the ground and allowing faeces to fall into a dehydration vault. Water and solid waste should not enter the faecal vault of a UDDT as this can compromise the dehydration process (Winblad and Simpson-Hébert, 2004). The particular ways in which these three sanitation facilities facilitate or hinder management of menstruation are examined, with the aim of providing insights into improved service design.

2.3 Methods

Fieldwork was carried out in early 2019, and involved conversational interviews with 31 female participants between the ages of 19 and 63, living in the city of Blantyre, Malawi. Most of these women (N=23) were interviewed individually (35 interviews in total, as some participants were interviewed more than once). A small number (N=9) of participants were interviewed in small groups (N=4). In addition, two Malawian female key informants (KIs), colleagues at the University of Malawi, provided contextual information over the course of on-going discussions. Initially, sampling was restricted to women who had not yet reached menopause and therefore had recent experience of menstruation to discuss with the researchers. However, this was later expanded to include post-menopausal women who could provide perspective on certain issues of interest, such as changes in societal openness around discussion of menstruation.

Participants were recruited from two locations, chosen to represent contrasting provision of sanitation facilities. Twenty women were recruited from a low-to-middle income suburb of Blantyre, where households typically used either pit latrines or UDDTs (promoted and installed by a local NGO). Recruitment in that site was achieved by following a transect walk across the suburb, and approaching a house every 50m to explain the purpose of the study and invite residents to participate. If the household was not interested, did not contain a woman over 18, or nobody was at home, then the next house was approached. The second recruitment location was a university campus, where 11 users of flush toilets and pit latrines were recruited by standing at a central point on the university campus and inviting passers-by to take part, and also by snowball sampling, whereby participants were asked to recommend others who might be willing to participate. Participants from the campus were a mix of female students and campus staff (cleaning and security). Refusal to participate was around 30%, with the most commonly cited explanation being unwillingness to spend time, or not seeing any personal benefit from participating. In addition, further insight was obtained through discussion of the research with the KIs, which induced contributions of their own personal experiences and reflections on the topic. With their permission, notes from these conversations were analysed alongside the interviews.

Most participants were interviewed individually; however, in some cases participants were with a female friend or relative when the interviewer arrived, and requested that the interview be carried out with them present. In other cases a female friend joined them partway through the interview, and the participant requested that the interview continue, with the friend also contributing responses and thus creating a relaxed and sociable feeling (friends and family who sat in on the interviews were not formally counted as part of the 32 participants, and their details are not included in Table 1). Subsequently, this atmosphere was therefore encouraged further through the recruitment of friends for small group interviews (2 – 3 participants). Interviews were initially conducted through a set of open-ended questions (e.g. what menstrual absorbents do you use, and how do you dispose of them?), but eventually moved towards a guided conversation format (e.g. please tell us about how you manage your menstruation), which encouraged participants to explain, explore and discuss different topics that had emerged from the data as well as describing their own experiences. Follow-up interviews were conducted where clarification was needed, or when the researchers had further questions after reflecting on the interview. These were mostly conducted with participants interviewed early on, as the volume of new insights decreased throughout the data collection process. Participants were also asked to reflect on preliminary conclusions and offer opinions on their validity.

Interviews were conducted by two of the authors (Tamandani – a Malawian researcher at the University of Malawi, and Heather – a British PhD student). Individual and group interviews were conducted in the preferred language of the participant, which was usually Chichewa (two were conducted in English). All but one participant agreed for their interviews to be recorded; these were then transcribed, and (for interviews in Chichewa) translated to English. For the one unrecorded interview, notes of the conversation were made immediately afterwards. Each transcript with associated notes was then read and discussed line by line by the two interviewers, to ensure a commonality of understanding and interpretation. Where transcripts contained ambiguity, participants were contacted again to clarify the meaning of their comments. Analysis was conducted by inductive thematic coding, based on the principles of grounded theory (Strauss and Corbin, 1990). The two interviewers (Heather and Tamandani) read transcripts and notes closely, and then noted and compared emerging impressions and themes. Subsequently, one author (Heather) developed a series of inductive codes, and the transcripts coded in Nvivo (version 12, QSR International). The codes were based around two main analytical categories, with some degree of overlap: codes relating to socio-culturally constructed beliefs, attitudes and practices surrounding menstruation, and codes relating to the physicality and practicality of menstruation's interaction with sanitation and solid waste management infrastructure. Below, pseudonyms are used, and an age range (rather than exact age) is shown to preserve anonymity.

Ethical consent was obtained from the University of Stirling General University Ethics Board (reference number: GUEP 541) and from the Malawi National Committee on Research in the Social Sciences and Humanities (reference number: NCST/RTT/2/6), before commencement of fieldwork. All participants provided informed, written consent to partake in the study.

2.4 Results

Characteristics of participants are shown in **Table 2.1**.

2.4.1 Menstrual absorbents used

The two most common menstrual absorbents used by participants were disposable shop-bought sanitary pads (42%), and menstrual cloths (42%), the latter made from pieces of old clothing or blankets, used to absorb blood, and then washed, dried, and reused. In addition, two women used cotton wool and gauze to fashion home-made sanitary pads, locally referred to as 'cotton'. Only one university student used tampons on an occasional basis, and so these are not discussed further. As the usage of shop-bought and home-made pads are similar in many regards, they are discussed under a single term – pads.

Table 2.1. Characteristics of participants.

Characteristic	No (%) participants
Age group	
19-29	14 (45%)
30-39	6 (19%)
40-49	5 (16%)
50-59	4 (13%)
60+	1 (3%)
Not known	1 (3%)
Menstrual absorbent	
Cloths	13 (42%)
Pads	13 (42%)
Cotton	2 (6%)
Tampons	1 (3%)
Not known	2 (6%)
Toilet used at home	
Pit latrine	7 (23%)
UDDT	11 (35%)
Flush	6 (19%)
Not known	7 (23%)
Recruitment location	
Blantyre suburb	20 (65%)
Institutional campus (staff)	5 (16%)
Institutional campus (student)	6 (19%)

2.4.2 Cultural aspects of menstruation

2.4.2.1 Secrecy and respectability

All participants described a profound secrecy around menstruation, as Chifundo [50s, suburb, UDDT, cloth] explained: '*It's because of our culture, it doesn't allow that anyone should see [blood]'*. It was important for all participants to hide any visual, olfactory, or behavioural signs of menstruation, and they would exert considerable effort and energy towards concealment. It was considered shameful for others to see signs of menstruation, as Elizabeth [late teens, suburb, pit latrine, pads] described: '*When I use the toilet, maybe I have spilt some blood and I didn't check and see it, and my dad enters the same toilet, he may feel disgusted… it doesn't bring respect'*. It was considered particularly essential to keep the signs of menstruation secret from men and young children; some participants even described it as 'dangerous' for them to see signs of menstrual blood. Others spoke about hygienic and moral imperatives to keep menstruation secret. Pilirani [20s, KI, flush, pads] described a conversation she had with her mother, who told her: '*Menstrual blood is filthy. It is not like the regular human blood. It stinks, so for others to see it is not good at all'*. Two participants mentioned that people may discreetly refuse to eat food that they had prepared if they were known to be menstruating: '*Others when you cook food may say they are full, they don't want the food, and see you as filthy'* [Dalitso, 20s, campus-student, flush, pads]. Most women said they would feel comfortable discussing menstrual health concerns with a doctor, due to their perceived confidentiality. Chifundo [50s, suburb, UDDT, cloth] said: '*Menstruation is a private thing… so if you have any problems it's better to go and see a doctor who cannot disclose it to anyone'.* Some women commented that secrecy around menstruation was less severe than previously, with young women today feeling more freedom to share their menstrual problems with friends, and in trusted spaces like church groups.

2.4.2.2 Menstrual cloths as healing objects

In apparent contrast to the taboos associated with menstrual blood described above, many women also believed that menstrual blood had healing properties, as Fatsani [30s, suburb, pit latrine, cloth] commented: '*There is goodness in menstrual blood*'. Small amounts of menstrual blood remaining in the menstrual cloth after washing (as evidenced by staining and discolouration of the material) was believed to give the cloth medicinal qualities; cloth which had never been used to absorb menses, or ordinary blood, were not thought to have the same effect. Chisomo [50s, campus-staff, cloth] explained '*The thing making cloth to be powerful is the [menstrual] blood.'* Many participants, particularly those who were older, described using (or being aware of others using) cleaned menstrual cloth in traditional medicine practices. Kondwani [40s, suburb, pit latrine, cloth] explained the use and process: *'If your child gets sick then you take the [clean] menstrual cloth and warm it on the fire then put it on the body of the baby and the baby gets well, or even when you are having flu or cough, you take the menstrual cloth and warm it on the fire, then inhaling it the cough or flu goes away.'* Limbani [50s, suburb, UDDT, cloth] added another example: '*If your child has been burned by fire, we take [the menstrual cloth] and we use it on the wound, and the wound dries up so easy'.* Several women kept their menstrual cloths in case they were required by an ill or injured family member, even after they were worn out and no longer functional in their original sense. One woman required permission from her husband before discarding menstrual cloths, as they were considered so valuable.

2.4.2.3 Fear of ufiti

Almost every participant feared menstrual blood being used in *ufiti* (witchcraft). If another person got hold of a menstrual cloth or used pad, or even stained underwear, it was believed that they could take it to a *sing'anga* (witch doctor) and use it to cast *ufiti* over the owner of the object, causing them harm. As Mercy [30s, suburb, UDDT, cloth] explained, '*It is dangerous for us women, taking the cloth with blood and disposing it… Someone sees it, maybe they can do some bad things to you*'. Possible effects were said to include menstruating continuously for several months at a time, infertility, or (more rarely) death. Many women, old and young, claimed to know friends or family members who had personally experienced harm from *ufiti* through stolen menstrual absorbents, and it was perceived as a relatively common occurrence. Mayeso [30s, suburb, pit latrine, cloth] described the experience of her mother: '*Other people can make you to be barren, like my mother, her cloth was stolen and she couldn't conceive again.'* Some women also believed that menstrual cloth or used pads could be stolen and used in other kinds of *ufiti* to bring wealth or prosperity to the thief.

The secrecy around menstruation was therefore due not only to embarrassment, but also to fear. Women took great care to keep their menstrual cloths secure and hidden at home, so that they were not vulnerable to *ufiti*. Some spoke of taking pains to hide them from their own husbands. For those who used disposable pads, they took care to dispose of these 'safely' so that nobody else could get them. Elizabeth [late teens, suburb, pit latrine, pads] described how she protected her used pads from being used in *ufiti*: *'it's just to be storing them safely like I do, I store them [in the bedroom] then burn them, in order to avoid such kinds of things'.* Whilst burning and discarding in pit latrines were thought to be safe options, many women were wary of the idea of discarding their pads in the open, or leaving them in a bin. The higher volume of waste created as a result of using disposable pads was seen as a negative aspect by some women, who felt that cloth was safer and left them less at risk of *ufiti*.

Fears of *ufiti* was generally felt more acutely by the older women. Some (but not all) of the younger university-attending women were prepared to discard pads in the bathroom bins on campus, provided that the bathrooms were kept locked out of hours, which they felt provided adequate protection against *ufiti*. The older women confessed their fears for the safety of the younger women as a result of their more relaxed attitudes; Tadala [40s, campus-staff, cloth] gently admonished the young female interviewer: *'You younger generation, you don't take things seriously, you don't even think that your own [pads] can affect you'*. Some, however, felt that times had changed and the risks of *ufiti* had reduced; Takondwa [60s, suburb, cloth] commented: *'During the olden days it was more dangerous* *[than now]'*. Chimwemwe [30s, suburb, UDDT, pads] regretted seeing more discarded waste as a result of this attitudinal shift: *'Pads, they are not well taken care of, they are just everywhere, because now people are not afraid of blood any more'.* Mphatso [30s, campus-staff, cloth] reflected on the differences, and speculated that it might be due to education: '*Our parents, when they teach us that, my child, take care of [the cloth] when menstruating, we were listening, maybe because of being uneducated. But now, today, when you tell them that cloths, don't keep them anywhere… they see it as useless.'*

2.4.2.4 Menstrual restrictions

There were a number of restrictions associated with the state of menstruation. Acts mentioned by participants which should be refrained from during menstruation included: adding salt to food; having sexual intercourse; picking vegetables from the field; having physical contact with children; and cooking food. The most common abstinence discussed was adding salt to food; this was something that several participants were advised to do by their elders, although none were able to explain why. These women would typically ask another member of the family to add it instead. The salt restriction appeared to be viewed similarly to a religious affiliation, with some women choosing to adhere to it and others choosing not to. Tadala [40s, campus-staff, cloth] explained: '*Others say [when menstruating] that you shouldn't add salt to relish [a dish of vegetables and/or meat to accompany rice or nsima], but me, with the way I pray, I don't see that there is any problem with it much.'* Some of those who refrained from adding salt added that whatever danger was once associated with it may no longer be present, but they still prefer to keep the practice anyway. Limbani [50s, suburb, UDDT, cloth] explained: *'The way we were told, when menstruating, adding salt, people [who eat the food] get swollen. But now, it's no longer there, we can add salt. But to us who got adapted [to not adding salt], we are still believing that.'*

2.4.3 Practical aspects of menstruation

Both pads and cloth require eventual disposal; pads are disposed after each use, and cloth is ultimately disposed when the material is worn out through repeated washing and no longer absorbs liquid. Pads generate a considerably larger volume of menstrual waste than cloth, which is often reused for months or years. Most participants disposed of their pads and cloth either by burning them, or by discarding in pit latrines. Methods of disposal were more complex outside of the home; some participants would dispose of their pads in bins at their place of work or study if they needed to change their pad during the day, whilst others would carry their used pads home to burn them there. Other participants, who were not comfortable with the disposal options available to them at home, would carry all of their used pads to their place of work or study for discarding. Women would often use a combination of disposal methods according to what was convenient at the time.

2.4.3.1 Reuse by washing

In terms of day-to-day menstruation management for cloth-using women, the most important household facility was the bathroom. In many Malawian households, the bathroom is located in a separate building to the main dwelling, and is typically a small room with a drain leading into either: the pit latrine; the ground (i.e., an improvised soakaway); or an open channel, possibly connecting to a public ditch or discharging elsewhere in the compound. The bathroom is usually separate to the toilet room, but may be adjacent. All washing activities (of the body and the cloth) take place in the bathroom, and the privacy of the space is very important. Water draining from the bathroom should not be publicly visible, so that bloodied water from washing the cloth cannot be seen by neighbours or passers-by. One cloth-using participant, Fatsani [30s, suburb, pit latrine, cloth], commented that covered drainage from her bathroom was the thing she desired most in her whole life.

2.4.3.2 Disposal by burning

Disposing of pads and cloth by burning was preferred by many women but, owing to the secrecy around menstruation, this had to be carried out in a discreet location either early in the morning or in the evening when nobody else was around. Pilirani [20s, KI, flush, pads] explained: '*Girls are supposed to… burn them in a secret place, if there are men in the house you're supposed to wait for them to be out.*' Some women noted that it can take a long time for a pad or cloth burn completely, particularly if it is wet. In order to speed up the burning process, they would therefore sometimes leave pads to dry in the sunshine on toilet rooftops, but admitted that they worried about the pads being stolen and used for *ufiti* whilst left unattended. Others mentioned that burning pads causes a noticeable odour, and which caused them to feel uncomfortable as it could alert neighbours to their activity: '*When you burn, it will produce air pollution, and people around the neighbouring houses will notice something [i.e., that you are menstruating]'* [Thoko, 20s, campus-student, flush, pads]. Despite these inconveniences, burning was generally regarded as a safe solution as it turned the pads and cloth to ash, protecting them from being used in *ufiti*, and preventing them from being seen by anybody. In one unusual case, a woman burned her pads directly inside her UDDT vault, by burying them in hot ash.

In order to conserve matches and paraffin, some women preferred to burn their used pads together, in one go, at the end of their period. However, storing used pads discreetly was challenging as they emitted a strong odour and attracted flies. Women worried about other people in the household smelling or finding the pungent pads, as well as experiencing personal discomfort from keeping them in their bedrooms. Pilirani [20s, KI, flush, pads] explained how she would '*gather [the used pads] in a plastic bag under my bed, they produce some bad smells and so windows are to be open, but during the night, eeiish…'* Having to store odorous pads in a bedroom shared with young children or boys caused particular anxiety. Some, however, developed innovations: Margaret [late teens, suburb, UDDT, pads] stored her used pads in an airtight container (made from an old paint tub) in her bedroom, which effectively contained the odour, after hearing the idea from a friend at church.

2.4.3.3 Disposal in toilets

Throwing pads and cloth in pit latrines was another common disposal route. This was regarded as a particularly useful 'emergency' option, as items could be dropped into a pit latrine quickly and discreetly. However, some pad-using women preferred not to routinely discard pads in their own pit latrines as they feared that it would cause the pit to rapidly fill up, shortening its useful lifespan, and would therefore only throw the occasional pad or cloth when unable to dispose of it by burning. If the pit latrine was designed for routine emptying, some women also had concerns about discarding pads in these toilets because of the potential for pads to physically cause problems with emptying devices (described by Elizabeth [late teens, suburb, pit latrine, pads] as '*blocking the pipes'*), and also due to embarrassment from others seeing the pads during the emptying process.

Those with flush toilets or UDDTs, unable to throw pads or rags in their own toilets, would sometimes secretively throw their items into their neighbour's pit latrines. Tiyamike [20s, suburb, UDDT, pads and cloth], who had a UDDT, admitted: '*Sometimes you fail to wash menstrual cloth, then you say I should dispose to the neighbour's toilet [a pit latrine]… you are to wait for the neighbour to be out or not around, then you run and dispose them*.' However Tiyamike worried that this could cause conflict with her neighbours if her actions ever came to light.

2.4.3.4 Disposal in bins or dumps

Discarding pads or cloth into the solid waste system, whether in bins or on local dumpsites, was generally seen as an unfavourable option and used as a last resort. This was partly due to the risk of pads or rags being taken (from either the bin, or the final destination) and used in *ufiti*, but also because it contravened the expectation that they should be kept hidden, and was therefore seen as immoral and disrespectful. This feeling was particularly strong among the older generation of participants, who felt dismayed to see bloodied pads scattered around like litter. Younger pad-using participants expressed particular anxiety about dogs scavenging their pads from bins and carrying them away, which may account for how pads end up dispersed in the urban environment despite the general wish to keep them hidden.

In spite of the general discomfort around discarding pads in bins (due to not knowing the ultimate destination of the waste, and whether this would be safe from *ufiti*), some campus students who had flush toilets at home and did not wish to burn their pads would nonetheless carry them to university each day and leave them in the bins there. Joyce [20s, campus-student, flush, pads], who has a flush toilet at home, explained: '*I don't feel comfortable burning them, so most of the times I do carry the ones that I've used, and throw them in the bin at the [campus] toilet*.' Cleaners at the campus confirmed that they regularly find bundles of used pads in plastic bags discarded in the bins.

2.5 Discussion

This study has provided detailed insights into the ways that different sanitation facilities in a low-resource setting can affect the management of menstruation, with important implications for infrastructural planning. The qualitative interview approach has provided rich data that offer a more nuanced understanding of how cultural beliefs, material constraints, and practical considerations can intersect, against a background of generational and socio-economic change, to shape women's experiences and practices of menstruation. Based on a sample of just 31 women in one city, the study cannot claim to provide a generalizable or representative picture of menstrual practices and beliefs in Blantyre or beyond; however, the ubiquity of certain themes, practices and beliefs described by participants suggests that these might be widely held, which could be confirmed by further research. The interviews revealed themes, beliefs and practices with relevance to sanitation and solid waste management infrastructure design, which are discussed in turn below.

2.5.1 Concealment in plain sight

The characterisation of menstruation as 'unclean' and 'shameful' concurs with similar studies elsewhere in sub-Saharan Africa (Scorgie et al., 2016; Mason et al., 2013), and is akin to many other cultures around the world (Tan et al., 2017; Johnston-Robledo and Chrisler, 2013). This leads to a culture of total concealment around menstruation. Whilst men are generally aware that women of reproductive age menstruate monthly, efforts to mask it essentially erase the status from public view. This aligns with Foucault's concept of 'heterotopias of deviation', whereby undesirable bodies are sequestered in particular, private places, such as psychiatric hospitals and prisons, in order to preserve a public 'utopia' (Foucault, 1967). In the case of menstruation, any detectable signs are dealt with in strict privacy in order to preserve the public-facing facade of clean, hygienic, non-menstruating women. This has led to ‘culturally sanitised’ versions of women becoming normalised, whilst those defying or not fitting the norm may be stigmatised (Roberts et al., 2002). Indeed, Bobel (2019) argues that even the use of the word ‘management’ in MHM – a period-positive movement - implies that the body is unruly in its natural state, requiring ‘protection’ through ‘sanitary’ products.

Recognition of the illusion of female non-menstruation, and whether/how to challenge menstruation stigma, inspires continued debate. Bobel (2019) suggests that by centring the mission of MHM on providing women with privacy and materials to conceal their menstruating status, MHM actually perpetuates the stigma surrounding menstruation rather than challenging it. However, it is not necessarily contradictory to challenge menstrual stigma whilst also supporting women’s access to privacy for the actual act of cleaning and/or discarding menstrual materials and blood, if desired.

Despite the aura of secrecy, in this study it was possible to speak openly about menstruation with women, and the interviews were conducted with ease. Whilst many participants said that they would not routinely discuss menstruation with their friends, others did not mind the presence of their friends during interviews, and interviews with small groups of friends were found to create a relaxed atmosphere. The general level of secrecy around menstruation was perceived by many women to be decreasing, which has been noted in similar studies elsewhere (Mohamed et al., 2018). Whilst the severe stigma attached to the sight of blood or bloodied materials is certain to persist for now, participants appeared to feel able to speak more freely about these topics than in decades past.

2.5.2 Paradox of dirt and value

Menstrual blood was perceived to be a powerful substance, with great potential for good or evil. In common with the Gambia (Shah et al., 2019), the fear of *ufiti* cast by *sang’anga* had a significant influence over how women handled and disposed of their menstrual waste, and even (for some) their menstrual absorbent preferences. These fears lie within a Malawian context of widespread and acute belief in *ufiti*, which is found both urban and rural areas, and periodically causes outbreaks of national panic (Ashforth, 2014). Use of menstrual cloth in healing practices, however, has not been identified elsewhere in the literature, either in Malawi or sub-Saharan Africa; it would be interesting to find out how widely such beliefs and practices might pertain.

There would appear to be a paradox between the conceptualisation of menstrual blood as filthy, disgusting, shameful, and dangerous, whilst being simultaneously revered for healing. Drawing on theories of dirt and disgust can help to explain this apparent contradiction. Douglas’ conception of ‘dirt’ as a substance or object that subverts an established cultural order (Douglas, 1966) resonates deeply with menstrual blood, which is a substance that has come out of its usual place (circulating within the body), to transcend bodily boundaries. Meanwhile, the more naturalistic theory of disgust proposed by Curtis characterises revulsion as an evolved psychological system designed to help us avoid potential sources of disease (Curtis et al., 2011). Encountering substances secreted or excreted from other human bodies, such as menstrual blood, naturally evokes a response of disgust as they induce undesired intimacy (Van Der Geest, 2015). Thus, menstrual blood is essentially 'dirty' on several counts. However, once menstrual blood has been washed, dried, and transformed into an odourless mark on a cloth, the automatic disgust triggered by the sight of a vivid human secretion is tempered. This allows another attribute to emerge: rule-breaking objects such as menstrual blood can be believed to embody great power, with both positive and negative potential (Buckley and Gottlieb, 1988; Douglas, 1966). Uses of menstrual blood in protective charms and pre-scientific medicine (e.g. in Ancient Rome and Morocco) demonstrate these positive and negative poles of symbolic menstrual power (Buckley and Gottlieb, 1988). Similarly, menstrual blood is also conceived of as a symbol of fertility and new life, despite being simultaneously seen as polluting (Wall et al., 2018; Gottlieb, 1988). Menstrual symbolism is therefore highly complex, and can mirror that of the post-menarche female body in general: concurrently reviled and revered, viewed as polluting but also life-giving, and requiring regulation and control (Ussher, 2006).

2.5.3 Menstrual absorbent type matters

When considering menstruation, it is critical to appreciate that the types of infrastructure and services required by women will vary depending on the type of menstrual absorbent that they use. Women who use cloth require a private bathroom to wash them in, with discreet drainage so that bloodied washing water is not visible (for instance, draining into a pipe or pit latrine, rather than discharging into an open drain that can be seen by neighbours). Another requirement is a private place to dry and store cloth, which was generally reported as the bedroom. By contrast, the toilet itself may be less relevant. During interviews, many cloth-using women seemed puzzled to be questioned about their toilet in relation to menstruation; this facility was not relevant to their menstrual management activities. Whilst a pit latrine (as opposed to other kinds of toilet) could be useful to occasionally dispose of a cloth, having discreet bathroom drainage was seen as considerably more important. The importance of discreet drainage from washing spaces has been described similarly elsewhere, for instance in the design of bathrooms in refugee camps in Pakistan (Nawaz et al., 2010).

For those who use pads, the most pressing need is for an inconspicuous disposal system. Women who feel comfortable burning their pads require a discreet place to do so, along with a supply of matches and paraffin, and should be made aware that fumes from the burning pads can contain carcinogens formed from chlorine (Elledge et al., 2018). Pit latrines were widely appreciated as a disposal method due to convenience and discretion, so, ironically, more sophisticated sanitation facilities that cannot receive pads (such as UDDTs, flush toilets, or pit latrines which are regularly emptied) may be less convenient for pad-using women if they do not have an alternative suitable waste disposal system.

MHM can therefore be seen to sit between the two distinct sectors of WASH and solid waste management, interacting with systems on either side, depending on what menstrual absorbent is used. As a result, whilst linkages between MHM and WASH have been correctly highlighted, these have sometimes been misleadingly characterised through an overemphasis on the role of toilets at the household level, when actually their relevance may depend on whether a woman uses disposable or reusable menstrual absorbents. For example, one study considered how national water and sanitation coverage estimates might be used to identify barriers to MHM and suggested that data on open defecation may provide a useful proxy (Loughnan et al., 2016). Whilst the authors acknowledge limitations of their indicators, the most crucial of these is not fully discussed: women using cloth do not necessarily manage their menstruation in the toilet, and openly defecating women are likely to be poor, and therefore likely to be cloth-users. Thus, open defecation rates, or quality of toilet facilities in general, are unlikely to provide a reflection of the state of menstrual hygiene management. Others have studied the relationship between household sanitation and experiences of menstruation in Nigeria, but did not look specifically at household bathrooms (Hennegan et al., 2018). The lack of relevance of toilets may explain why they were unable to find any meaningful relationship, and concluded that 'existing [sanitation] indicators are not suitable to women's menstrual needs'.

2.5.4 Changing composition of menstrual waste

Disposable sanitary pads have become much more widely available in the last two decades, and are now commonly used (particularly by younger women) in urban areas. Many younger women interviewed felt disgusted by the idea of washing and reusing cloths, and feared being teased by their peers for using them. However, despite appreciating the convenience of disposable pads, many pad-using participants found disposing of their pads discreetly to be inconvenient, time and labour intensive, and stressful.

Given the increasing preference of younger and more educated women for using pads, it would appear that the menstrual waste profile of urban Malawi is changing rapidly. Increasing preference for disposable pads over reusable cloth will mean a dramatic increase in the volume of menstrual waste produced. This trend is unlikely to be associated with the poorest women, who will probably continue using cloth due to their lower cost, and will be most pronounced in middle income groups, and among women in education or employment (due to the convenience that disposable pads offer for moving around). Traditional methods of disposal, such as burning or discarding waste in pit latrines, may come under pressure as a result of the increased volume of waste associated with pad use.

2.5.5 Future of menstrual waste management

Menstrual waste disposal issues resulting from a combination of socio-cultural constraints and inadequate infrastructure have been reported in this study, and elsewhere around the world (Elledge et al., 2018; Kaur et al., 2018). Participants described important requirements around the management of menstrual waste (i.e. that it is unseen, and secure from use in *ufiti*) that result in methods of disposal being used that can have negative effects on health, sanitation, and the environment. For instance, burning can expose users to carcinogenic fumes, whilst disposal in pit latrines results in rapid filling and emptying problems. These challenges are particularly pertinent for disposable pad users, who generate greater volumes of waste. When the rapidly increasing popularity of disposable pads is also considered, it is clear that environmental and public health consequences could be serious if suitable infrastructure, products, and services, are not made available to women.

However, in order to see the way forwards for menstrual waste management, there now needs to be an expansion and integration of qualitative understanding with quantitative data on urban menstrual waste generation and disposal in order to confirm significance and extent. Initiatives around solution design, concerning both waste generation and disposal, require a strong participatory component to ensure suitability for women's needs and preferences. For instance, participatory research could explore whether community menstrual waste disposal points, or waste storage facilities at the household level, can be innovatively designed in such a way as to satisfy user requirements for privacy, security, and hygiene. Meanwhile, in order to reduce the generation of menstrual waste, further research could explore how to improve the availability and manufacturing standards of high-quality reusable sanitary pads. These combine many of the beneficial aspects of disposable pads (e.g. high absorbency, comfort), with traditional practices (i.e. washing and reusing cloth, which generates smaller volumes of waste), but also improve on them by utilising materials with fast drying times and requiring small volumes of water for washing (Hennegan et al., 2016; Scott et al., 2013). Development and promotion of affordable compostable pads could potentially make disposal in pit latrines more compatible with pit emptying programmes, although this has admittedly proved a challenging venture elsewhere (Bobel, 2019; Mahajan, 2019).

2.6 Conclusions

Using qualitative interview methods to understand practices, preferences, and socio-cultural norms surrounding menstruation among pit latrine, flush toilet, and UDDT users in Blantyre has revealed that: i) menstrual blood is a highly sensitive substance, culturally imbibed with significant power for harm and healing; ii) the kinds of menstrual absorbents that women use dictate their infrastructural and service needs; and iii) increasing preference for disposable pads over reusable cloth suggests that Blantyre's menstrual waste profile may be changing substantially. Menstrual waste is no ordinary waste: the complete concealment of blood, and the state of menstruation in general, is important due to shame, stigmatisation and fear of blood being used in *ufiti*.

Socio-cultural norms must be taken into account in order for the infrastructure to be used effectively, and these might not be immediately obvious to service designers (especially those who are male). As a result, there is a strong case for the use of participatory methods to develop user-designed menstrual waste management solutions. Crucially, pad users and cloth users must be recognised to have different needs and priorities. Our research suggests that for pad users, solutions might be centred on discreet and convenient disposal systems which are not easily accessible to others, whilst for cloth users there might be a greater focus on private spaces with covered drainage to wash and dry cloths.

Other avenues that would benefit from further research include characterising Blantyre's menstrual waste profile, i.e., quantifying the volumes produced of different types of menstrual waste and identifying their destinations. This would allow the potential benefits of capturing menstrual waste on both environmental and human health to be evaluated, in addition to providing data for the design of solid waste management services. Our research suggests increasing preferences for disposable sanitary pads among younger women, indicating that the overall volume of menstrual waste is likely to be growing rapidly in line with demographic change.

Chapter 3 | Blood flows: mapping journeys of menstrual waste in Blantyre, Malawi

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R.S. Quilliam, K. Hampshire, E.A. Tilley, and D.M. Oliver supervised the project. H. Roxburgh designed the data collection tools with support from all other authors. C. Magombo and K. Kaliwo carried out the data collection with support from H. Roxburgh and E.A. Tilley. H. Roxburgh analysed and interpreted the data. H. Roxburgh produced the manuscript, and all authors commented on draft versions.

3.1 Abstract

The interplay between menstrual waste and urban sanitation infrastructure is largely hidden from view. Qualitative research has highlighted socio-cultural aspects of menstruation, but few quantitative studies have mapped the physical situation at scale. This study surveyed 258 women in Blantyre, Malawi about their menstrual absorbent choices, disposal practices, and socio-demographic characteristics. A Sankey diagram visualised flows of menstrual waste in the urban environment and identified ultimate disposal points. Most participants used either disposable pads and/or old cloth and disposed of them by either burning and/or throwing in pit latrines. Pad and cloth use were associated with age, education, employment, marital status, and household wealth. Younger women's preference for disposable pads suggests that demographic shifts may cause volumes of menstrual waste to increase. However, differences in waste volume produced by disposable and reusable absorbents was less than previously assumed. The volume of menstrual waste discarded in pit latrines, and cultural barriers to disposing it elsewhere, highlights challenges for the pit emptying industry and faecal sludge value recovery sector, with the problem anticipated to be most acute in high-density settlements. Widening access to

sustainable disposal strategies, affordable reusable menstrual products, and tackling stigma, are key to addressing this social and environmental challenge.

3.2 Introduction

Sustainable management of pit latrines by periodic emptying is critical to delivering universal sanitation in rapidly densifying urban areas, as space constraints mean that continuing to abandon full pit latrines is infeasible (Berendes et al., 2017; Chunga et al., 2016). However, the ubiquitous presence of menstrual waste in pit latrines poses a challenge to easy and safe emptying (Tembo et al., 2019). When full pits are emptied by mechanical methods, such as pumps, discarded menstrual cloth can wrap around the propelling blades of these devices and cause them to malfunction (Sisco et al., 2017). As pit emptying businesses are unlikely to be able to afford pumps with powerful maceration capabilities, manual emptying of the waste is instead necessary to avoid blocking the pumps (Chipeta et al., 2017). Furthermore, the presence of menstrual absorbents and other solid waste in faecal sludge makes it economically challenging to reuse the material (Tembo et al., 2019). Compost and biogas are valuable resources in low-income peri-urban contexts that can be produced from faecal sludge, but the presence of solid waste can affect both the quality of these products and the profitability of their production operations (Niwagba et al., 2014).

Menstrual absorbents are highly sensitive and private materials due to cultural etiquette, and also because many believe that they can be used to perform witchcraft rituals, causing severe personal harm to the owner (Chinyama et al., 2019; Scorgie et al., 2016). Menstruating women therefore require disposal options for their absorbents that are discreet, convenient, and considered safe from witchcraft (Roxburgh et al., 2020a (i.e., Chapter 2)). There is therefore a need to combine insights from social sciences and engineering in order to sensitively and appropriately address gendered sanitation issues such as menstrual waste management (Tilley et al., 2013). In recent years, advances in qualitative studies have given detailed insights into the socio-cultural aspects within which menstrual waste is generated and managed (e.g., Scorgie et al., 2016; Chinyama et al., 2019; and Roxburgh et al., 2020a (i.e., Chapter 2)). However, there is still a lack of quantitative data on how menstrual waste moves through the physical environment in urban areas. This information is necessary to and inform the conceptualisation and design of improved menstrual waste management systems.

The aim of this study was to understand, at scale, how women currently manage menstrual waste, identify interactions and potential conflicts between menstrual waste and other urban infrastructure. There were three objectives to the study. Firstly, to characterise and quantify the menstrual absorbent choices and disposal methods of women in the city of Blantyre and explore associations with a variety of socio-demographic characteristics. Secondly, to investigate how preferences for different menstrual absorbents have changed over the last decade. Thirdly, to map the menstrual waste disposal pathways, identifying interactions with sanitation and solid waste infrastructure in urban environments, and locating its ultimate destination(s).

3.3 Method

3.3.1 Questionnaire survey

Data were collected through the use of a questionnaire survey with female members of the general public in Blantyre (the second largest city in Malawi), conducted in March 2020 (Roxburgh et al., 2020b). The design of the questionnaire was informed by previous qualitative work, including semi-structured interviews with 31 women in Blantyre to identify the main types of menstrual absorbents and disposal routes used (Roxburgh et al., 2020a (i.e., Chapter 2)). Participants were assisted to complete the questionnaire by the enumerators.

The questionnaire gathered information on menstruation and menstrual practices, including: whether the participant experienced menstrual cycles (and if not, whether they had experienced any within the last two years), what absorbents participants used during their last period, and for disposable options (e.g. disposable pads and tampons), how they were discarded. For reusable options (e.g., menstrual cloth or reusable pads), participants were asked to think back to when they last discarded one of these items and explain what they did with it. Many participants utilised multiple absorbents and multiple disposal strategies during their last period. For these cases, where the participants struggled to complete the questionnaire, the enumerators had a discussion with the participant about their menstrual practices in order to help them to assign percentages to the relative usage of each absorbent, and the approximate proportion of absorbents assigned to each disposal pathway. If participants were old enough to have been menstruating 10 years prior to the survey, in 2010, they were also asked to recall what absorbents they had used then. To do this, the enumerator asked the participant their current age, and then asked them to think back to when they were [their current age minus 10] years old. They were then asked if they could recall what menstrual absorbents they were using at that time in their life.

Participants discarding menstrual absorbents in pit latrines, bins, or rubbish pits were asked what usually happens to these receptacles once they become full. If pit latrines were emptied, and the contents removed from site, participants were asked to specify whether their pit emptying service is usually carried out using a manual bucket and spade, or by another device such as a machine.

Demographic information was also collected, including age, highest educational level attained, source of personal income, and marital status. Asset ownership was used as a proxy for household wealth, measured by asking participants whether any member of their household owned a mobile phone, TV, or vehicle (motorbike, car, or truck). Participants were also asked what kind of toilet they had at home, and about the regularity of their solid waste collection service. The survey was conducted with 258 female participants, aged 18 or above, recruited from seven different areas of the city. The questionnaire was administered by two female residents of Blantyre, who were fluent in Chichewa. The questionnaire took about 15 minutes to complete, and the refusal rate was approximately 25%.

The seven recruitment locations were purposefully chosen to represent the most populous wards in the city, but also to cover a diversity of neighbourhood types in terms of wealth, density, and sanitation / solid waste infrastructural characteristics. The two largest informal settlements in Blantyre (Bangwe and Ndirande) were included, along with peri-urban areas (e.g., Chigumula). Originally, a larger sample size was planned, but the COVID-19 pandemic meant that data collection had to be terminated sooner than expected, and one neighbourhood (Bangwe) was relatively oversampled as a result. However, the sample size of 258 is considered representative of the female population of the Blantyre urban area (which was estimated at 400,132 in 2018 (National Statistics Office, 2019)) with a margin of error of 6%, and a confidence level of 95%.

Participants were recruited through two different methods. For the first method, questionnaire administrators selected streets to provide a cross-section of neighbourhood types across each recruitment location and knocked on the door of every '*n*'th house (adjusted according to settlement density) to invite a woman from the household to participate. For the second method, the questionnaire administrators approached women in public spaces (primarily at hair salons and marketplaces), similarly selected to represent a societal cross-section within each recruitment location, and invited them to participate. This complementary recruitment procedure was intended to eliminate bias that might result from only recruiting women found at home during the daytime. Approximately half of participants were recruited through each method.

Ethical consent for the survey was obtained from the University of Stirling General University Ethics Board (reference number: GUEP 806), and from the Malawi National Committee on Research in the Social Sciences and Humanities (reference number:

NCST/RTT/2/6, protocol number: P.03/20/464), prior to commencement of fieldwork. As the survey involved discussion of a culturally sensitive topic, care was taken at the recruitment stage to ensure that participants were fully informed of what the survey would involve, that they could withdraw their participation at any time, and that they were not obliged to answer all of the questions. The enumerators were both female and had previous experience of carrying out research on menstruation or similar sensitive research subjects.

3.3.2 Data analysis

The types and combinations of menstrual absorbents used by participants were characterised using descriptive statistics and visualised using a tree map. The composition and flows of menstrual absorbents through disposal pathways to destinations was visualised using a Sankey diagram. The destinations of menstrual waste were determined using the data gathered from participants on how they disposed of their menstrual absorbents, and what happened to their disposal receptacles.

For menstrual absorbents discarded in pit latrines, the pit emptying method (i.e., mechanical or manual) was used as a proxy to indicate whether the pit emptier was formal or informal, and therefore whether the pit contents were likely to have been taken to a wastewater treatment works for disposal (i.e., mechanical) or dumped into the environment (i.e., manual).

For the subset of participants who experienced menstrual cycles ten years prior to the survey, changes in their menstrual absorbent uses over the last decade were also visualised using a Sankey diagram.

Significant associations between demographic, recruitment, and infrastructural variables and use of the two most common absorbents (pads and cloth) and disposal methods (burning and throwing in pit latrines) were tested using Chi square tests for independence. Yates' Correction for Continuity was used for tests where characteristics were defined by just two levels (e.g., whether the participant was recruited at home or in a public place), in order to compensate for potential overestimation of the Chi square value when used for a 2 x 2 table (Hoffman, 2019). Post-hoc testing was carried out for tables greater than 2 x 2 by calculating p-values from adjusted residuals and comparing these to an α value adjusted using the Bonferroni correction, in order to compensate for potential type 1 family wide errors (Holm 1979; García-Pérez and Núñez-Antón 2003). As the Bonferroni correction is sometimes considered conservative, results which were significant in the absence of the correction are also indicated. Finally, binary logistic regression models were constructed to model the use of pads and cloth as a function of demographic variables.

Statistical analysis was carried out using SPSS (IBM SPSS Statistics Version 26), Sankey diagrams were created using MetaFlow (Graphical Memes Version 1.2), and the tree map was produced using the 'geom_treemap' function from the R package 'treemapify' (R Package Version 2.5.3) (Wilkins, 2019). The dataset is available to download (Roxburgh et al., 2020b).

3.4 Results

3.4.1 Characterisation of participants

The demographic characteristics of participants and details of their sanitation and solid waste services are shown in **Table 3.1**. Almost all participants (90%, *n* = 233) were still experiencing menstrual cycles at the time of the survey (i.e., they had not yet reached menopause or otherwise ceased to menstruate) and were therefore able to respond to the questions on the basis of recent personal experience. The sample population was weighted towards younger participants, with the majority (56%, *n* = 144) being under the age of 30. This corresponds to the general age profile of Blantyre city, which is skewed towards a younger demographic. Almost all participants (97%, *n* = 250) had received at least some education, with over three quarters (78%, *n* = 202) attending secondary school. Almost a third (30%, *n* = 78) had received some kind of higher education, attending either a technical college or university. Less than a third (28%, *n* = 73) were formally employed, with just over a quarter receiving support from their husband, friends or family (27%, *n* = 68) and the largest percentage involved in business activities or farming (36%, *n* = 92). Of the assets used as a proxy for household wealth (ownership of a mobile phone, TV, or vehicle), only a small percentage of participant households (3%, *n* = 9) had none. Almost all (94%, *n* = 242) had a mobile phone, and the majority (72%, n = 186) had a TV. Vehicle ownership was less common (29%, *n* = 74) and assumed to occur amongst wealthier households. Almost half of participants were married (48%, *n* = 124). All participants had toilets at home, and for the majority (87%, *n* = 255) this was a pit latrine. Over half of participants had no waste collection service in their area (51%, *n* = 131, and less than one fifth (19%, *n* = 49) had their waste collected more than twice a month.

Table 3.1. Demographic characteristics and sanitation services of participants.

Characteristics		Participants (n = 258)	
Recruitment location	Bangwe	61	24%
	Blantyre	15	6%
	Chigumula	30	12%
	Chirimba	38	15%
	Machinjiri	33	13%
	Mbayani	46	18%
	Ndirande	35	14%
Survey conducted	At home	121	53%
	Public space	137	47%
Menstrual status	Menstruating	233	90%
	Stopped in last 2 years	10	4%
	Stopped more than 2 years ago	13	5%
	Missing [c]	2	1%
Menstrual absorbents used during last period	Pads	157	61%
	Cloth	130	50%
	Cotton [a]	21	8%
	Tampons	13	5%
	Reusable pads	11	4%
Age	18-29	144	56%
	30-39	70	27%
	40-49	26	10%
	50-59	13	5%
	60+	4	2%
	Missing [c]	1	<1%
Highest educational level attained	None	5	2%
	Primary school	48	19%
	Secondary school	124	48%
	Technical college	41	16%
	University	37	14%
	Missing [c]	3	1%
Main source of personal income	Piecework [b]	25	10%
	Business or farming	92	36%
	Employment	73	28%
	Husband	25	10%
	Family and friends	43	17%
Marital status	Never married	86	33%
	Married	124	48%
	Previously married	46	18%
	Missing [c]	2	1%
Household asset ownership	No assets	9	3%
	Mobile	242	94%
	TV	186	72%
	Motorbike	21	8%
	Car or truck	53	21%
	Missing [c]	5	2%
Household toilet	Pit latrine	255	87%
	Flush	56	22%
	No toilet	0	0%

	Missing [c]	11	4%
Regularity of waste collection by Blantyre City Council	Never	131	51%
	Less than twice a month	50	19%
	More than twice a month	49	19%
	Missing [c]	28	11%
Notes [a] 'Cotton' refers to homemade pads using cotton wool [b] 'Piecework' refers to small jobs like tailoring, assembling items, or other types of casual day labour [c] 'Missing' indicates that the participant either did not know or did not want to answer.			

Menstrual absorbents used by participants during their last period are shown in **Figure 3.1**.

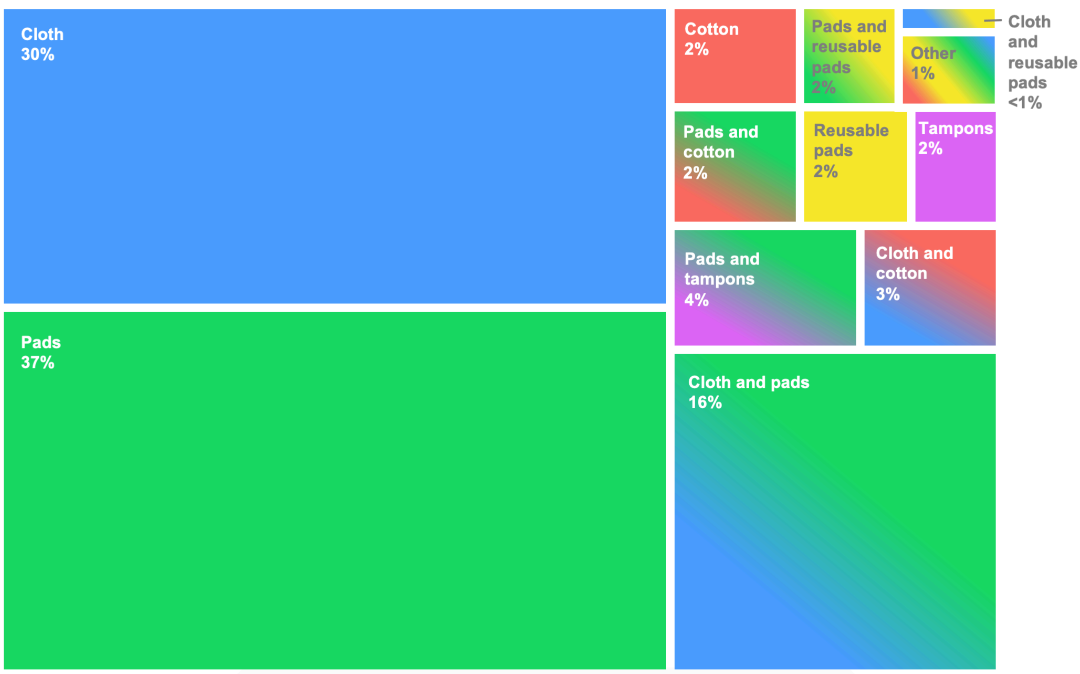

Figure 3.1. Combinations of menstrual absorbents used by participants at their last period (n = 258). Blue represents cloth; green represents pads; red represents cotton; yellow represents reuseable pads; and magenta represents tampons. Mixed-coloured squares represent a mix of two or more absorbents.

Almost three quarters of participants (72%, n = 187) used only one kind of menstrual absorbent, and the rest used two (26%, n = 68) or more (1%, n =) combinations of absorbents. About a third of participants used pads only (37%, *n* = 95), about another third used cloth only (30%, *n* = 78), and most participants (83%, *n* = 214) used either pads, cloth, or a combination of both. Even when other absorbents (tampons, cotton, or reusable pads) were used, the majority of these participants still used these materials in combination with either pads or cloth, with 95% (*n* = 244) of participants overall using either pads or cloth in some way.

For a subset of participants using exclusively pads (*n* = 94) or cloth (*n* = 55), the number of pads discarded during the last period, and cloths discarded during the last year, are shown in **Figures 3.2 and 3.3**. The mean number of pads thrown away was 9.1 per period, whilst the mean number of cloths thrown away was 29.2 per year, with skewness of 3.4 and 29.5 respectively. Within this subset of participants, 51% (*n* = 48) used eight or less pads during their last period, and 53% (*n* = 29) discarded more than 12 menstrual cloths over the last year.

The peak in **Figure 3.2** (monthly pad use) is likely to relate to the number of pads in a packet. Most commercial brands in Malawi sell disposable pads in packs of 10, so the peak at 10 pads may suggest a tendency to budget for and use one packet of pads each month. The subsequent small peak at 15 pads may suggest that some participants budget and use 1.5 packs each month. The peaks in **Figure 3.3** (yearly cloth use) in the centre and right side of the figure reflect the estimations made by participants who use higher numbers of cloths per year. These participants often found it difficult to estimate their yearly disposal, so they instead estimated their number of cloths disposed per month, which was then multiplied by 12 to arrive at a yearly estimate.

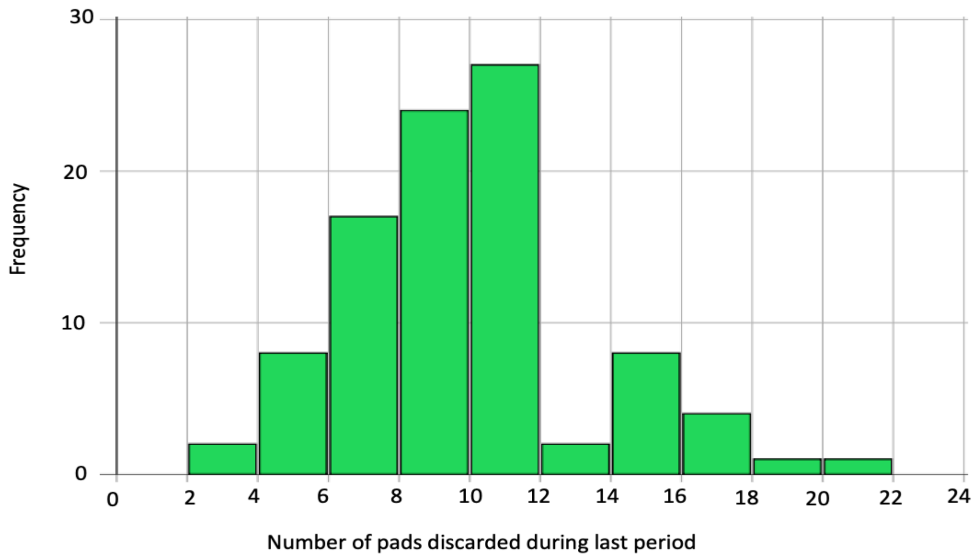

Figure 3.2. Number of pads discarded during last period by survey participants who just use pads (n = 94).

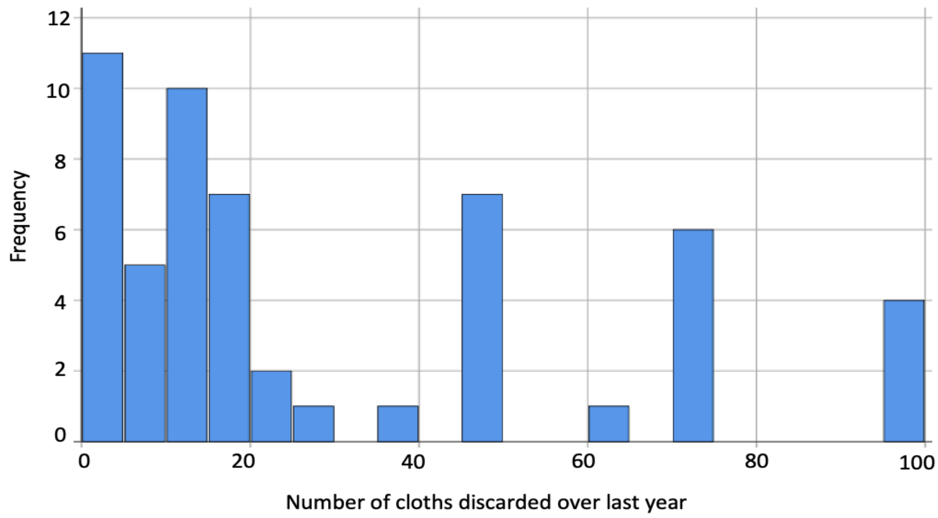

Figure 3.3. Number of menstrual cloths discarded over the last year by survey participants who just use cloth (n = 55).

3.4.2 Menstrual waste disposal pathways

Six final destinations for menstrual waste were identified: being buried, burned, deposited at the wastewater treatment works, thrown into the environment, reaching the landfill site, or being kept. Some menstrual waste reached these destinations directly, but most travelled through an intermediary disposal receptacle, such as a pit latrine, bin, rubbish pit, or flush toilet. **Figure 3.4** shows the composition of menstrual absorbents used by participants (n = 258) at their last period, together with their known/anticipated disposal pathways and destinations. Disposal pathways for disposable pads, cotton, and tampons reflect those used during participants' last period, and disposal pathways for cloth and reusable pads are estimated based on how participants most recently disposed of them. Destinations for menstrual absorbents disposed in pit latrines, bins, and rubbish pits are estimated based on what participants anticipate will happen to these receptacles once they are full, and a breakdown of waste destinations is given in **Table S1**.

The vast majority of menstrual absorbents are either thrown in pit latrines (55%) or burned (41%). Only a small percentage of menstrual absorbents were disposed of by other means (i.e., thrown in bins (2%) or rubbish pits (2%), flushed down the toilet (1%), buried (<1%), or kept (1%)).

The majority of pit latrines containing menstrual absorbents are expected to be either abandoned when full, or their contents dug out and buried nearby, therefore leading to 40% of menstrual absorbents ending up underground (i.e., assigned to the destination 'buried'). Some pit latrines are expected to be emptied and the contents removed, and therefore 11% of menstrual absorbents are anticipated to be taken to the wastewater treatment works by formally registered pit emptiers (identified by their use of mechanical equipment, such as a pumping device), whilst 4% are anticipated to be discarded into the environment by informal pit emptiers (identified by their use of rudimentary equipment, such as a bucket and spade).

Participants who discarded their menstrual absorbents into bins and rubbish pits reported a variety of final destinations for this waste. Menstrual absorbents which are discarded into a rubbish bin or rubbish pit which is ultimately burned is assigned to the destination 'burned' (2%). If households have their solid waste collected by Blantyre City Council, then menstrual absorbents discarded into the bin are presumed to reach the destination 'landfill' (1%). Some households empty their bins into the surrounding environment; menstrual absorbents discarded into bins in this instance are assigned to the destination 'environment' (1%). Some households using rubbish pits do not do anything further (e.g., burning, moving) to the waste in this pit; in these cases, the pit is presumed to eventually be abandoned and covered with earth, and menstrual absorbents discarded into these pits are assigned to the destination 'buried' (1%). The flushed menstrual absorbents (exclusively tampons) are presumed to reach the destination 'wastewater treatment works' (1%).

A small proportion of participants never discard their menstrual cloth, preferring to keep it even when the material is too worn (through repeated washing) to absorb more blood, as the cloth is believed to have uses in traditional medicine practices. Thus, 1% of all menstrual absorbents (predominantly menstrual cloth) are anticipated to be kept for these reasons.

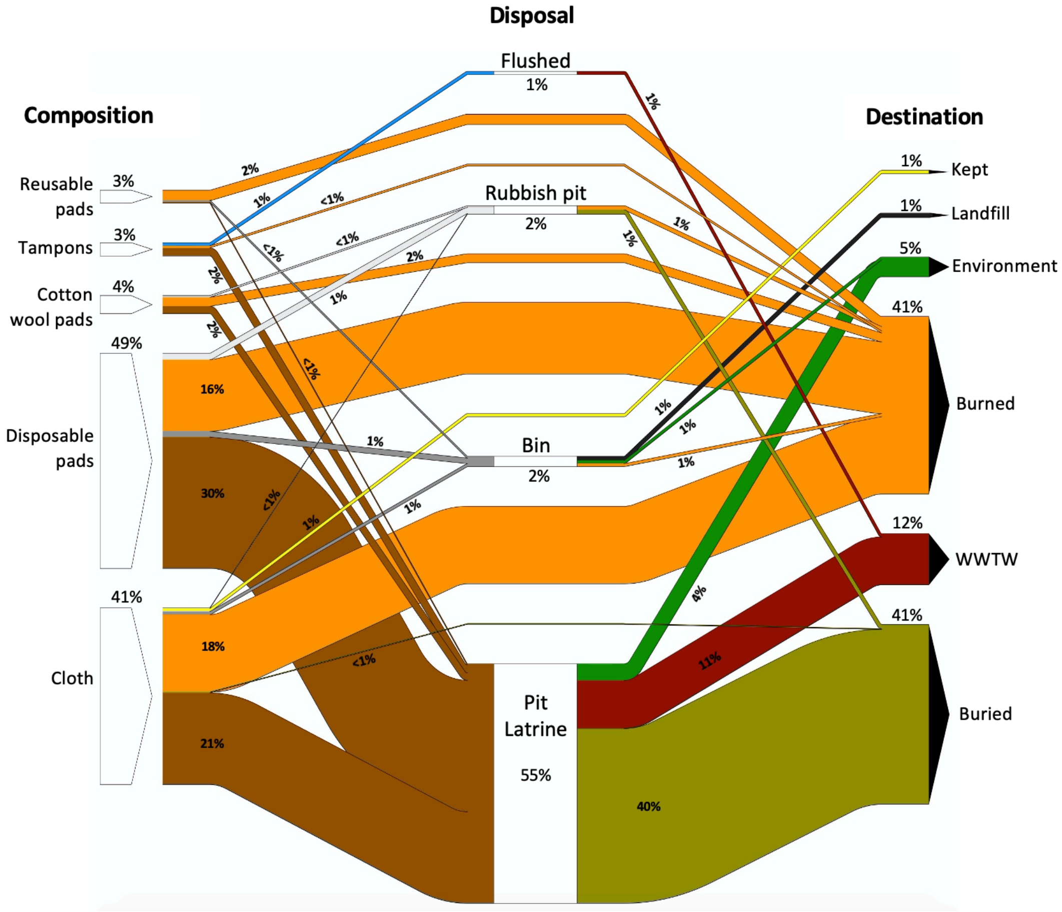

Figure 3.4. Composition and known/anticipated disposal pathways of participants' (n = 258) menstrual absorbents at their last period. Disposal pathways for reusable menstrual absorbents (cloth, reusable pads) are estimated based on how participants most recently disposed of their cloth / reusable pads. Destinations for menstrual absorbents disposed in pit latrines, bins, and rubbish pits are estimated based on what participants anticipate will

happen to these receptacles once they are full. Arrows are coloured according to their final or intermediate destination.

3.4.3 Determinants of menstrual practices

The majority of participants used pads and/or cloth (95%, $n = 244$) and disposed of their absorbents by burning them and/or throwing them in a pit latrine (95%, $n = 246$), and therefore associations between these practices and demographic / household infrastructure characteristics were explored using Chi square tests. Results are presented in **Table 3.2**, and full details of the omnibus and post-hoc Chi square tests and Bonferroni corrected alpha levels are given in **Tables S2**, **S3**, and **S4**. Only pad / cloth use and burning / pit latrine disposal were assessed, as there were not enough observations to conduct robust analysis of associations between use of other menstrual absorbents (e.g. tampons, reusable pads, cotton), other disposal practices (flushing, throwing in bins, rubbish pits, burying, or keeping), and other characteristics.

As shown in **Table 3.2**, significant and strong associations were found between use of pads and all demographic variables, as well as use of cloth and all demographic variables, which were: age, highest educational level, main source of income, marital status, and household asset ownership. Women aged 18-29 were most likely to use pads (71%, $p < 0.001$) and least likely to use cloth (42%, $p = 0.002$), and those who had attended university were most likely to use pads (84%, $p = 0.002$) and least likely to use cloth (11%, $p = 0.001$). Those in piecework (i.e., small jobs like tailoring, assembling items, or other types of casual day labour) were least likely to use pads (32%, $p = 0.002$), and those in formal employment were least likely to use cloth (34%, $p = 0.001$). Those who had never married were most likely to use pads (78%, $p < 0.001$) and least likely to use cloth (30%, $p < 0.001$), whilst those who were previously married were least likely to use pads (35%, $p < 0.001$) and most likely to use cloth (76%, $p < 0.001$). Excluding participants of households without mobile phones (for whom there were not enough observations to confirm associations), participants of households who owned a mobile phone but no other assets were least likely to use pads (44%, $p = 0.002$) and most likely to use cloth (73%, $p < 0.001$), whilst participants of households who owned a car/truck were least likely to use cloth (26%, $p < 0.001$).

As shown in **Table 3.2**, no significant association was detected between using pads and the recruitment location, or the use of cloth and the recruitment location, and whether they were recruited at home or in a public space. Participants with flush toilets were most likely to use pads (75%, $p = 0.017$) and least likely to use cloth (29%, $p < 0.001$). No significant association was detected between regularity of waste collection and use of either pads or cloth.

No significant associations (using Bonferroni corrected alpha levels) with method of waste disposal (i.e. throwing in a pit latrine or burning) were detected for whether participants were recruited at home or in a public space, regularity of waste collection, highest educational level, main source of income, and household asset ownership, as shown in **Table 3.2**. Associations were detected between throwing menstrual absorbents in pit latrines and two recruitment sites (Chigumula (37%, $p = 0.003$) and Chirimba (84%, $p = 0.002$)), being aged 18-29 (71%, $p < 0.001$), being aged 40-49 (32%, $p < 0.001$), and being previously married (41%, $p = 0.002$). There was a strong association between owning a pit latrine and disposing of menstrual waste in a pit latrine (97%, $p < 0.001$). Associations were detected between burning menstrual absorbents and being aged 18-29 (37%, $p = 0.002$), 40-49 (81%, $p = 0.001$), and being previously married (65%, $p = 0.003$).

Table 3.2. Correlations of absorbent use and disposal choice with demographic / household infrastructure characteristics and recruitment location.

Characteristics		By type of absorbent				By disposal method			
		Use pads (*n* = 157)		Use cloth (*n* = 130)		Burn menstrual absorbents (*n* = 118)		Throw menstrual absorbents in pit latrine (*n* = 158)	
Recruitment location	Bangwe	38	(62%)	32	(53%)	27	(44%)	44	(72%)
	Blantyre	7	(47%)	8	(53%)	8	(53%)	6	(40%)
	Chigumula	19	(63%)	14	(47%)	18	(60%)	* **11**	(37%)
	Chirimba	17	(45%)	26	(68%)	12	(32%)	* **32**	(84%)
	Machinjiri	21	(64%)	14	(42%)	15	(46%)	* 15	(46%)
	Mbayani	29	(63%)	21	(46%)	21	(46%)	30	(65%)
	Ndirande	26	(74%)	15	(43%)	17	(49%)	20	(57%)
Survey conducted	At home	74	(61%)	65	(50%)	50	(42%)	79	(50%)
	Public space	83	(61%)	65	(50%)	68	(50%)	79	(50%)
Waste collection by City Council	Never	79	(60%)	66	(50%)	60	(46%)	75	(57%)
	< 2 x month	28	(56%)	27	(54%)	20	(40%)	36	(72%)
	> 2 x month	34	(69%)	22	(45%)	26	(53%)	28	(57%)
Household toilet	Pit latrine	134	(60%)	* **122**	(54%)	* **97**	(43%)	*** **149**	(97%)
	Flush	* **42**	(75%)	*** **16**	(29%)	31	(55%)	30	(54%)
Age	18-29	** **102**	(71%)	* **60**	(42%)	* **53**	(37%)	** **102**	(71%)
	30-39	36	(51%)	38	(54%)	34	(49%)	* 36	(51%)
	40-49	14	(54%)	17	(65%)	** **21**	(81%)	** **8**	(32%)
	50-59	5	(39%)	* [a] 10	(77%)	8	(62%)	[a] 9	(69%)
	60+	* [a] 0	(0%)	* [a] 4	(100%)	[a] 1	(25%)	[a] 3	(75%)
Highest educational level attended	None	[a] 1	(20%)	* [a] 5	(100%)	[a] 4	(80%)	[a] 1	(20%)
	Primary	*** **13**	(27%)	*** **41**	(85%)	20	(42%)	35	(73%)
	Secondary	82	(66%)	64	(52%)	50	(40%)	79	(64%)
	Technical college	29	(71%)	13	(32%)	24	(59%)	* 19	(46%)
	University	* **31**	(84%)	*** [a] **4**	(11%)	18	(49%)	22	(60%)

Main source of personal income	Piecework	* **8**	(32%)	** 19	(76%)	9	(36%)	18	(72%)
	Business/ farm	54	(59%)	49	(53%)	43	(47%)	55	(60%)
	Employment	50	(69%)	* **25**	(34%)	36	(49%)	42	(58%)
	Husband	12	(48%)	* 18	(72%)	10	(40%)	18	(72%)
	Family / friends	* 33	(77%)	19	(44%)	20	(47%)	25	(58%)
Marital status	Never married	*** **67**	(78%)	*** **26**	(30%)	33	(38%)	82	(66%)
	Married	73	(59%)	68	(55%)	53	(43%)	57	(66%)
	Previously married	*** **16**	(35%)	*** **35**	(76%)	* **30**	(65%)	** **19**	(41%)
Household asset ownership	No assets	* [a] **1**	(11%)	[a] 7	(78%)	[a] 5	(56%)	[a] 4	(44%)
	Mobile	* **24**	(44%)	** **40**	(73%)	28	(51%)	27	(49%)
	TV	83	(68%)	60	(49%)	57	(46%)	82	(67%)
	Motorbike	[a] 9	(69%)	[a] 6	(46%)	[a] 3	(23%)	[a] 9	(69%)
	Car or truck	* 39	(74%)	** **14**	(26%)	22	(42%)	33	(62%)

Notes
Bold font indicates difference is significant at alpha level corrected by sequential Bonferroni method, or Yates' Correction for Continuity (for 2 x 2 tables).
* $p < 0.05$ ** $p < 0.01$ *** $p < 0.005$
[a] There were not enough observations to determine whether the difference was significant.

Direct binomial logistic regression was performed to assess the predictive power of demographic characteristics on the likelihood that respondents used cloth or pads. The binomial logistic regression models, containing the independent variables: 'age' and 'highest educational level', are shown in **Table 3.3**.

The model for pad use was statistically significant, χ^2 (4, n = 254) = 48.5, $p < 0.001$, indicating that the model was able to distinguish between respondents who used and did not use pads. The model explained between 28% (Cox and Snell R square) and 37% (Nagelkerke R squared) of the variance in pad use, and correctly classified 72.8% of all cases. Both variables made unique statistically significant contributions to the model. The strongest predictor of using pads was attending university, recording an odds ratio of 14.688. This indicated that respondents who went to university were over fourteen times more likely to use pads than those who did not, controlling for all other factors in the model.

The model for cloth use was also statistically significant, χ^2 (12, n = 247) = 82.8, $p < 0.001$, indicating that the model was able to distinguish between respondents who used and did not use cloth. The model explained between 31% (Cox and Snell R squared) and 42% (Nagelkerke R squared) of the variance in cloth use, and correctly classified 73% of all cases. Both variables made unique statistically significant contributions to the model. The strongest predictor of using cloth was age, recording an odds ratio of 1.082. This indicates that for every additional year of age, respondents were 1.082 times more likely to use cloth, controlling for all other factors in the model.

Initially, models predicting pad and cloth use were produced containing five independent variables (age, highest educational level, source of personal income, wealth, and marital status), which were selected on the basis that they showed significant correlation with absorbent type (as shown in **Table 2**). These initial models were statistically significant (χ^2 (12, n = 247) = 61.5, $p < 0.001$ for pads, and χ^2 (12, n = 247) = 92.5, $p < 0.001$ for cloth), and correctly classified 74% and 73% of all cases for pads and cloth respectively. However, only two of the independent variables (age and highest educational level) made unique statistically significant contributions to the models, and therefore the other variables were dropped with minimal loss in predictive power. The initial models are shown in **Table S5**.

Table 3.3. Binomial logistic regression models for pad and cloth use.

Variable	B	S.E.	Wald	df	*p*	Odds ratio	95.0% C.I. for odds ratio	
							Lower	Upper
Probability model of whether participant uses pads								
Age	- 0.050	0.016	10.451	1	0.001	0.951	0.922	0.980
Highest education:								
None/primary			28.391	3	< 0.001			
Secondary	1.484	0.378	15.444	1	< 0.001	4.412	2.104	9.248
Tech college	1.852	0.476	15.147	1	< 0.001	6.372	2.507	16.191
University	2.687	0.562	22.856	1	< 0.001	14.688	4.882	44.197
Constant	0.631	0.572	1.216	1	0.270	1.880		
Probability model of whether participant uses cloth								
Age	0.079	0.019	16.535	1	< 0.001	1.082	1.042	1.124
Highest education:								
None/primary			42.708	3	< 0.001			
Secondary	- 1.613	0.461	12.257	1	< 0.001	0.199	0.081	0.492
Tech college	- 2.765	0.556	24.752	1	< 0.001	0.063	0.021	0.187
University	- 4.323	0.722	35.804	1	< 0.001	0.013	0.003	0.055
Constant	- 0.512	0.669	0.586	1	0.444	0.599		

Notes
B = Unstandardised regression weight
S.E. = Standard error
Wald = Chi Square value from the Wald test
df = Degrees of freedom
C.I = Confidence interval

3.4.4 Changes in menstrual absorbent use

Figure 3.5 shows the changes in menstrual absorbent use among a subset of participants (n = 190) who experienced menstrual cycles at the time of the survey (2020) and 10 years prior (2010). Among this subset, pads and cloth were the most commonly used materials in 2010 (47% and 49% of absorbents used, respectively) and in 2020 (46% and 42% of absorbents used, respectively), although they shrank slightly as a percentage of total absorbents used. No participants reported using tampons in 2010, however by 2020 tampons had grown to 3% of menstrual absorbents used, being adopted by participants who had previously used pads. Uptake of reusable pads grew considerably from a share of <1% in 2010 to 4% in 2020 but remained a small percentage of overall absorbent choice.

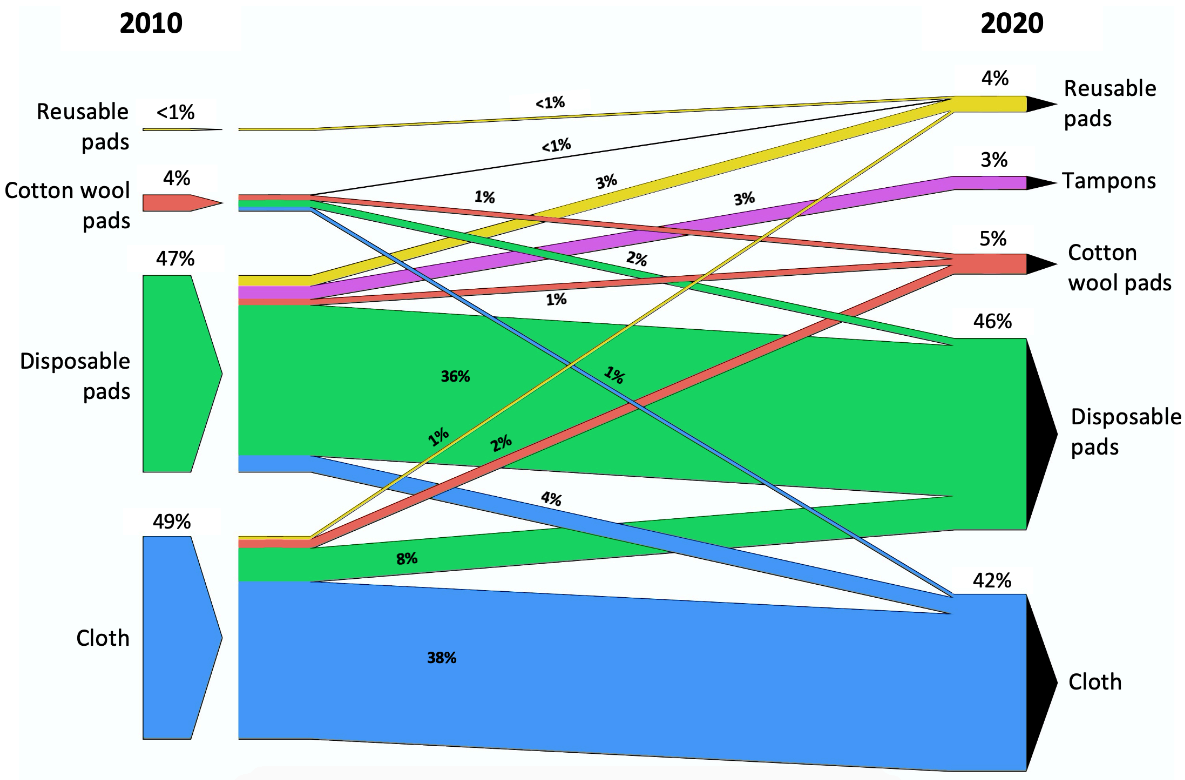

Figure 3.5. Menstrual absorbents used by sub-set of participants who experienced menstrual cycles at the time of the survey (2020) and 10 years prior (2010) (n = 190).

3.5 Discussion

Quantifying volumes and compositions of menstrual waste is an important part of identifying how this particular waste stream fits within the larger picture of solid waste production and disposal. This study has presented the first empirical evidence of how menstrual waste travels through the urban environment of a low-income country city, in addition to generating novel insights into the usage patterns of menstrual absorbents and characteristics of their user groups.

3.5.1 Identity and empowerment

The patterns between pad/cloth use and demographic characteristics indicate a higher prevalence of pad use among women who are younger, more highly educated, wealthier, and in formal employment. Conversely, there is a higher prevalence of cloth use among women who are older, less highly educated, poorer, and in informal employment. Household economics undoubtedly plays a crucial role; pads can be expensive relative to the average income, and therefore women who are poorer or have less control over household expenditures may be more likely to use old cloth (Hennegan et al., 2017). However, the associations between menstrual absorbent use, education, and employment type are particularly compelling. For instance, the linkage between use of disposable pads and being in formal employment might not only be an economic consequence of higher average wages, but also a prerequisite: leak-proof and conveniently changeable absorbents are required in order to participate in a workplace (particularly where a safe or private toilet is not always working or available). Whilst the linkages between school attendance and menstrual practices have been extensively examined (Hennegan and Montgomery., 2016), there is no such exploration on how access to menstrual absorbents affects other kinds of participation in the economy and civil society. In a Western context, Moffat and Pickering (2019) and Wiseman (2019) have discussed how the menstruating uterus and associated stigma can become a 'leash' restricting women to, or close to, the home when suitable materials or infrastructure are not available to manage and conceal menstrual blood. In a similar way, use of cloth or other improvised absorbents might be anticipated to act as a barrier to participation in certain workplaces due to lack of changing facilities, as has been shown to be the case in schools (Hennegan et al., 2017). As menstruation affects women but not men, this constitutes a significant obstacle to gender equality. Furthermore, gendered expectations mean that struggling to manage menstruation is considered a failure of womanhood, which can lead to detrimental impacts being underplayed; this invisibility further compounds the impact of menstruation on gender equality (Hennegan et al., 2020).

3.5.2 'Disposable' and 'reusable' in practice

Use of disposable menstrual absorbents typically generates a greater volume of waste than reusable ones (Kaur et al., 2018). This study supports this assertion, with an average of 9.1 disposable pads and 2.4 menstrual cloths discarded per month by participants exclusively using these absorbents. However, great diversity in behaviour was noted among cloth users, with some discarding up to eight cloths per month and others not throwing any away at all. The former participants appeared to treat cloth more like a disposable material than a reusable one, whilst the latter reserved it for uses in traditional medicine, which has been previously shown to be a valuable commodity (Roxburgh et al., 2020a (i.e., Chapter 2)). These findings highlight that there is much that remains undocumented about the diverse behaviour of cloth users. Cloth is a particularly problematic material with regards to removing faecal sludge as it can entangle the blades of pumping devices (Sisco et al., 2017), and therefore frequent discarding of cloth into pit latrines poses a very significant conflict with developing safe pit emptying practices.

Some pad users appeared to use notably low numbers of pads. Around half of participants used eight or fewer pads per period, suggesting that many are using fewer than two a day if their period is five days in length. Whilst this might be partly explained by some women having short and/or light periods, some may use small numbers of pads due to financial constraints. Studies of schoolgirls have highlighted the difficulties that they experience in acquiring money to buy pads, and also linked poor menstrual hygiene to periods of longer duration (which require more pads) (Belayneh et al., 2019; Crankshaw et al., 2020). In this study, however, although wealth was associated with using pads, no correlation was detected between wealth and numbers of pads used. It may be that the wealth metric used (family ownership of a selection of assets) was too coarse to detect a relationship. Furthermore, if women are not in control of the household finances, they may be less able to direct resources according to their menstrual needs, thus further obscuring any potential relationship.

3.5.3 Disposal by faeces and fire

The study highlights two main disposal routes for menstrual absorbents used by participants: throwing in pit latrines (55% of all absorbents) and burning (39% of all absorbents). Pads are more likely than cloth to be discarded in pit latrines, which may reflect the fact that pad users generate waste more regularly and in greater volume than cloth users, and therefore may seek a more convenient disposal strategy than burning. Finding the time and space to burn menstrual waste in secret can be laborious and inconvenient. This challenge can be particularly acute for disposable absorbent users who struggle to find privacy at home, and may resort to hiding badly smelling used pads before a convenient time to dispose of them can be found (Roxburgh et al., 2020a (i.e., Chapter 2)). Very few menstrual absorbents are mixed with solid waste; less than 5% enter bins and pits and only 1% are estimated to eventually reach the local landfill. Qualitative research has explored the reasons why many women feel uncomfortable with discarding menstrual absorbents alongside solid waste: fears of the waste being seen by others, scavenged by dogs, or being taken for use in rituals have been highlighted as various factors (Scorgie et al., 2016; Chinyama et al., 2019). Menstrual waste can therefore be seen to have mostly limited interactions with solid waste management systems and infrastructure. Despite being essentially solid waste, it nonetheless is disposed of differently to other kinds of solid waste due to its sensitivities and perceived dangers.

The greatest proportion of participants discarding menstrual absorbents into pit latrines was found in one of the high-density informal settlements, Chirimba (84%, $n = 32$), whilst the lowest proportion was found in a peri-urban settlement, Chigumula (37%, $n = 11$). Participants living in densely populated areas may be less likely to burn their menstrual waste due to the necessary privacy required to do so secretly and may turn to pit latrines as a disposal method instead. However, discarding solid waste in pit latrines causes them to fill more quickly (Still and Foxon, 2012), and high-density areas are also more likely to require full pit latrines to be emptied because the space is insufficient for abandoning and re-digging them. Thus, high-density neighbourhoods may be viewed as particularly critical areas with regards to the challenge of menstrual waste in pit latrines, as the presence of waste in pit latrines complicates the process and increases the cost of removing the faecal sludge (Chipeta et al., 2017, Sisco et al., 2017). This constitutes an important potential conflict with the requirements of sustainable faecal sludge management systems, and by extension, delivery of safe sanitation for dense urban settlements. The root cause of this, however, is the gendered stigma attached to menstruation and subsequent requirements for privacy. Further research to explore how disposable and reusable menstrual absorbent use is situated within the broader context of solid waste management and sanitation infrastructure in densely populated urban settings is strongly recommended.

3.5.4 Looking to the future

The strong correlation between menstrual absorbent choice and age indicates the possibility of a demographic shift in menstrual waste. As older women (predominantly cloth-users) reach menopause, and younger women (predominantly pad-users) reach menarche, the proportion of disposable absorbents being used in the community will increase, leading to a rise in menstrual waste generation (Roxburgh et al., 2020a (i.e., Chapter 2)). To a certain extent, this rise may be offset by adoption of tampons and reusable pads, as both generate smaller volumes of menstrual waste (due to either being reusable or compact in size) and have increased in popularity over the last decade. However, at present tampons and reusable pads make up such a small percentage of the menstrual waste composition (at just 6% of absorbents used by participants) that their slow expansion is unlikely to have a noticeable impact in the near future. Tampons in particular are likely to have socio-cultural constraints on their widespread acceptability, due to their use being believed to compromise virginity (Crankshaw et al., 2020).

Innovative and reusable menstrual products, such as high-quality reusable pads and menstrual cups, may offer dual benefits by reducing volumes of waste generated whilst also providing improved functionality and convenience over cloth and disposable pads. Reusable pads are washable pads designed to be worn in the underwear, and menstrual cups are a small cup (usually made of medical-grade silicone or similar materials) which is inserted into the vagina to collect blood, and then periodically emptied (Scott et al., 2013; Van Eijk et al., 2019). Whilst menstrual cups may face similar limitations to tampons in their uptake, reusable pads in particular have potential for extremely broad cultural acceptability due to similarities with traditional practices, and utilise materials to optimise comfort, absorbency, and speed of drying, thus providing improved performance over cloth (Hennegan et al., 2017). This study suggests that the user base of reusable pads has expanded over the last decade but remains very small (as shown in **Figure 3.5**). The availability and cost of purchasing reusable pads may be a significant limitation in their adoption, as they are not widely available and struggle to compete with disposable pads despite having a lower cost per period over their lifetime. Importantly, further research could be used to determine whether subsidies, tax breaks, or distribution by local organisations could improve uptake, although it is crucial that any such interventions do not distort and damage markets for other local menstrual products. Ultimately, it is important that all women have access to a variety of menstrual absorbent products regardless of their socio-economic status, and widening access to a variety of menstrual absorbents, and in particular, high-quality reusable pads, is an immediate avenue for research and action.

In the case of reusable menstrual absorbents, it is particularly important for users to have sufficient water to wash them (in terms of both quantity and quality), and suitably private locations to wash and dry them. In particular, it is important that the bloodied washing water can be drained discreetly (Nawaz et al., 2010). Expansions of water coverage, and in particular access to piped water at home, are therefore vital long-term infrastructure improvements for menstrual hygiene and well-being, as well as for creating a supportive environment for uptake of reusable menstrual absorbents.

3.5.5 Limitations

The self-reporting method used in the survey had certain limitations, including the risk of inducing social desirability bias. This bias can occur when recalling activities where people might be widely aware of the need to perform it but in practice do it less often, such as hand washing, and therefore report a slightly exaggerated account of their true behaviour (Chidziwisano et al., 2020). In the case of the menstrual flow data, it is likely that some pathways, such as discarding menstrual waste into the environment or into bins, were somewhat underreported as these are not viewed as 'respectable' methods of disposal, and some participants may have felt too embarrassed to admit to doing this. The self-reporting method also may have induced inaccuracies in that many women may be unlikely to accurately remember the exact proportions of different menstrual absorbents used, and the ways in which they were disposed. In particular, the comparison of menstrual absorbents used 10 years ago to those used today must be viewed as indicative, rather than precise, although the trends reported are supported by other independent studies (Crankshaw et al., 2020). The challenges of recall bias were mitigated to some extent by the skill of the enumerators, who would carefully discuss the participant's practices with them in order to determine an estimate. Importantly, the menstrual waste data must be viewed as an illustration of how menstrual waste composition changes and moves in the city, with the potential for further refinement in accuracy and validation through future research. However, whilst it would be misleading to quote precise percentages of flows with certainty, particularly for the less widely used absorbents, it is nonetheless valid to conclude that substantial volumes of pads and cloth are either burned or thrown into pit latrines.

3.6 Conclusion

There is currently a paucity of options to manage a growing volume of disposal pads safely, conveniently, and sustainably within urban environments. Menstrual waste predominantly ends up being burned or buried, with detrimental consequences to individual health and urban sanitation systems. This should be viewed as a systematic failure of waste management, with no blame attributed to those who produce the waste, who have a right to go about their lives in comfort and with convenience (Bobel, 2019). Women are placed in a difficult position by the severe, gendered societal etiquette which mandates concealment of their menstrual status, whilst their choice of absorbent and means of disposal are further constrained by economics, availability, practical considerations, and the threat of witchcraft (Scorgie et al., 2016; Chinyama et al., 2019). There is an urgent need to provide a range of menstrual absorbent choices and improved waste disposal options which are sensitive to their socio-cultural-infrastructural conditions, for the benefit of women, furtherment of gender equality, and protection of urban environmental health.

Choice of absorbent and disposal method are contingent on a range of highly personal circumstances. For instance, reusable absorbents must be washed, and therefore if household drainage is uncovered, then a woman might struggle to conceal the bloodied washing water from her neighbours and therefore prefer disposable pads. However, another woman who has limited privacy to burn menstrual waste at home may find reusable absorbents to be a better solution, and it is therefore vital that a diverse selection of menstrual absorbents is available at a variety of price points (Shannon et al., 2021). High-quality reusable products have particular potential to provide widespread benefits to women and the environment, especially in economically and spatially constrained settings like high-density low-income settlements. Participatory research methods also can be used to explore barriers to adoption (e.g., availability and cost) and also support the development of alternative disposal options. Ultimately, however, dismantling the social stigma of menstruation is one of the most important requisites for improving the management of menstrual waste, gender equality, and menstrual wellbeing. Multi-disciplinary collaborations (particularly between solid waste management, sanitation, and gender and health specialists) will be needed to tackle the challenge of finding sustainable disposal solutions for menstrual waste. Supporting markets for reusable pads in order to increase their uptake may be a promising policy intervention avenue, but future research is required to determine what particular interventions will be most effective and sustainable.

Chapter 4 | Can feeding activity of black soldier fly larvae reduce pathogen concentrations in faecal wastes?

4.1 Abstract

The successful incorporation of black soldier fly larvae (BSFL) into organic waste treatment has invited speculation as to whether these larvae can also be used to treat faecal sludge from pit latrines. BSFL are highly efficient converters of organic matter into biomass and insect frass, and co-processing faecal sludge with other organic wastes, such as food waste, could potentially be used to optimise system operation and by-product production. The aim of this chapter is to determine the effect of BSFL on concentrations of two commonly used faecal indicator organisms, *Escherichia coli* and *Enterococcus faecalis*, in substrates of human faeces, with or without the addition of food waste. Experiments were conducted to investigate the growth of larvae on substrates with different ratios of faecal matter to food waste, and the effect of larval feeding on concentrations of *E. coli* and *E. faecalis* in substrates with different ratios of faecal matter to food waste. Greater larval growth was achieved from rearing larvae on vegetable waste combined with human faeces than on human faeces alone. The presence of BSFL resulted in increased declines in *E. coli*, however, they persisted for longer in the boxes containing vegetable waste, both with and without the addition of BSFL. The BSFL did not appear to cause *E. faecalis* concentrations to decline in either substrate; they remained constant in the 100% faeces substrate and slightly proliferated in the 50% faeces 50% vegetable waste substrate. The results implied that subsequent treatment processes are required regardless of whether faecal sludge is co-treated or not, and co-treatment may be beneficial for producing larger volumes of BSFL than are produced from faecal sludge treatment alone. Further exploration of how co-treatment mixtures can affect end products, such as the quality of organic fertiliser, may reveal further benefits to co-treatment.

4.2 Introduction

Black soldier fly larvae (BSFL) (*Hermetia illucens*) are highly efficient converters of organic matter into biomass (i.e., larval bodyweight) and insect frass (i.e., insect faeces: a soil-like material with bio-fertiliser properties) (Lohri et al., 2017; Quilliam et al., 2020). Speed of biodegradation facilitated by BSFL are similar or faster than traditional methods of treating organic waste, such as composting and aerobic / anaerobic digestion (Čičková et al., 2015). As a result, BSFL are gaining prominence as a novel waste treatment method around the world, where organic waste is processed into fertiliser (or soil amendment products) at an industrial scale, whilst the larvae can be used as animal feed or for other commercial uses (da Silva and Hesselberg, 2019; Li et al., 2019).

The successful incorporation of BSFL to organic waste treatment has invited speculation as to whether these larvae can also be used to treat human excreta, as safe and economical excreta management remains a substantial challenge in many resource-constrained low-income countries (Banks et al., 2014). This problem is particularly acute in poor urban settlements, where pit latrines are the predominant method of sanitation and environmental health risks are exacerbated by high population density (Taweesan et al., 2015; Berendes et al., 2017). The lack of faecal sludge management in these settings has been described as an 'impending crisis', and there is an urgent need to establish robust systems to regularly remove and treat faecal sludge from pit latrines, as are used in parts of South Africa (Yesaya and Tilley, 2021; Sutherland et al., 2014). The tropical climate frequently found in low-income countries is favourable to BSFL, which originate from South America and have since colonised all continents except Antarctica (da Silva and Hesselberg, 2019). However, whilst BSFL can survive and thrive on faecal sludge in laboratory experiments, there are few documented examples of this being applied in practice, and at scale (Banks et al., 2014).

Considerable uncertainty surrounds the process under which BSFL modify their substrates, although they have been shown to reduce odour, reduce dry matter and moisture content, and – importantly for faecal substrates – reduce concentrations of certain pathogenic organisms (Gold et al., 2018; Beskin et al., 2018). BSFL feeding activity can reduce concentrations of *Escherichia coli* (including *E. coli* O157:H7), various strains of *Salmonella* (*S.enterica*, *S. typhimurium*, *S. dublin*, *S. senftenberg*, and *S. typhimurium* DT104), reovirus type 3, canine adenovirus I, porcine enterovirus I, and bacteriophage ΦX174 in the faeces of humans, pigs, cows, and poultry (Erickson et al., 2004; Liu et al., 2008; Lalander et al., 2013; Lalander et al., 2015a, Lalander et al., 2015b). However, the concentration of other bacteria such as *Enterococcus faecalis* and helminths such as *Ascaris suum*, do not appear to decline as a result of BSFL feeding activity, although there is some suggestion that their growth and development may be supressed (Lalander et al., 2013; Lalander et al., 2015a).

Whilst BSFL can survive and grow on fresh faeces, or from layers within the upper-most metre of pit latrines, larval survival and bioconversion rates are lower when feeding on sludge from the bottom of pit latrines (Banks et al, 2014; Banks, 2014). Pit latrine waste alone may not be the optimal diet for BSFL survival and growth, and it has been suggested that co-processing faecal sludge with other organic wastes, such as food waste, could be used to optimise system operation and by-product production (Joly and Nikiema, 2019). However, it remains unclear whether pathogen survival can also be affected by the composition of BSFL substrate mixtures.

Therefore, the aim of this chapter was to determine the effect of BSFL on concentrations of two commonly used faecal indicator organisms, *E. coli* and *E. faecalis*, in substrates of human faeces, with or without the addition of food waste.

4.3 Methods

4.3.1 Experimental design

Three experiments were conducted (**Table 4.1**). Experiment 1 investigated the growth of larvae on substrates with different ratios of faecal matter to food waste. Experiment 2 investigated the effect of larval feeding on concentrations in *E. coli* and *E. faecalis* in substrates with different ratios of faecal matter to food waste. Experiment 3 investigated the effect of larval feeding on concentrations of *E. coli* in faecal matter in a larger volume of substrate than was used in Experiment 2, to reduce interference from the material drying out.

Control treatments, containing pathogen-inoculated substrates but no larvae, were used to verify whether a significant difference in *E. coli* / *E. faecalis* concentrations could be established between the larval-treated material and non-larval treated material. Each treatment in each experiment had four replicates; each replicate was conducted in a plastic container measuring 20 x 15 cm x 10 cm. A 10 x 5 cm hole in the lid of each box, covered with paper towel, allowed air exchange.

Table 4.1. Experimental set-up for the three experiments.

		Substrate		Bacteria added to substrate	Larvae (n)	Average larvae start weight (g)	Control treatments without larvae
		Faeces (g)	Food waste (g)				
E1	T1	200 (100%)	0 (0%)	None	100	0.038 (± 0.0011)	No
	T2	150 (75%)	50 (25%)				
	T3	100 (50%)	100 (50%)				
E2	T1	160 (100%)	0 (0%)	*E. coli* and *E. faecalis*	60	0.028 (± 0.0027)	Yes
	T2	80 (50%)	80 (50%)				
E3	T1	460 (100%)	0 (0%)	*E. coli*	227	0.039 (± 0.0043)	Yes

Notes
E Experiment
T Treatment
Standard error for average larvae start weight is given in brackets

4.3.2 Materials for experimental mesocosms

A colony of BSFL (Blue Lizard Reptiles, UK) was established in a fly tent in a controlled environment cabinet (Reftech B.V., Netherlands) at 28 °C, 70% relative humidity, and a 12 h photoperiod. The larvae were fed wheat bran (Harbro Ltd., Aberdeenshire, UK) and shredded mixed vegetables, and pupated in a bark chip substrate. After the flies had emerged, the inside of the fly tent was sprayed with water twice a day, and eggs were collected from corrugated cardboard strips above a container of feed substrate. The larvae that hatched from this colony were used for the first two experiments, whilst for the third experiment, larvae were used directly from the BSFL supplier, Blue Lizard Reptiles.

An environmental isolate of *E. coli* was isolated from wildfowl faeces, and an isolate of *E. faecalis* was isolated from sewage sludge by mixing approx. 5 g of faeces or sludge with 25 ml of phosphate buffered saline (PBS) and vortexing for 30 sec. The solution was serially diluted and streaked out onto the surface of a plate containing membrane lactose glucuronide agar (MLGA) (CM1031, Oxoid, Basingstoke, UK) for the selection of *E. coli*, or onto Slanetz & Bartley medium (CM0377, Oxoid) for selection of *E. faecalis*. Following incubation of the inverted plates at 37 °C for 24 h (*E. coli*) or at 44 °C (± 0.2 °C) for 48 h (*E. faecalis*), colonies of each species were picked off with a sterile toothpick and cultured in Luria-Bertani (LB) broth (CM1018, Oxoid), at 37 °C, at 100 rev min^{-1}, for 18 h. Cells for both species were subsequently centrifuged and washed three times in PBS and resuspended in PBS immediately prior to use in the experimental mesocosms.

The faeces substrate was composed of fresh human faeces collected from composting toilets (used by a campsite and wildlife reserve visitors) near Aviemore, and Stirlingshire, Scotland. Excess toilet paper was removed, the material was stored at - 20 °C, and then thawed before use. For the food waste substrate, a food waste mixture was simulated by shredding equal weights of bananas, apples, carrots and wheat bran in a food processor immediately before each experiment. This uniform mixture was then mixed thoroughly with the thawed faeces using a spoon and placed in the mesocosms.

4.3.3 Experiment 1: do different ratios of faeces to food waste affect BSFL growth?

On day zero, 100 ten-day old larvae were added to replicate boxes containing 200 (± 2) g of substrate (see Table 1 for proportions of substrate for each treatment). The experiment ran for 10 days in total with daily measurements of larval weight and substrate moisture content, pH, and electrical conductivity (EC).

For measurements of larval weight, the substrate was turned in five different places in each box. At each spot where the substrate was turned, the two leftmost larvae visible in the newly exposed substrate were removed using a pair of tweezers. The combined total of ten larvae were weighed to 4 decimal places. Visibly attached substrate was removed from the larvae before weighing by rinsing them in water and patting dry with paper towel. For measurements of moisture content, composite substrate samples of approximately 5 g, taken from four different places in the box using sterile disposable spatulas (one spatula used per replicate), were dried at 105 °C for 24 h, and then weighed to 4 decimal places. For measurements of pH and EC, composite substrate samples of approximately 2 g, taken from four different places in the box using a spatula, were added to 20 ml of deionized water and vortexed for 30 seconds, and then measurements were taken using a HI 2550 Multiparameter bench meter (HANNA instruments, Bedfordshire, UK). All measurements of pH and EC were conducted at room temperature.

4.3.4 Experiment 2: do different ratios of faeces to food waste affect concentrations of *E. coli* and *E. faecalis*?

For each larval treatment, 60 ten-day old larvae were placed into boxes containing 160 (± 2) g substrate inoculated with *E. coli* and *E. faecalis* (**Table 4.1**). Control treatments, containing the same amount of inoculated substrate, but no larvae, were also used. Inoculation was performed by pipetting 50 ml of the PBS solution containing a mixture of resuspended *E. coli* and *E. faecalis* (1.3×10^9 CFU ml^{-1} and 6.8×10^8 CFU ml^{-1} respectively) onto the surface of the substrate in each box and thoroughly mixing with a spoon. Measurements of bacterial concentrations and moisture content were taken daily, and measurements of larval weight and pH were taken every 2/3 days, and the experiment ran for seven days in total.

Samples for pH, EC, moisture content and larval weight were taken in the same way as described for Experiment 1. For microbiological analysis, substrate samples, weighing approximately 2 g each, were taken using sterile disposable spatulas (one spatula used per replicate), and added to 20 ml of PBS and vortexed for 30 seconds. Then, 30 µl of the solution was then cultured on places of MLGA (CM1031, Oxoid) or Slanetz & Bartley medium (CM0377, Oxoid). Twelve serial dilutions were used to establish the initial bacteria content. Following incubation of the inverted plates at 37 °C for 24 h (*E. coli*) or at 44 °C (± 0.2 °C) for 48 h (*E. faecalis*), plates containing 10 – 100 colony forming units (CFU) were counted, and the concentration of bacteria per dry gram of substrate was calculated. Moisture content measurements were used to establish the dry weight of each microbiological sample size.

4.3.5 Experiment 3: do different ratios of faeces to food waste affect concentrations of *E. coli* (repeated measurements)?

A third experiment was subsequently set up to measure the reduction of *E. coli* in a larger volume of faeces to avoid interference in bacterial die-off resulting from the substrate drying out. For the larval treatments, 227 ten-day old larvae were added to replicate boxes containing 460 (± 1) g faeces inoculated with *E. coli*, using the same method as described for Experiment 2. Whilst treatments in the first two experiments were exposed to a 12 h photoperiod in controlled environment cabinets, the treatments in the third experiment were kept in the dark, in an incubator at 28 °C. Leaving the treatments in the dark had the benefit of encouraging the photophobic larvae to explore the surface layers of the material. This led to the surface layer being agitated and mixed with the rest of the material, resulting in a uniform, moist substance without a dry top layer. Measurements of CFU, moisture content, larval weight, and pH were taken daily, using the same procedures as described for Experiments 1 and 2.

4.3.6 Statistical analysis

Repeated measures analysis of variance (ANOVA) with 95% confidence interval was used to establish whether there was statistically significant difference between concentrations of pathogens in the larval-treated material and the control. In cases where a statistically significant difference was found, Tukey multiple comparisons of means (95% family-wise confidence level) was performed. All analyses were conducted in SPSS (IBM SPSS Statistics Version 26).

4.4 Results

4.4.1 Experiment 1: do different ratios of faeces to food waste affect BSFL growth?

In Experiment 1, the average larvae weight increased from their initial values until approximately day eight, at which point they started to decline as they neared pupation (**Figure 4.1**). On day five, the average weight of larvae in the treatments with 50% faeces was significantly higher than those in the 100% faeces treatments ($p < 0.05$), which persisted until the end of the experiment. The average larval weight of larvae in the treatment with 75% faeces was significantly higher than the 100% faeces treatments on day 1 ($p < 0.05$), but there were no significant difference from the other treatments on subsequent days. The highest average larval weight (mean = 0.210 g, SE = 0.006 g) was attained by larvae in the boxes containing 50% faeces and 50% food waste, and the lowest average larval weight (mean = 0.182 g, SE = 0.003 g) was attained in the boxes containing 100% faeces. The larvae in boxes containing 75% faeces and 25% food waste reached an average weight between the former two values (mean = 0.191 g, SE = 0.002 g).

Larval weights in the treatments containing 100% faeces and 50% faeces began to noticeably decrease from day 9, indicating that they were reaching the prepupal life stage (Liu et al., 2017). For larvae in the treatment containing 75% faeces, this decline was initiated slightly earlier, on day 8.

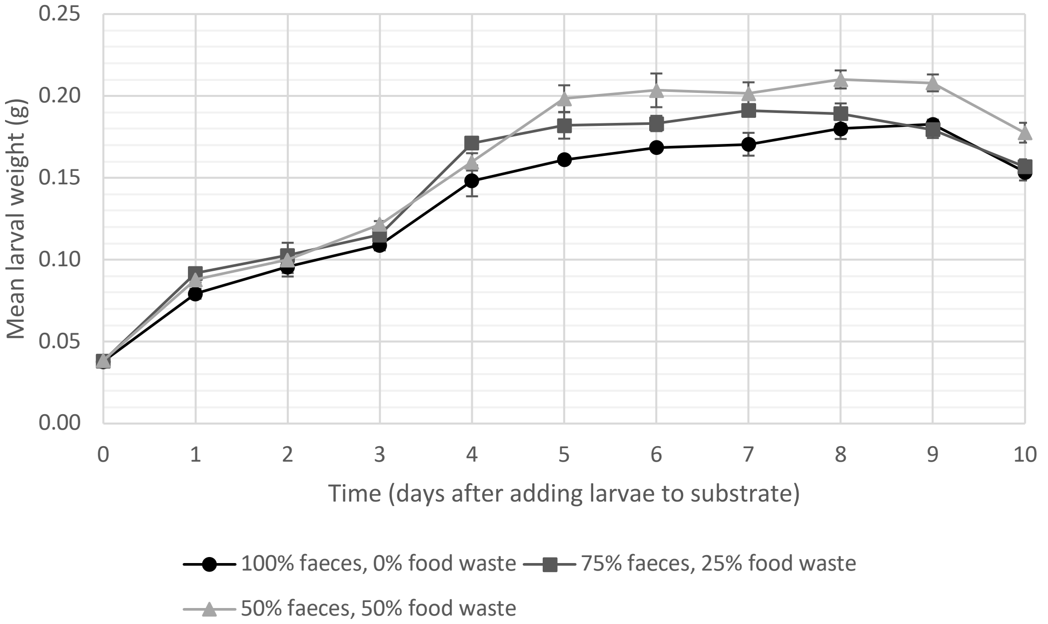

Figure 4.1. Larval growth on substrates with different proportions of faeces to food waste. Data points represent the mean ($n = 4$) ± SE.

In Experiment 1, the final pH values for all treatments were significantly different from their starting values ($p < 0.01$), decreasing in the case of treatment 1 (100% faeces substrate) and rising in the case of treatments 2 and 3 (75% and 50% faeces substrates). There was no significant difference between the final pH values of the three treatments, however the starting value for treatment 1 (8.03) was significantly higher than those for treatments 2 and 3 (6.87 and 6.89, respectively) ($p < 0.001$). EC did not change significantly over the duration of the experiment for treatments 1 and 2 but did increase significantly for treatment 3 (50% faeces substrate) ($p < 0.05$). The physio-chemical parameters of the substrates at the start and end of Experiments 1, 2 and 3 are shown in **Table 4.2**.

Table 4.2. Physiochemical changes in substrates.

Experiment / treatment	pH			EC (μS/m)	
	Start	End (with larvae)	End (without larvae)	Start	End (with larvae)
E1/T1 (100% faeces)	8.03 (0.04)	7.49 (0.06) [a]	NA	3835 (166)	3853 (388)
E1/T2 (75% faeces)	6.87 (0.17)	7.36 (0.04) [a]	NA	3319 (252)	3850 (158)
E1/T3 (50% faeces)	6.89 (0.13)	7.50 (0.04) [a]	NA	2454 (336)	3750 (248) [a]
E2/T2 (50% faeces)	5.28 (0.06)	6.38 (0.43)	5.62 (0.21)	NM	NM
E3/T1 (100% faeces)	6.56 (0.10)	8.50 (0.04) [a b]	7.63 (0.03)	NM	NM

Notes
Values given are the mean, with ± SE in brackets
[a] Significant difference ($p < 0.05$) from start values
[b] Significant difference ($p < 0.05$) from control box (without larvae)
E Experiment
T Treatment
NA Not applicable, i.e., the experiment did not include a control box (without larvae)
NM Not measured

Although not measured, it was observed that odour from the larval-treated material diminished considerably after a few days but persisted in the control material.

4.4.2 Experiments 2 and 3 - do different ratios of faeces to food waste affect concentrations of *E. coli* and *E. faecalis*?

Challenges were encountered with the faeces substrate drying out and killing the *E. coli*, which interfered with quantifying *E. coli* die-off as a result of BSFL feeding. Conversely, *E. faecalis* in the faeces substrate appeared able to survive the drying effect without noticeable detriment, as concentrations close to initial inoculation values persisted until day 5 (after which sampling terminated, as the dried substrate became too difficult to sample). The faeces and food waste substrate did not dry out, presumably due to different biomass composition, which resulted in less surface area being exposed to the air.

The reduction of *E. coli* and *E. faecalis* in the larval-treated and control substrates, for both substrates of 100% faeces and 50% faeces / 50% food waste, and the accompanying substrate moisture contents, are shown in **Figure 4.2a** and **b**.

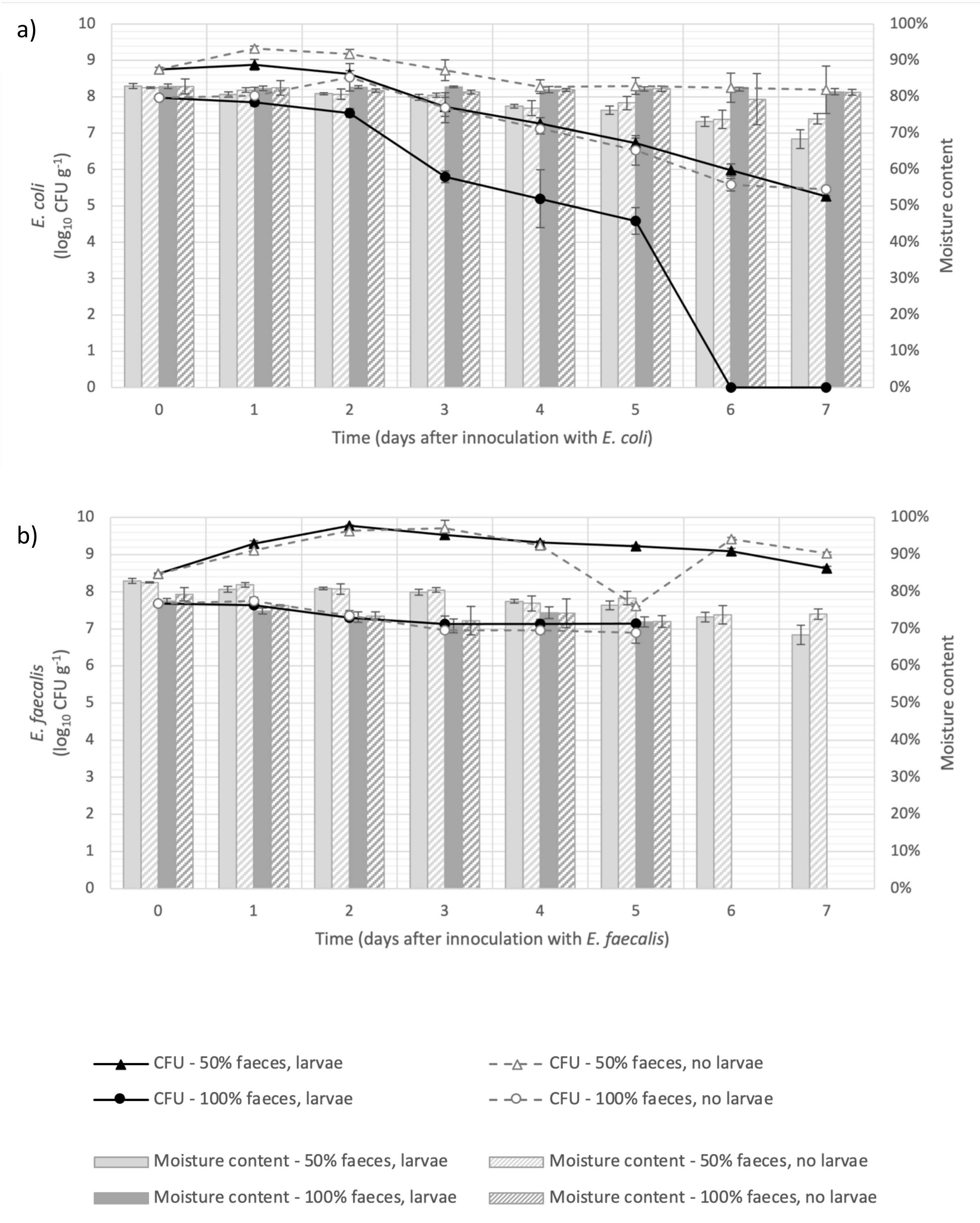

Figure 4.2. Log_{10} concentration of **(a)** *E. coli* (CFU g $^{-1}$) and **(b)** *E. faecalis* (CFU g^{-1}) in the treatments with larvae (filled symbols) and without larvae (open symbols) over the course of the experiment. Circles indicate a substrate of 100% faeces, and triangles indicate a substance of 50% faeces and 50% food waste. Data points represent the mean (n = 4) ± SE. Moisture

content of treatments are indicated by bars; dark grey bars indicate a substrate of 100% faeces, and light dry bars indicate a substrate of 50% faeces and 50% food waste; solid bars indicate treatments with larvae, and hatched bars indicate treatments without larvae.

In Experiment 2, in the substrate containing 100% faeces, the concentration of *E. coli* had decreased significantly compared to the starting value by day four for the substrates containing larvae ($p < 0.01$) and by day seven for the substrates not containing larvae ($p < 0.05$). Significantly lower concentrations of *E. coli* were found in the substrates containing larvae as compared to the substrates not containing larvae from day three onwards ($p < 0.05$). The concentration of *E. coli* in the substrates containing larvae fell below the detection threshold on day six, and therefore a total reduction in *E. coli* of at least 4.0 $\log_{10}$ CFU g^{-1} dry weight was inferred by day six, whilst a total reduction in *E. coli* of 3.8 $\log_{10}$ CFU g^{-1} dry weight was observed in the substrates without larvae by day seven. The detection threshold varied slightly according to the moisture content of the substrate but was approximately 4.1 $\log_{10}$ CFU g^{-1} dry substrate.

In the substrate containing 50% faeces and 50% food waste, the concentration of *E. coli* in the substrates containing larvae had decreased significantly compared to the starting value by day four ($p < 0.01$). In the control material, whilst *E. coli* concentrations fluctuated slightly, there was no significant increase or decrease. The concentration of *E. coli* was significantly lower in the substrates containing larvae compared to the control material on day two ($p < 0.05$) and from day four onwards ($p < 0.05$), and a total reduction in *E. coli* of 3.5 $\log_{10}$ CFU g^{-1} dry substrate was observed by day seven.

In the substrate containing 100% faeces, no significant difference in the concentration of *E. faecalis* was observed between the substrates containing larvae and the control material. There was also no significant reduction in the concentration of *E. faecalis* in the substrates containing larvae compared to their starting values over the course of the 7-day experiment. A total reduction in the concentration of *E. faecalis* of 0.8 $\log_{10}$ CFU g^{-1} dry substrate was observed by day five in the control material.

In the substrate containing 50% faeces and 50% food waste, there was no significant difference in the concentration of *E. faecalis* between the substrates containing larvae and the control material, with the exception of outlying data points from all four replicates of the boxes not containing larvae on day 5 ($p < 0.01$). The concentration of *E. faecalis* increased in both the substrates containing larvae and the substrates not containing larvae and remained significantly higher than the starting values ($p < 0.05$), except for day five in the control material, and day seven in the substrates containing larvae. The maximum concentration of *E. faecalis* observed were 9.78 $\log_{10}$ CFU g^{-1} dry substrate in the substrates containing larvae on day two, and 9.03 $\log_{10}$ CFU g^{-1} dry substrate in the control material on day three. The concentration of *E. faecalis* subsequently reduced to 8.63 $\log_{10}$ CFU g^{-1} dry substrate in the substrates containing larvae and 9.03 $\log_{10}$ CFU g^{-1} dry substrate in the control material by day seven, resulting in a net increase of 0.1 $\log_{10}$ CFU g^{-1} dry substrate and 0.5 $\log_{10}$ CFU g^{-1} dry substrate from the starting values, respectively.

In experiments 2 and 3, in the substrate of 100% faeces containing larvae showed a significant rise in pH ($p < 0.001$) compared to the starting value, and a significant difference from the substrates not containing larvae ($p < 0.01$). In the substrate containing 50% faeces, there was no significant change in pH for the substrates containing larvae or the substrates not containing larvae from the starting values, and no significant difference between them (Table 2).

4.5 Discussion

Rearing larvae on vegetable waste combined with human faeces achieves greater larval growth than is achieved by rearing larvae on human faeces alone, however, there did not appear to be a lengthening of larval development time in the 100% faeces substrates, in contrast to other studies (Nyakeri et al., 2017). The presence of BSFL was responsible for increased declines in *E. coli*, however, the substrate also appeared to have an impact on the persistence of *E. coli*, as they persisted for longer in the boxes containing vegetable waste, both with and without the addition of BSFL. The BSFL did not appear to cause *E. faecalis* concentrations to decline in either substrate; concentrations of *E. faecalis* appeared to remain constant in the 100% faeces substrate and slightly proliferate in the 50% faeces 50% vegetable waste substrate. This suggests that there is no benefit from a pathogen reduction point of view to supplementing faecal sludge with vegetable waste, although there may be some benefits in terms of greater volumes of larvae produced, if these are to be harvested for productive use. When rearing BSFL on waste streams, there is often significant variability in material composition, meaning that efforts to optimise BSFL diet for small increments in growth or pupation rate can however be undermined regardless of the inherent variability of the substrate (Gold et al., 2020).

Although the substrates had broadly similar moisture contents, one difference between them which may have impacted on bacterial survival and proliferation was the way in which moisture was bound within the material. One notable difference between the substances was the greater fluidity of the vegetable waste substrate, despite having a similar moisture content to the faeces substrate (i.e., the vegetable waste substrate flowed to fill the shape of the container, whilst the faeces substrate did not and appeared to have a more rigid structure). Whilst this was anecdotally observed rather than directly measured, it suggests that the relative fluidity of the processed vegetable matter may have provided a more hospitable environment for *E. coli*.

The daily sampling process, which involved taking a piece of substrate from the middle of four different points of each box, may have accelerated the drying of substrates over what they would experience in a more naturalistic setting. For most of the faecal samples, a dry crust naturally formed over the top layer, which would have had the effect of preserving moisture within the material below if it had not been repeatedly broken for sampling each day. The faecal samples containing BSFL in Experiment 3, however, did not develop a crust due to the activity of the larvae moving through the surface layer, since these treatments were kept in the dark and therefore there was no light to discourage the photophobic larvae from exploring the surface (Dortmans et al., 2017). Other studies have demonstrated that *E. coli* tends to associate more with the liquid fraction of manure, whilst *E. faecalis* tends to be more associated with the solid fraction (Guber et al., 2007). Thus, under desiccated conditions, *E. faecalis* appeared to persist better than *E. coli* in the experiments.

The outlying data point in **Figure 4.2b** on day 5 (treatment: faeces and food waste without larvae; open triangle symbol), which is strikingly different to data from the preceding and following day, suggests a potential sampling error. However, anomalous readings were not taken from one or two replicates, but rather from all four, and with a relatively small standard error between them. As it seems implausible that the concentrations of *E. faecalis* declined from 9.2 $\log_{10}$ CFU to 7.6 $\log_{10}$ CFU and then increased back to 9.4 $\log_{10}$ CFU over the space of two days when no other such fluctuations were found in the other treatments, it seems most likely to be a result of human error whereby a tube containing composite samples may have been mislabelled, and the data point actually derived from one of the other treatment boxes.

The mechanisms by which BSFL feeding activity causes declines in concentrations of certain pathogenic organisms has not been conclusively established. However, it has been demonstrated that when *E. coli* and *Salmonella* spp. are inoculated into BSFL frass, their concentrations decline even when BSFL are not present in the frass (Lopes et al., 2020). This suggests that, at least in part, the concentration decline of these species is due to antimicrobial compounds being secreted by BSFL into the frass. Other mechanisms that may have contributed to the decline of *E. coli* concentrations in the experiments presented in this chapter include passing through the BSFL digestive system, and the alteration of physio-chemical conditions within the material.

Whilst the persistence of *E. faecalis* suggests that BSFL feeding activity alone is insufficient to treat faecal sludge (even when faeces are mixed with other organic wastes), it does not mean that BSFL treatment cannot be beneficial to faecal sludge management processes. BSFL treatment can rapidly reduce odorous compounds from faecal sludge and significantly decrease the volume of material, making it easier to handle or transport, and apply further treatment measures (Beskin et al., 2018; Lalander et al., 2013). The process can further add benefits by seeding the material with beneficial microorganisms derived from the BSFL biome, which can positively benefit soil health when used as a soil conditioner (Liu et al., 2019). As such, whilst BSFL may not necessarily be the most straightforward treatment option for faecal sludge, processing by BSFL might be able to add value to the treatment process where there is demand for high-quality organic fertiliser or soil amendment products. However, if BSFL frass is used for agricultural purposes, it will be necessary to reduce concentrations of not only human pathogens, but also others (e.g., those affecting plants or livestock) within the material, as these have been shown to persist through BSFL feeding activity elsewhere (Kawasaki et al., 2020).

Ultimately, the degree to which BSFL feeding treatment can contribute towards faecal sludge management depends on the specific local situation, and, particularly, the economics of scalability. The presence of local markets and supply chains will determine the degree to which products harvested from the BSFL process might be able to offset the cost and complexity of their production process. However, even if BSFL treatment processes are unable to self-fund their operations, this is not necessarily reason not to do them; after all, sewerage systems benefit from substantial subsidy despite tending to serve the wealthiest members of the population (Dodane et al., 2012; Berendes et al., 2017).

4.6 Conclusion

BSFL are a biological treatment technology with potential for deployment in low- and middle-income countries, where climatic conditions are suitably tropical and large quantities of organic waste and faecal sludge are produced but currently untreated. This chapter shows that there appears to be no benefit from co-treating vegetable waste with faecal sludge using BSFL from a perspective of pathogen reduction; on the contrary, *E. coli* and *E. faecalis* appeared to proliferate and persist for longer in the substrate containing vegetable waste and faeces than in the substrate containing faeces alone. However, subsequent treatment processes are required regardless of whether faecal sludge is co-treated or not, as BSFL feeding activity does not remove all pathogens from faecal sludge. Exploration of how co-treatment mixtures can affect end products, such as the quality of organic fertiliser, may reveal benefits in supplementing faecal sludge with other types of organic matter. Furthermore, co-treatment with other kinds of organic matter may be beneficial for producing larger volumes of BSFL than are produced from faecal sludge treatment alone, if these are harvested for further use. The removal of gram-negative *E. coli* but not gram-positive *E. faecalis* under BSFL feeding activity lends support to the hypothesis that antimicrobial agents secreted by BSFL into the frass are the primary method by which bacteria concentrations are affected, as these agents have been shown to have antibacterial effects against gram-negative, but not gram-positive, bacteria.

Chapter 5 | Demonstrating samples of composted, granulated faecal sludge strongly influences acceptability of its use in peri-urban subsistence agriculture

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R.S. Quilliam, K. Hampshire, E.A. Tilley, and D.M. Oliver supervised the project. H. Roxburgh designed the data collection tools with support from all other authors. Fieldworkers carried out the data collection with support from H. Roxburgh and E.A. Tilley. H. Roxburgh analysed and interpreted the data with support from R.S. Quilliam, K. Hampshire, and E.A. Tilley. H. Roxburgh produced the manuscript, and all authors commented on draft versions.

5.1 Abstract

Using human excreta derived fertiliser (HEDF) in agriculture reduces dependence on diminishing phosphorus rock reserves, improves soil health, and facilitates sustainable nutrient recycling. Such schemes have particular scope for expansion in peri-urban areas of low-income countries, where large quantities of faecal sludge from on-site sanitation systems are available. However, public acceptability is a critical unknown factor. This study used surveys of 534 peri-urban subsistence farmers in Blantyre, Malawi, to investigate the public acceptability of HEDF. Two factors are highlighted as having a particularly strong association with acceptability: showing a sample of composted, granulated faecal sludge to participants at the start of the survey, and having heard of HEDF before. For instance, almost all participants who were shown the composted, granulated sample and had prior knowledge of HEDF were willing to buy maize grown in HEDF (96%). Conversely, less than a third of participants who had not heard of HEDF before and were not shown the composted, granulated sample were willing to do so (30%). Maize was the most widely accepted crop for use with HEDF, as there is perceived to be little contact between the edible parts and the ground. This suggests that HEDF has the potential to be widely accepted by subsistence maize farmers and the general public in

Malawi. However, uptake rates could be substantially improved with public engagement campaigns involving demonstrations or samples of a visually appealing product, and by promoting the concept through channels such as farmer radio programmes or agricultural extension workers.

5.2 Introduction

Using human excreta derived fertiliser (HEDF) in agriculture has a long and geographically diverse history (Ferguson, 2014). This practice occurs both formally in higher income countries, and informally in the Global South (Christodoulou and Stamatelatou, 2015; Thebo et al., 2017), and can produce crop yields comparable to those grown with commercial synthetic fertiliser (Moya et al., 2019a). Despite the widespread availability of human excreta, the majority of phosphorus currently used in agriculture comes from phosphorus rock (Karamesouti and Gasparatos, 2017). However, with a growing recognition of the geopolitical risks associated with a dependence on commercial phosphorus mining, and with 'peak phosphorus' potentially being reached in the coming decades, there is increasing interest in harvesting the agricultural value from human excreta at greater scale (Chowdhury et al., 2017; Iwaniec et al., 2016).

One region with soil that could benefit particularly strongly from HEDF is sub-Saharan Africa. Crop yields in many parts of the continent are constrained by soil infertility and a lack of soil moisture (Tadale, 2017), whilst financial constraints mean that many farmers are unable to use synthetic fertiliser in sufficient quantities for their needs (Danlami et al., 2016). Organic soil amendments, such as HEDF, can improve soil health by providing nutrients and increasing water retention capacity, resulting in increased productivity and resistance to dry conditions (Eden et al., 2017; Oldfield et al., 2018). Human excreta is widely available from on-site sanitation systems such as pit latrines, although currently, the majority of this excreta does not have a safe or productive destination (Nakagiri et al., 2015a; Peal et al., 2020). Use of HEDF, particularly in peri-urban areas, can therefore strengthen waste management and agricultural linkages within a circular economy, and benefit resource-poor farmers (Trimmer and Guest, 2018).

Whilst there are clear benefits from using HEDF in agricultural systems, there is often concern about the public acceptance of such ventures. Humans are naturally predisposed to avoid faeces due to a psychological system that has evolved to protect us from sickness (Curtis et al., 2011), and faeces are generally endowed with deep cultural significance as a symbol of filth and disgust (Jackson and Robins, 2018). Promoting HEDF to a disinterested or oppositional population therefore has potential to raise ethical concerns and/or be economically unfeasible. Studies trying to gauge the socio-cultural acceptability of using HEDF typically assume that certain cultures, demographics, or types of farmer may be predisposed, and attempt to identify such characteristics using surveys (e.g. Cofie et al. 2010). Alternatively, interviews, and other ethnographic techniques might be used to examine the particular features and practices of farmers who already use HEDF (e.g. Knudsen et al. 2008), or more broadly, explore what human excreta means to society in general (e.g. Van Der Geest, 1988). Acceptability of using HEDF is commonly assessed by asking hypothetical questions to farmers who do not currently use HEDF (e.g. whether they would be willing to use HEDF on their own farms), and the general public (Appiah-Effah et al., 2015).

HEDF is used in agriculture in many countries around the world, both with and without the initiation or support of external organisations such as NGOs. In some areas it is ubiquitous, e.g. 92% of surveyed farmers in Nghe An province, Central Vietnam, used HEDF (Mackie Jensen et al., 2008), whilst in other areas it is much rarer, e.g. 4% of surveyed farmers in Ashanti region, Ghana, used HEDF (Appiah-Effah et al., 2015). Some farmers are enthusiastic about the use of HEDF, whilst others are disgusted, although most have a perception somewhere between these two extremes (Buit and Jansen, 2016) and there is often embarrassment and sensitivity when discussing the use of HEDF (Knudsen et al., 2008). Certain structural barriers to using HEDF exist; for example, in India, this may be due to persisting legacies of caste (Simha et al., 2017), whilst in Islamic countries this may be linked to religious notions of purity (Khalid, 2017). However, the presence of such barriers does not necessarily determine acceptability of HEDF. Muslim farmers in Pakistan were keen to use HEDF provided that the process was economical and efficient (Khalid, 2017), whilst farmers in Ghana were not interested despite there being no obvious societal or faith-related reason (Appiah-Effah et al., 2015). Any differences in receptivity between demographic or farming groups are often marginal (Cofie et al., 2010), although an appreciation of the nutritive value of HEDF, together with the associated benefits to crop growth, is often associated with a greater acceptance (Cofie et al., 2010; Mariwah and Drangert, 2011). Previous studies have provided detailed snapshots of practices and attitudes in places where HEDF is used; however, they do not necessarily advance an understanding of how to scale-up HEDF use in areas where it is not currently used.

The aim of this study was to assess factors influencing the public acceptability of using HEDF in peri-urban agriculture for a range of locally grown crops, using the sub-Saharan African country of Malawi as a case study. Specifically, the objectives were to: (1) define an appropriate method of measuring acceptability; (2) investigate the relationship between acceptability and other factors (such as demographic characteristics, prior knowledge of HEDF, and viewing samples of HEDF); and (3) determine which factors had the greatest influence on acceptability, in order to inform potential marketing strategies for scaling up of HEDF business ventures.

5.3 Methods

Malawi was selected for this study because it is a densely populated nation with only a small proportion of land suitable for cultivation despite being heavily dependent on subsistence farming (Harris et al., 2018). Agriculture extends onto marginal land which results in poor crop returns, whilst spatial constraints mean there is little opportunity to rotate crops or allow land to lie fallow in order to preserve soil fertility (Li et al., 2017). There is therefore, an urgent need to improve the health and productivity of the soil, although the use of organic fertilisers, such as compost, is rare due to a lack of practical knowledge and raw materials, labour-intensive application, difficulty of transportation (due to bulk), and dependence on commercial fertiliser (Cai et al., 2019; Ndambi et al., 2019).

Fieldwork was conducted between December 2018 and March 2019, in the urban conglomeration of Blantyre and Limbe, which sits within the administrative boundary of Blantyre city district (**Figure 5.1**). This location was selected due to the high density of people and the substantial amounts of human excreta being generated. The urban population continues to engage in small-scale subsistence farming, and thus provides a potential market within a localised context.

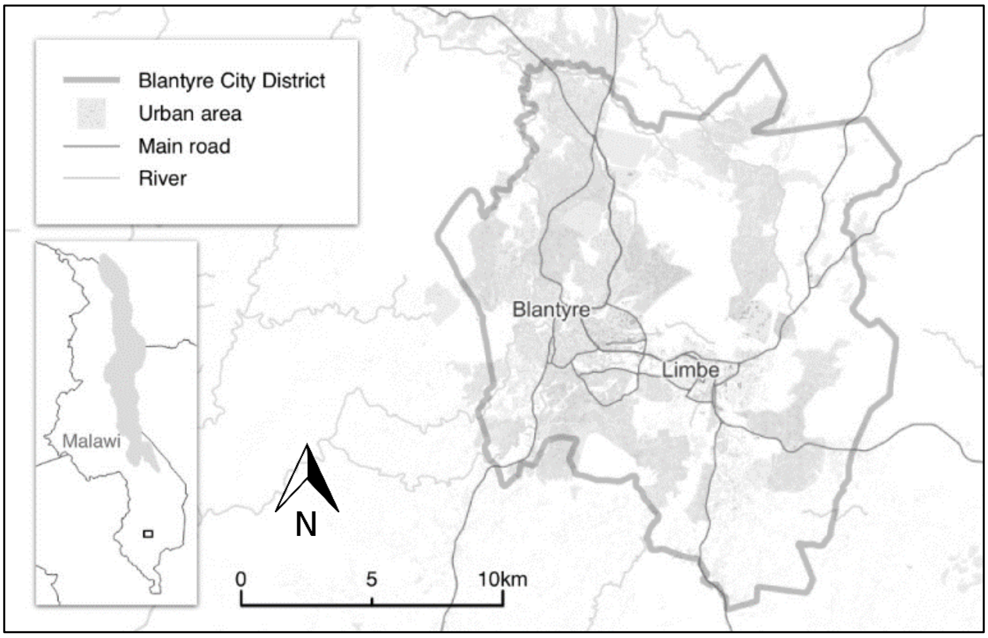

Figure 5.1. Location of Blantyre and Limbe within Blantyre City District

The main data collection method utilised was a questionnaire survey with members of the public. The design of this questionnaire was informed by a pilot survey and preliminary qualitative work, involving semi-structured interviews with peri-urban farmers. Data collection was carried out by three Malawian fieldworkers, all fluent in the Chichewa language, familiar with the local area, and trained in environmental research and data collection methods. They also had personal experience of farming on their family land.

5.3.1 Questionnaire design

In order to capture the attitudes of members of the public towards HEDF use, it was first necessary to formulate and pilot questions that were clear and concise, and could capture feelings towards the use of HEDF in a variety of situations and degrees of intimacy. Therefore, preliminary interviews were conducted with 39 subsistence farmers. The interviews were used to identify local terms used to describe materials and processes, and to design and pilot suitable questions to capture how people felt about using HEDF. Interviews were conducted across three locations: a high-density urban settlement (Ndirande); a mid-density peri-urban settlement (Kapeni), and a low-density peri-urban settlement (Chigumula). Farmers were recruited by following a transect walk through each location and stopping at every 'n' household (where 'n' was determined by location) to invite the household to participate. Interviews were conducted in either Chichewa or English, according to participant preference.

As a result of the interviews, the term 'human manure' was used to describe HEDF when talking to participants, as this was found to be the locally used, widely understandable, vernacular term for any kind of fertiliser or soil amendment derived from human excreta (i.e., HEDF). Examples of human manure used locally included faecal sludge, wastewater sludge, and excreta, which had received some degree of treatment (such as dehydration or composting) to reduce odour.

The following hypothetical questions were developed and tested for use in the public survey:

- Whether the participant would buy crops (maize, pumpkins, tomatoes, leafy green vegetables, and beans) grown in human manure (yes, no, maybe – each crop evaluated independently);
- Whether the participant would feel uncomfortable if a fellow passenger on a bus carried a sack of human manure (very uncomfortable, somewhat uncomfortable, comfortable, unsure);
- Whether the participant would feel uncomfortable if their neighbour used human manure on their farm (very uncomfortable, somewhat uncomfortable, comfortable, unsure); and
- How the participant would describe a farmer who used human manure on their farm (words volunteered were classified into 'positive' or 'negative' descriptions).

These questions are termed the 'attitudinal indicators' and functioned as a composite measure of acceptability in the public survey.

5.3.2 Piloting

Following the development and trial of the attitudinal indicators, they were formulated into a pilot questionnaire, which also captured demographic information and whether or not the participant had heard of HEDF before. The pilot questionnaire was trialled with 102 members of the public recruited at three fruit and vegetable markets around the city, administered by a male fieldworker, and took about 8 minutes to complete. The fieldworker began by explaining the concept of human manure as "using human excreta or faecal sludge as a fertiliser, after it had been treated to remove smell and any harmful pathogens, so that it is safe to use on crops and does not pose a risk to people". A proportion (41%) of the participants were then shown an example of HEDF in the form of dried faecal sludge, in cake-form (**Figure 5.2a**). This material was taken from a sludge drying bed at the local wastewater treatment plant, which is a faecal sludge discharge point for registered pit emptying companies. It is routinely sold to local farmers by workers at the treatment plant. The rest of the participants were not shown any sample, and therefore relied only on the explanation given by the administrator, and any relevant prior knowledge and experience, to conceptualise the term 'human manure'. Participants were then asked their opinions on HEDF.

After piloting, extra sections were added to the questionnaire to capture additional data on farming practices and willingness to pay for HEDF. The attitudinal indicator and demographic questions remained the same. By the time the main survey was administered, a sample of composted, granulated faecal sludge had been acquired from a local pit emptying business (**Figure 5.2b**). This material was produced by thermophilic composting of faecal sludge to remove pathogenic organisms, and then mechanically pulverising the treated faecal sludge using a rotating sieve to produce a granular substance resembling soil. This sample was shown to all participants of the main survey as an example of HEDF as it provided a more accurate representation of what commercialised HEDF would look like (i.e., treated to remove pathogenic organisms, and processed into a form that can be easily applied to fields).

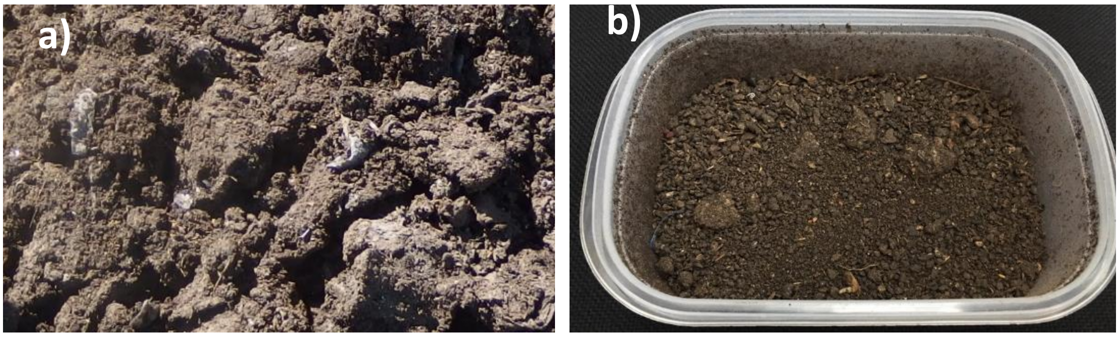

Figure 5.2. Samples of a) dried faecal sludge, and b) composted, granulated faecal sludge, shown to survey participants

5.3.3 Survey

The main questionnaire survey was conducted with 432 participants, recruited across seven fruit and vegetable market sites, three of which were used for the pilot survey. The questionnaire was administered by one male and one female fieldworker. The initial explanation given to participants was the same as with the pilot survey and all participants were shown an example of HEDF, in the form of a sample of composted, granulated faecal sludge, acquired from a local supplier (**Figure 5.2b**). The questionnaire included most of the same questions as the pilot questionnaire, but was expanded to include questions on past and anticipated farming practices. The questionnaire took about 15 minutes to complete.

Markets where the questionnaires were administered were purposefully chosen to represent a selection of large and small market sites across the city. Participants were recruited using time-space sampling, whereby questionnaire administrators were stationed at the entrance to market sites according to a randomised schedule, and asked every 'nth' person passing if they would participate in the survey. The 'n' value was adjusted according to the flow of people passing. The sample size for the survey is representative of the population of the Blantyre/Limbe urban conglomeration (margin of error: 5%, confidence level: 95%), which was estimated at 920,226 in 2016 by the National Statistics Office (2017).

Data from the surveys was inputted into SPSS (IBM SPSS Statistics Version 23). Chi square tests for independence were used to test for associations between categorical data, and the Mann Whitney U test was used to test for correlations between continuous and categorical data. Statistically significant differences in demographic characteristics of respondents between the pilot and main surveys, and associations between demographic characteristics / recruitment locations and responses to the attitudinal indicator questions / prior knowledge about HEDF, were identified. Finally, associations between being shown samples of faecal sludge at the start of the survey / having heard of HEDF before, and responses to the attitudinal indicators, were assessed.

When presenting results of Chi square tests, Yates' Correction for Continuity is shown for comparisons where characteristics were defined by just two levels (e.g., male and female), in order to compensate for potential overestimation of the Chi square value when used by a 2 x 2 table (Hoffman, 2019). Post-hoc testing was carried out for tables greater than 2 x 2 by calculating *p*-values from adjusted residuals and comparing these to an α value adjusted using the Bonferroni correction, in order to compensate for potential type 1 family wide errors (Holm, 1979; García-Pérez and Núñez-Antón, 2003).

Ethical consent for the interviews and surveys was obtained from the University of Stirling General University Ethics Board (reference numbers: GUEP472 and GUEP544), and from the Malawi National Committee on Research in the Social Sciences and Humanities (reference number: NCST/RTT/2/6), prior to commencement of fieldwork.

5.4 Results

When data analysis commenced, striking differences in the acceptability of HEDF were found between the results of the pilot survey and the main survey. Consequently, results from the pilot and main survey are presented side by side for comparison below, in **Tables 5.1**, **5.4** and **5.5**.

5.4.1 Participant demographics and farming characteristics

The median ages of participants were 35 and 29 for the pilot and main surveys respectively, and there was a significant tendency for participants of the main survey to be older ($p < 0.001$). Both surveys had a small majority of female participants (58%) (**Table 5.1**). Almost all participants (90% and 92% respectively for the pilot and main survey) were Christian, and the majority were from the Blantyre city district (79%, question asked in main survey only). Almost half of participants described their position within the family as 'household head' (47% and 42% respectively for the pilot survey and main survey), one third described their position as 'wife of household head' (35% and 33%), and approximately one fifth described themselves as the 'child of household head' (17% and 23%). Almost all of participants had attended primary school (99%) and more than half had attended secondary school (56% and 71%). A significantly greater proportion of participants had attained higher levels of education in the main survey, as compared to the pilot survey ($p < 0.05$). Lomwe, Ngoni, and Yao were the most commonly represented tribal groups, making up around three quarters of participants in both surveys (31% and 42% Lomwe, 24% and 18% Ngoni, and 22% and 10% Yao in the pilot and main survey, respectively). In the main survey, there was significantly more Lomwe ($p < 0.01$), whilst there were significantly more Yao in the pilot survey ($p < 0.01$). The asset ownership patterns (measured as a proxy for wealth) of participants were significantly different between the two surveys ($p < 0.01$), with a higher proportion of participants owning televisions in the main survey (71%, compared to 54% in the pilot survey). This was not a consequence of the additional market sites visited in the main survey, as the significant difference remained when comparing participants recruited at Blantyre, Limbe, and Zingwangwa market sites only.

The majority of participants from the main survey who had been engaged in farming activities at some point in the last four growing seasons ($n = 301$; 70% of total main survey participants) had small plots of land (≤ 1 hectare) (**Table 5.2**). Typically, farmed land was owned (88%), and was located close to the household plot (74%). All but three (99%) of the farmers grew maize, and the majority tended to keep and consume the maize that they grew: 80% did not sell any maize at all, and only 5% sold more than half of their crop. Two thirds of participants (66%) owned livestock of some kind. Thus, participants in the main survey who engaged in farming activities could be characterised as smallholder subsistence maize farmers. Almost half (46%) of participants had previously received a fertiliser subsidy coupon; however, only 18% had received a coupon during the last growing season.

Table 5.1. Demographic characteristics and recruitment locations of participants.

		Pilot survey participants (n = 102)		Main survey participants (n = 432)	
Recruitment location	Blantyre	30	(29%)	95	(22%)
	Chirimba			37	(9%)
	Limbe	40	(39%)	95	(22%)
	Lunzu			34	(8%)
	Manje			32	(7%)
	Ndirande			95	(22%)
	Zingwangwa	32	(31%)	44	(10%)
Gender	Female	59	(58%)	249	(58%)
	Male	43	(42%)	182	(42%)
Area of residence	Blantyre city district	Question not asked		344	(79%)
	Blantyre rural district			53	(12%)
	Thyolo district			16	(4%)
	Chiradzulu district			2	(1%)
	Elsewhere			17	(4%)
Relationship to household head	Household head	48	(47%)	180	(42%)
	Wife of…	36	(35%)	144	(33%)
	Child of…	17	(17%)	100	(23%)
	Other	[a] 1	(1%)	8	(2%)
Highest educational level attended	No education	[a] 2	(2%)	9	(2%)
	Primary	***43**	(42%)	119	(27%)
	Secondary	*44	(43%)	239	(55%)
	Vocational/higher	12	(12%)	64	(15%)
Ethnicity	Chewa	8	(8%)	45	(10%)
	Lomwe	**32	(31%)	183	(42%)
	Yao	****22**	(22%)	41	(10%)
	Ngoni	24	(24%)	78	(18%)
	Tumbuka	[a] 8	(8%)	16	(4%)
	Njanya	[a] 0	(0%)	13	(3%)
	Sena	[a] 2	(2%)	40	(9%)
	Tonga	[a] 1	(1%)	4	(1%)
	Ngonde	[a] 0	(0%)	2	(1%)
	Other	[a] 5	(5%)	9	(2%)
Religion	Christian	92	(90%)	399	(92%)
	Muslim	10	(10%)	32	(7%)
	Other	[a] 0	(0%)	1	(<1%)
Asset ownership	No assets	4	(4%)	12	(3%)
	Mobile	****42**	(41%)	111	(26%)
	Mobile and TV	*49	(48%)	265	(61%)
	Mobile, TV, and vehicle	7	(7%)	44	(10%)

Notes

Bold indicates the difference between the pilot and main survey is significant at alpha level corrected by sequential Bonferroni method, or Yates' Correction for Continuity (for 2 x 2 tables). * $p < 0.05$ ** $p < 0.01$ *** $p < 0.005$

[a] There were not enough observations to determine whether the difference was significant.

Table 5.2. Characterisation of farming practices.

		Farming participants [a] (n = 301; 70% of total main survey participants)
Farm size (Ha)	Mean Range Standard deviation	1.5 0.0002 – 150 9.2
Farm ownership	Own all land Rent all land Own part, rent part	264 (88%) 20 (7%) 14 (5%)
Distance to farmland	At or near household plot Less than one day journey One day journey or more	224 (74%) 72 (24%) 6 (2%)
Maize harvest from farmer's last growing season [b] (kg)	Mean Range Standard deviation	920 0.5 - 15,000 1,305
Amount of maize sold from farmer's last growing season [b]	No maize sold Less than half About half More than half All or almost all	242 (80%) 29 (10%) 7 (2%) 14 (5%) 0 (0%)
Fertiliser usage in farmer's last growing season [b]	Used synthetic fertiliser Used plant manure [c] Used animal manure Used human manure No fertiliser used	255 (85%) 10 (3%) 99 (33%) 10 (3%) 35 (12%)
Livestock ownership	Own fowl Own sheep, goats, or pigs Own cows No animals	185 (61%) 67 (22%) 27 (9%) 102 (34%)
Farming practices	Farmed last growing season	236 (78%)
Fertiliser subsidy coupons	Have ever received Received last growing season	137 (46%) 53 (18%)

Notes
[a] 'Farming participants' refers to participants who grew food in the last four growing seasons.
[b] 'Farmer's last growing season' refers to the last time that the participant grew maize.
[c] 'Plant manure' is the local term used to refer to compost made from plant material and food waste.

5.4.2 Attitudes towards human manure

Demographic characteristics and recruitment locations of all respondents (from both the pilot and main survey) were checked for significant associations with their responses to the attitudinal indicators and prior knowledge of HEDF (**Table 5.3**). Characteristics that had significant and consistent associations with not accepting human manure use were Yao (ethnicity) or Muslim, i.e., these characteristics were significantly associated with fewer positive responses to all five attitudinal indicators ($p \leq 0.05$). Whilst some other demographic characteristics showed significant associations with some attitudinal indicators, no others showed such consistent and strong associations with all of them.

Showing the composted, granulated faecal sludge sample to the participant evoked a more positive response to the attitudinal indicator questions compared to showing either the dried faecal sludge sample, or no sample (**Table 5.4**). Significant differences for all five attitudinal indicators were found between participants seeing the composted, granulated sample and seeing the dried sample, and between people seeing the composted, granulated sample and not seeing any sample ($p < 0.001$). However, there were no significant differences in attitudinal indicator responses between participants not seeing a sample and being shown the dried sample. Participants shown the composted, granulated sample were significantly more likely to respond positively to all the attitudinal indicator questions ($p < 0.001$), which suggests that seeing the composted, granulated sample had a significant and positive effect on the participants' acceptance of HEDF, whilst seeing no sample, or the dried sample, did not.

Having previously heard of HEDF also had a significant effect on participants' responses to the attitudinal indicators (**Table 5.5**). Significant differences ($p < 0.05$) were found between all attitudinal indicators, and effect sizes were strongest amongst participants who were not shown the sample of composted, granulated faecal sludge. This result suggests that prior knowledge of HEDF has a significant and positive association with a participant's acceptance of HEDF, and the association is stronger in the absence of seeing the composted excreta sample.

5.4.3 Perceived suitability of different crops

Another important factor in public opinion emerged from both the preliminary interviews and the questionnaires, which was the varying degrees of perceived acceptability of different crops for being grown in HEDF. For instance, participants generally agreed that maize was acceptable for growing in HEDF: 52% and 93% of participants from the pilot and main surveys respectively said that they would buy such maize. Leafy green vegetables were generally agreed to be less suitable for growing in HEDF than maize; 23% and 82% of participants from the pilot and main surveys respectively said that they would buy leafy green vegetables grown in this way. This is statistically significantly lower than the acceptance rates for maize ($\chi^2 = 35$, $p < .001$ for the pilot survey, and $\chi^2 = 118$, $p < .001$ for the main survey, using the Chi-square goodness-of-fit test), but in the case of those who saw the composted, granulated sample, still relatively high. The difference in acceptability between the growing of maize and leafy vegetables in HEDF is less prominent for participants who had been shown the composted sample than for those who were not.

Table 5.3. Relationships of recruitment and demographic characteristics with attitudinal indicators and prior knowledge (pilot and main survey participants).

		Has heard of human manure before	Knows someone using human manure	Would buy maize grown in human manure	Comfortable with human manure being carried on a bus	Comfortable with neighbour using human manure	Describes a person using human manure positively	Would use human manure on their own farm
Gender	Female (*n* = 308)	200 (64%)	84 (27%)	259 (84%)	228 (74%)	236 (77%)	143 (46%)	228 (74%)
	Male (*n* = 225)	152 (68%)	62 (28%)	195 (87%)	162 (72%)	175 (78%)	121 (54%)	163 (72%)
Market place	Blantyre (*n* = 126)	85 (67%)	*28 (22%)	105 (83%)	85 (52%)	90 (71%)	60 (48%)	84 (66%)
	Chirimba (*n* = 37)	24 (65%)	5 (14%)	35 (94%)	*33 (89%)	**35 (95%)	22 (59%)	30 (81%)
	Limbe (*n* = 135)	82 (61%)	41 (30%)	*106 (79%)	*87 (64%)	97 (72%)	63 (47%)	93 (69%)
	Lunzu (*n* = 34)	28 (82%)	10 (29%)	[a] 33 (98%)	*30 (88%)	30 (88%)	*18 (53%)	30 (88%)
	Manje (*n* = 32)	25 (78%)	*****18** (56%)	[a] 31 (97%)	***30 (94%)	28 (88%)	17 (53%)	*29 (91%)
	Ndirande (*n* = 95)	65 (68%)	22 (23%)	*89 (94%)	**81 (85%)	81 (85%)	49 (52%)	*78 (82%)
	Zingwangwa (*n* = 76)	43 (57%)	22 (29%)	***56** (74%)	***45 (59%)	51 (67%)	*36 (47%)	**47 (62%)
Relationship to household head	Household head (*n* = 228)	145 (64%)	66 (29%)	194 (85%)	163 (71%)	176 (77%)	113 (50%)	156 (68%)
	Wife of… (*n* = 180)	115 (64%)	54 (30%)	153 (85%)	132 (73%)	139 (77%)	92 (51%)	139 (77%)
	Child of… (*n* = 117)	85 (73%)	*24 (21%)	100 (85%)	89 (76%)	91 (78%)	54 (46%)	89 (76%)
Highest educational level	Primary (*n* = 162)	106 (65%)	49 (30%)	**129 (80%)	*107 (66%)	*116 (71%)	75 (46%)	118 (73%)
	Secondary (*n* = 283)	190 (67%)	74 (26%)	*251 (89%)	***223** (79%)	***233** (82%)	145 (51%)	219 (77%)
	Vocational/higher (*n* = 76)	48 (63%)	18 (24%)	66 (87%)	52 (68%)	54 (71%)	40 (53%)	47 (62%)
Ethnicity	Chewa (*n* = 53)	37 (70%)	15 (28%)	48 (91%)	*45 (85%)	45 (85%)	28 (53%)	45 (85%)
	Lomwe (*n* = 215)	133 (62%)	66 (31%)	185 (86%)	159 (74%)	169 (79%)	104 (48%)	*164 (76%)
	Yao (*n* = 63)	37 (59%)	21 (33%)	*****42** (67%)	*****32** (51%)	*****36** (57%)	****25** (40%)	*****34** (54%)
	Ngoni (*n* = 102)	63 (62%)	21 (21%)	91 (89%)	75 (74%)	81 (79%)	53 (52%)	76 (75%)
Religion	Christian (*n* = 491)	325 (66%)	134 (27%)	425 (87%)	369 (75%)	388 (79%)	247 (50%)	369 (75%)
	Muslim (*n* = 42)	26 (62%)	11 (26%)	*****29** (69%)	*****21** (50%)	*****23** (55%)	****18** (43%)	*****21** (50%)
Asset ownership	No assets (*n* = 16)	6 (38%)	5 (31%)	[a] 13 (81%)	[a] 10 (63%)	[a] 11 (69%)	[a] 7 (44%)	[a] 10 (63%)
	Mobile (*n* = 153)	102 (67%)	52 (34%)	**121 (79%)	104 (68%)	*109 (71%)	*65 (42%)	108 (71%)
	Mobile and TV (*n* = 314)	210 (67%)	80 (25%)	*277 (88%)	***245** (78%)	****259** (82%)	***167** (53%)	243 (77%)

		Has heard of human manure before	Knows someone using human manure	Would buy maize grown in human manure	Comfortable with human manure being carried on a bus	Comfortable with neighbour using human manure	Describes a person using human manure positively	Would use human manure on their own farm
	Mobile, TV, vehicle (*n* = 51)	34 (67%)	9 (18%)	44 (86%)	32 (63%)	*33 (65%)	26 (51%)	30 (59%)

Notes
Bold font indicates difference between different categories of respondent is significant at alpha level corrected by sequential Bonferroni method, or Yates' Correction for Continuity (for 2 x 2 tables). * $p < 0.05$ ** $p < 0.01$ *** $p < 0.005$
[a] There were not enough observations to determine whether the difference was significant.

During the initial preliminary interviews, when participants could expand on their opinions in detail, farmers explained that acceptability was related to the degree of contact that the edible part of the crop was perceived to have with the ground. Maize was considered as a suitable crop for growing in HEDF because the edible part of the plant is situated on a stalk high above the ground: the contamination risk is considered low. For leafy green vegetables, on the other hand, farmers highlighted the proximity and exposure of the edible part of the crop to the ground as a greater contamination risk: *"For maize and tomatoes [grown in human manure] people can buy and eat it, because the fruit is up a stem, but for leafy green vegetables [grown in human manure], people can't buy them."* [Female, 49 years old, 0.5 Ha farm] *"Leafy green vegetables grow on the ground, so they are in contact with human manure, that's why I can't use [human manure] on leafy green vegetables."* [Male, 30 years old, 1 Ha farm]

Other crops caused a divergence of opinion; some farmers thought that pumpkins could be grown in HEDF due to the edible part of the crop being protected from contamination by a thick skin. Others thought that pumpkins grew too close to the ground to be suitable: *"For the pumpkins it is okay [to use human manure] as we clean them and eat the inside part."* [Female, 25 years old, 3 Ha farm] *"The pumpkins grow on the ground, in contact with human manure, so I don't want to buy and eat them."* [Male, 30 years old, 1 Ha farm]

Table 5.4. Relationship between attitudinal indicator responses and samples of excreta shown.

	Pilot survey				Main survey		Chi Square test (with Yates' Correction for Continuity) between…		
	Sample not shown (n = 60)		Dried faecal sludge sample shown (n = 42)		Composted, granulated faecal sludge sample shown (n = 432)		Sample not shown (n = 60) and dried sample shown (n = 42)	Sample not shown (n = 60) and Composted, granulated sample shown (n = 432)	Dried sample shown (n = 42) and Composted, granulated sample shown (n = 432)
Would you buy the following crops if they were grown in human manure?									
Maize	31	(52%)	22	(52%)	402	(93%)	$\chi^2 = 0, p = 1.000$	$\chi^2 = 82, p < 0.001$	$\chi^2 = 63, p < 0.001$
Pumpkins	16	(27%)	14	(33%)	376	(87%)	$\chi^2 = 0, p = 0.613$	$\chi^2 = 115, p < 0.001$	$\chi^2 = 72, p < 0.001$
Tomatoes	23	(38%)	16	(38%)	362	(84%)	$\chi^2 = 0, p = 1.000$	$\chi^2 = 61, p < 0.001$	$\chi^2 = 47, p < 0.001$
Leafy green vegetables	13	(22%)	10	(24%)	352	(82%)	$\chi^2 = 0, p = 0.989$	$\chi^2 = 95, p < 0.001$	$\chi^2 = 67, p < 0.001$
Beans	25	(42%)	16	(38%)	370	(86%)	$\chi^2 = 0, p = 0.875$	$\chi^2 = 62, p < 0.001$	$\chi^2 = 54, p < 0.001$
How would you feel if someone boarded a bus carrying a bag of human manure?									
Uncomfortable	43	(72%)	30	(71%)	67	(16%)	$\chi^2 = 0, p = 0.989$	$\chi^2 = 92, p < 0.001$	$\chi^2 = 72, p < 0.001$
Comfortable	17	(28%)	11	(26%)	363	(84%)			
Don't know [a]	0	(0%)	1	(2%)	2	(1%)			
How would you feel if your neighbour used human manure on their farm?									
Uncomfortable	30	(50%)	22	(52%)	64	(15%)	$\chi^2 = 0, p = 0.610$	$\chi^2 = 37, p < 0.001$	$\chi^2 = 17, p < 0.001$
Comfortable	30	(50%)	18	(43%)	364	(84%)			
Don't know [a]	0	(0%)	2	(5%)	4	(1%)			
How would you describe a person who uses human manure on their farm?									
Positive descriptions	30	(50%)	13	(31%)	222	(51%)	$\chi^2 = 1, p = 0.321$	$\chi^2 = 18, p < 0.001$	$\chi^2 = 25, p < 0.001$
Negative descriptions	27	(45%)	20	(48%)	54	(13%)			
Unclear [a]	0	(0%)	2	(5%)	36	(8%)			
No answer [a]	3	(5%)	7	(17%)	121	(28%)			

Notes

[a] There were not enough observations to determine whether the difference was significant.

Table 5.5. Relationship between attitudinal indicators and having heard of human manure before.

	Pilot survey Dried faecal sludge sample shown / sample not shown [b] (n = 102)					Main survey Composted, granulated faecal sludge sample shown (n = 432)				
	Not heard before (n = 47)		Heard before (n = 55)		Chi square test (with Yates' Correction for Continuity)	Not heard before (n = 135)		Heard before (n = 297)		Chi square test (with Yates' Correction for Continuity)
Would you buy the following crops if they were grown in human manure?)										
Maize	14	(30%)	39	(71%)	$\chi^2 = 16, p < 0.001$	116	(86%)	286	(96%)	$\chi^2 = 15, p < 0.001$
Pumpkins	5	(11%)	25	(46%)	$\chi^2 = 13, p < 0.001$	105	(78%)	271	(91%)	$\chi^2 = 14, p < 0.001$
Tomatoes	9	(19%)	30	(55%)	$\chi^2 = 12, p = 0.001$	98	(73%)	264	(89%)	$\chi^2 = 17, p < 0.001$
Leafy green vegetables	3	(6%)	20	(36%)	$\chi^2 = 11, p = 0.001$	94	(70%)	258	(87%)	$\chi^2 = 17, p < 0.001$
Beans	9	(19%)	32	(58%)	$\chi^2 = 15, p < 0.001$	100	(74%)	270	(91%)	$\chi^2 = 20, p < 0.001$
Potatoes						96	(71%)	265	(89%)	$\chi^2 = 21, p < 0.001$
How would you feel if someone boarded a bus carrying a bag of human manure?										
Uncomfortable	40	(85%)	33	(60%)	$\chi^2 = 8, p = 0.004$	32	(24%)	35	(12%)	$\chi^2 = 10, p = 0.001$
Comfortable	6	(13%)	22	(40%)		102	(76%)	261	(89%)	
Don't know [a]	1	(2%)	0	(0%)		1	(1%)	1	(<1%)	
How would you feel if your neighbour used human manure on their farm?										
Uncomfortable	35	(74%)	17	(31%)	$\chi^2 = 21, p < 0.001$	33	(24%)	31	(10%)	$\chi^2 = 16, p < 0.001$
Comfortable	10	(21%)	38	(69%)		99	(73%)	265	(89%)	
Don't know [a]	2	(4%)	0	(0%)		3	(2%)	3	(<1%)	
How would you describe a person who uses human manure on their farm?										
Positive descriptions	8	(17%)	35	(64%)	$\chi^2 = 22, p < 0.001$	52	(39%)	170	(57%)	$\chi^2 = 22, p < 0.001$
Negative descriptions	33	(70%)	14	(26%)		31	(57%)	23	(8%)	
Unclear [a]	2	(4%)	0	(0%)		10	(29%)	26	(9%)	
No answer [a]	4	(9%)	6	(11%)		42	(31%)	78	(26%)	

Notes

[a] There were not enough observations to determine whether the difference was significant.

[b] In the pilot survey, participants were either shown a sample of dried faecal sludge, or not shown any sample, before completing the survey. There was no statistically significant differences in responses to the attitudinal indicator questions between being shown or not shown the dried sample, as shown in Table 4.

5.5 Discussion

This study has examined the public acceptability of using HEDF in peri-urban agriculture for a range of different locally grown crops in Blantyre, Malawi, and shown that the practice can be acceptable to a significant proportion of the population. Therefore, there could be a substantial market among peri-urban farmers in Blantyre for HEDF. Two factors were identified as having a particularly strong and positive influence on public opinion: firstly, being shown a sample of composted, granulated faecal sludge, and secondly, having previously heard of the idea of using HEDF.

The strongest effect on responses to the attitudinal indicator questions came from showing participants a sample of composted, granulated faecal sludge. The sight and odour of raw excreta naturally provokes disgust (Curtis et al., 2011), which is why transformation of the substance – both physically and conceptually – is important for its acceptance in agriculture (Buit and Jansen, 2016). It is therefore easier to ascertain people's opinions of using HEDF more accurately by giving them an example to view, so that they can visualise what kind of substance is being discussed and thus form their opinions accordingly. However, the visual appearance of HEDF is variable; there was a considerable difference in appearance between the dried faecal sludge taken from the wastewater treatment works by local farmers, and the commercialised composted, granulated sample. The composted, granulated sample resembled fertile soil, and the sight of this sample appeared to reassure participants about the concept of human manure, and led to significantly more positive responses. The lumpy dried faecal sludge sample however, whilst odourless, may have maintained enough resemblance to human excreta to not have the same effect, and thus there was no difference in response between those people who saw the dried faecal sludge sample and those who saw no sample at all.

Whilst the visual appearance of the composted, granulated faecal sludge sample was clearly important, it is not possible to say from this study which parts of the treatment/processing procedure, i.e., composting or pulverising, were most effective in securing public acceptance, or whether both were equally critical. Likewise, we cannot determine whether viewing the dried faecal sludge sample would have been similarly influential if it had been ground into a different texture. Exploring how visual attributes (e.g., colour, texture) and processing techniques (e.g., granulating, pelletizing) can influence people's perception of HEDF products would generate additional criteria that can be used for further quantifying the acceptability of HEDF.

In light of these findings, it becomes easier to understand why previous surveys of the public acceptability of HEDF have produced such diverse results. For instance, a study conducted in Madagascar, where samples of composted human excreta were shown to farmers, found that

72% of farmers were willing to use it on their own farms (Moya et al., 2019a). However, other studies, such as those of Appiah-Effah et al. (2015) and Mariwah and Drangert (2011) in Ghana found lower acceptability rates of 32% and 46% respectively. In the latter two studies, samples of HEDF were not shown, and so participants had to rely on their own imagination to visualise the substances described as 'faecal sludge compost' and 'sanitised excreta'. Like our study, not providing a composted excreta sample resulted in lower acceptability rates by participants.

Participants who had come across the idea of using HEDF prior to the survey were also significantly more likely to respond positively to the attitudinal indicators. This result suggests that greater familiarity with the concept of HEDF results in increased likelihood of acceptance. However, unlike being shown a sample, prior knowledge of HEDF is not randomly allocated among respondents. Instead, these participants may have a background, worldview, or cultural orientation that means they are more likely to become exposed to such information, and draw positive inferences from it (Kahan et al., 2013). Further research could determine whether differential effects of information exposure occur for different sub-populations.

Even participants with a positive view of HEDF were not necessarily willing to use it on any type of crop. The perceived degree of contact between the edible part of the crop and the soil was important in discerning acceptability, and crops tended to fall on a spectrum between maize (the most acceptable) and leafy green vegetables (the least acceptable), depending on the morphology and phenology of the crop. This difference was more pronounced in the case of the pilot survey. Similar results have been found in studies of recycled water, albeit primarily in high-income country contexts; for example, a study of the general public in Israel showed greater willingness to use recycled wastewater for purposes which were perceived to have lower human contact (Friedler and Lahav, 2006). Interestingly, participants in Blantyre had resistance to higher perceived levels of contact with the crop despite all participants being asked to evaluate HEDF on the basis that it had been suitably treated, and posed no risk to users. It may be that the reassurances on safety were not believed, or that they were not sufficiently strong to temper disgust completely.

Disgust is closely linked to perceived safety, having developed as a psychosocial disease-avoidance mechanism designed to resist contact with dangerous substances (Curtis et al., 2011). However, assurances of safety do not necessarily eliminate disgust, e.g., it is possible for disgust to be elicited from an object known to be sterile (Rozin and Fallon, 1987). Disgust is often considered a basic emotional system or sensory effect (Celeghin et al., 2017; Panksepp, 2007), and it is not always possible for people to consciously elicit reasons for their reactions of disgust. During the farmer interviews, participants were often unable to explain precisely why they felt disgusted by the idea of HEDF, or why they did not feel disgusted: they just did. As a result, interviews were not a particularly helpful tool for evaluating the reasons why people chose to accept HEDF or not. By contrast, the surveys, with controlled variables in the form of different representations of the substance, provided a more insightful picture into what strategies might be used to increase public acceptability.

Most demographic categories (e.g., gender, age, education) did not show strong, consistent relationships with the attitudinal indicators. However, two particular demographic groups (i.e. being Muslim and/or from the Yao ethnicity), were significantly less likely to have a positive view of HEDF. The two characteristics are interrelated, as Yao people are largely Muslim. A strong focus on water-based cleanliness is important in Islamic culture, and this has been cited as a reason why HEDF use has not always been welcomed in Muslim communities (Nawab et al., 2006). Nonetheless, the role of this should not be overstated; most (81%) Muslim participants who were shown the composted, granulated faecal sludge sample (n = 32) were willing to buy maize grown in HEDF, and most (73%) of those who intend to farm in the future (n = 26) said they would be willing to grow maize in HEDF. Therefore, even among demographic groups who are less receptive to HEDF use, high levels of acceptance are still found after showing the composted, granulated sample.

The positive response from the public towards the composted, granulated sample suggests that use of HEDF in peri-urban agriculture has potential to be widely accepted by subsistence farmers and the general public. Maize is the staple food of Malawi, and is grown more widely and in greater volume by subsistence farmers than any other crop (National Statistical Office, 2017), providing a strong potential market for HEDF in maize cultivation alone. However, uptake rates likely could be substantially improved by incorporating demonstrations with samples (in a processed form that is more visually appealing to the audience) into public engagement campaigns and by promoting the concept through channels such as farmer radio programmes or agricultural extension workers. Whilst situated within a different context, there is precedence for such an approach in places like Singapore and San Diego, where campaigns involving educational and demonstrational activities have been successfully used to facilitate public acceptance of controversial wastewater reuse technologies (Ricart and Rico, 2019; Furlong et al., 2019). Similar projects without such outreach schemes have however been decisively rejected (Morgan and Grant-Smith, 2015).

This study intended to focus solely on the aspect of public acceptability in the HEDF use debate, and therefore participants were asked to evaluate HEDF on the basis that it posed no risk to users. However, even after public acceptability is established, creation of a safe and effective market for HEDF still poses many logistical challenges that require further research. Entrepreneurs will need to make sufficient profit whilst also adhering to treatment standards, set at a level to provide public protection whilst avoiding unnecessary stringency (Strande, 2014b). Such standards would need to be straightforward to regulate and follow, ensure sufficient removal of pathogenic microorganisms, and control levels of other contaminants (such as heavy metals and pharmaceuticals) where necessary. Sufficient maturation of the compost must also be ensured, in order to provide appropriate levels of nutrition to the soil. Any lapse in standards could result in reputational damage to the market, as subsistence farmers are generally resource-poor and therefore unwilling to risk unreliable inputs (Moya et al., 2019a). Barriers to export for crops grown in HEDF also persist, as such crops are prevented from being classed as 'organic' and fulfilling certain commonly used agricultural standards (Moya et al., 2019b). Nonetheless, it appears that in the case of Blantyre, public acceptability at least does not pose a barrier.

5.6 Conclusion

Quantitative surveys of the public in Blantyre, Malawi, have revealed two factors as having a particularly strong and significant association with willingness to use HEDF in agriculture. These are: being shown a sample of composted, granulated faecal sludge at the beginning of the survey, and having prior knowledge of using HEDF. These results suggest that being able to see samples of composted, granulated faecal sludge can result in higher levels of trust and confidence in HEDF. Further research is needed to confirm which visual attributes (e.g., colour, texture) and processing techniques to achieve them (e.g., granulating, pelletizing) are most effective in influencing acceptance. Whilst the results suggest that prior knowledge of HEDF also has a positive effect, further work would also be needed to confirm whether this is causal or correlated, and whether the outcome is the same for different sub-groups within the population.

The high percentage of respondents willing to use HEDF on their own farms demonstrates that there is a substantial market for such a product. However, the scale of success will depend on appropriate marketing strategies, with demonstration sites; the provision of free samples in a visually appealing form will likely play a key role in increasing uptake. This sensitization could be supported by a wider promotion effort through services such as the Farmer Radio station and Agricultural Extension Workers. Further research to refine a public engagement campaign and demonstration strategy, tailored for different sub-groups of the population, would be beneficial. It will also be important to establish a price point for the product, and explore how other adaptations, such as branding or certification, affect this. Successful uptake could result in substantial amounts of phosphorus being recovered from human excreta, with positive implications for soil fertility, food and nutrient security, and monetary savings for peri-urban subsistence farmers. Whilst there are many additional technical, regulatory, and economic challenges on the pathway to creating a viable, safe, market for HEDF, there appears to be strong demand for such products among subsistence farmers.

Chapter 6 | Willingness to pay for fertiliser derived from human excreta

6.1 Abstract

The production and use of human excreta derived fertiliser (HEDF) contributes towards resolving two pressing public and environmental health challenges: rehabilitating intensively farmed soils, and developing safe and sustainable management systems for faecal sludge from pit latrines. These issues can be particularly acute in urban and peri-urban areas, but also can be tackled most efficiently in these locations, as large quantities of faecal sludge are generated in close proximity to farming land. Establishing willingness to pay (WTP) for HEDF is an important part of determining the viability of such operations. Using a contingent valuation method, this study found that the highest tested valuation point of 12,000 MWK (approximately $16 USD) is an acceptable price for a 50 kg bag of HEDF for almost half (n = 167, 47%) of surveyed urban and peri-urban smallholder farmers, and modifications such as certification or pelletisation increased value further. Younger farmers and those who had heard about HEDF from agricultural extension workers were likely to have higher WTP values, whilst those who had used HEDF before were likely to have lower WTP values, reflecting the influences of risk aversion, trust, and personal experience on their valuations. The results suggest there are opportunities to promote HEDF in Blantyre, as a confluence of chemical fertiliser subsidy withdrawals and price rises have generated WTP for organic alternatives, with agricultural extension workers identified as a channel for particularly effective promotion.

6.2 Introduction

Pit latrines are a commonly used sanitation technology across sub-Saharan Africa, in both rural and urban areas, and the human excreta within contains key nutrients essential for healthy crop growth (Peal et al 2020; Wielemaker et al., 2018). As such, pit latrines constitute a widely available but under-utilised potential source of agricultural nutrients. In particular, recovering phosphorus from excreta is likely to be important in coming years as finite phosphorus rock resources are increasingly concentrated in geopolitically fragile regions (Chowdhury et al., 2017; Iwaniec et al., 2016). Human excreta has been used in agriculture around the word for millennia, and is known to improve soil structure and productivity (Ferguson, 2014; Eden et al., 2017; Oldfield et al., 2018). In areas where commercially produced fertiliser usage is low, human excreta derived fertiliser (HEDF) has the potential to play an important role in sustaining the livelihoods of resource-poor farmers (Moya et al., 2019a; Trimmer and Guest, 2018).

Despite its potential benefits, there are many economic challenges associated with producing HEDF at scale in resource-poor settings. The value associated with excreta-derived products is generally low, and therefore the revenue derived is usually insufficient to offset the costs of faecal sludge removal, treatment, and further processing, meaning that additional financial input is required (Mallory et al., 2020a). Therefore, establishing locally accurate price points for HEDF is an important part of determining the viability of production and assessing the scale of subsidy contribution that might be required. Acceptability of HEDF is often perceived as a barrier to sales, but recent studies have revealed that acceptability of usage can be high among farmers and the general public for locally grown crops (Roxburgh et al., 2020c (i.e., Chapter 5), Moya et al., 2019a).

The southern African country of Malawi is a pertinent case study for HEDF usage. Smallholder farmers represent a large proportion of the population and depend on agriculture for their nutrition and livelihoods; however, only a relatively small proportion of the land is suitable for cultivation (Harris et al., 2018). High population density puts pressure on available soil resources and results in poor crop returns in some areas (Li et al., 2017; Harris et al., 2018). Synthetic chemical fertilisers have been heavily promoted and subsidised in recent decades, whilst the use of organic alternatives, such as compost, are rare because they are bulky to transport, hard to find, and there is a lack of training on their usage (Cai et al., 2019; Ndambi et al., 2019). However, as subsidies for farm inputs are scaled down (Nkhoma, 2018), there is likely to be increased interest in organic alternatives in the near future, which represent a timely opportunity to investigate the feasibility of HEDF markets, and how they can be taken to scale.

A number of studies have explored variation in willingness to pay (WTP) for HEDF in order to identify potential markets among African farmers (i.e., identifying the maximum price at, or below which, a customer would be interested in buying the product) (Agyekym et al., 2014; Danso et al, 2017; Kusi, 2019). However, there remains a need to bring together and interrogate three important questions in HEDF valuation, which have so far been examined separately. First, what kind of farmers, in terms of their detailed demographic characteristics and farming practices, are interested in buying HEDF, and for what price? Certain personal characteristics were found to be associated with increased WTP among farmers in Ghana, including: increased household size and income, being younger, and owning their farmland, whilst the influence of education varied between studies (Agyekym et al., 2014; Kusi, 2019). Second, how does prior exposure to HEDF, i.e., whether they have heard of and/or used it before, influence WTP, and what implications does this have for marketing campaigns? The effects of prior knowledge of HEDF on WTP have not been thoroughly examined to date. Third, how do modifications to

HEDF affect market price among particular purchasing groups? In Uganda, modifications to HEDF, such as certification and pelletisation, were found to increase WTP for HEDF among farmers in Kampala (Danso et al., 2017). The interactions between farmer characteristics, prior knowledge, and HEDF modifications on WTP need to be considered and interpreted within locally specific markets and contexts.

The aim of this study was to establish the WTP for HEDF among peri-urban farmers in Blantyre (the second largest city and the main commercial centre of Malawi) and to ascertain the value added by attributes such as certification and pelletisation. This was achieved by: characterising the farming population and their prior knowledge of HEDF; identifying the acceptability of different price points for the basic product and value-added attributes; and describing characteristics of purchasing groups. This information was then used to suggest price points and future marketing strategies for HEDF enterprises in Blantyre.

6.3 Methods

Fieldwork was conducted in March 2019, in the urban conglomeration of Blantyre and Limbe. Over three quarters of this urban population use pit latrines, meaning that there is a tremendous amount of faecal sludge being generated in proximity to peri-urban farmland (National Statistical Office, 2017). Smallholder farmers are particularly suited to using HEDF as they require smaller volumes than commercial farmers, and therefore are a suitable market for small-scale, localised HEDF producers and would allow faecal sludge to be treated close to where it is generated.

6.3.1 Questionnaire design

The data were collected using a questionnaire survey with members of the public, described in Roxburgh et al. (2020c (i.e., Chapter 5)). At the start of the questionnaire, the concept of HEDF was explained to the participants as "using human excreta or faecal sludge as a fertiliser, after it had been treated to remove smell and any harmful pathogens, so that it is safe to use on crops and does not pose a risk to people". An example of HEDF was then shown to participants (**Figure 6.1**). This sample was acquired from a local entrepreneur who emptied sludge from pit latrines and then treated it by thermophilic composting and processed the material into granules by mechanically pulverising it with a rotating sieve. This sample was shown to participants so that they could see what commercialised HEDF would look like (i.e., treated to remove pathogens and processed into a form for easy application to fields).

Figure 6.1. Sample of composted, granulated faecal sludge shown to survey participants (container is 15cm x 25cm).

Survey participants were filtered to identify potential customers for HEDF by asking them whether they intended to farm, or otherwise grow food in the next 5 years. For those who answered ‘yes’ or ‘maybe’, they were asked whether they would consider using HEDF on their crops. For those who answered ‘yes’ or ‘maybe’, their WTP for HEDF was established; these participants are termed the ‘WTP survey participants’.

All WTP survey participants were asked about their demographic characteristics, their prior knowledge and experience of HEDF, and also about their farming practices if they had undertaken farming activities within the last four years. A proxy measure for household wealth was created by asking whether anybody in the household owned a mobile phone, a TV, or a car / truck, thereby generating a simplified ‘wealth index’. These items were selected from the list of household assets used to assess household wealth by the Malawi Demographic Health Survey (National Statistical Office and ICF, 2017). The complete list of household assets was not used because during piloting it was found to be overly time-consuming, and participants were suspicious about why they were being extensively questioned about their possessions.

6.3.2 Sample size

The number of participants taking part in various parts of the survey is shown in **Figure 6.2**. The HEDF acceptability survey had 432 participants, of which 392 intended to farm in the near future and were therefore asked if they would be willing to use HEDF on their own farm. A total of 359 participants (92%) were willing to use HEDF and were therefore asked the WTP questions – these are termed the WTP survey participants. Of these 359 participants, 282 (79%) had farmed recently (defined as growing food at some point in the last four rainy seasons) and were therefore asked about their farming practices.

The sample size for the WTP survey (*n* = 359) was representative of the population of the city (margin of error: 5%, confidence level: 95%), which was estimated at 920,226 in 2016 (National Statistics Office, 2017).

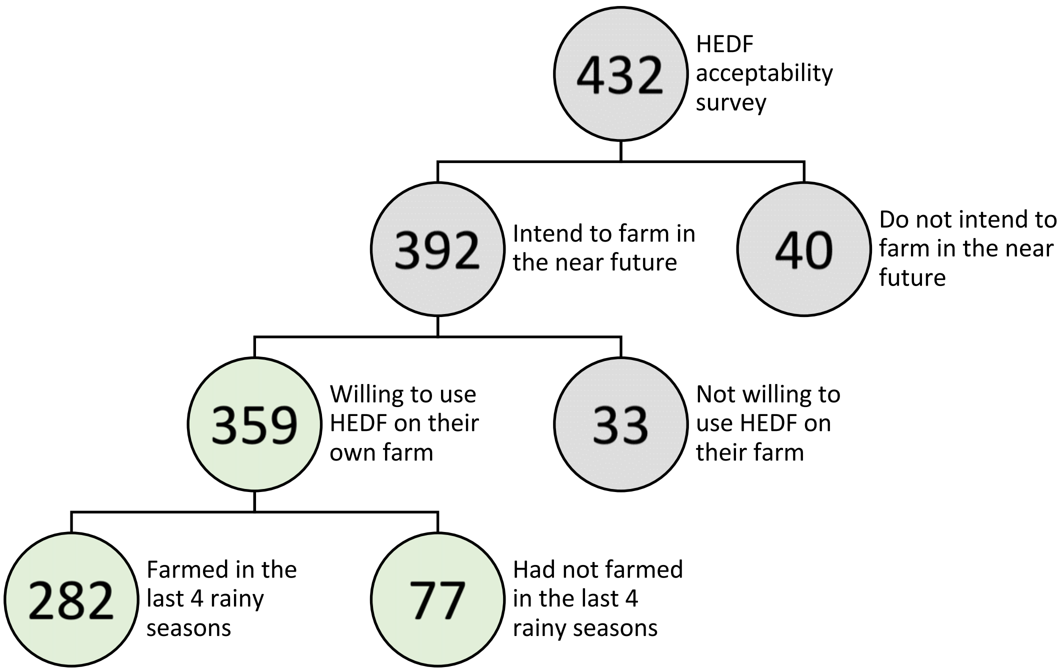

Figure 6.2. Numbers of participants taking the HEDF acceptability survey and being asked WTP and farming questions. Participants in green circles (*n* = 359) were asked about their WTP for HEDF and are termed the 'WTP survey participants'.

6.3.3 Determination of WTP

WTP for a defined quantity of HEDF – in this survey, a 50 kg sack – was established in order to provide a 'baseline' WTP value, and then the 'added' value of two additional attributes - certification by the Malawi Bureau of Standards (the national agency responsible for the testing and certification of organic products (Malawi Bureau of Standards, 2019)), and pelletisation –

was then established. The quantity was defined as a 50 kg sack because it is common for commercial NPK fertiliser to be sold in this unit, therefore making it easy for farmers to visualise the amount. The process of determining WTP is shown in **Figure 6.3: Figure 6.3a** shows the questions asked to establish a 'baseline' WTP value, and **Figures 6.3b** and **6.3c** show the questions asked to establish the 'added' value of the two additional attributes. All WTP survey participants were asked about their baseline WTP (**Figure 6.3a**), certification WTP (**Figure 6.3b**) and pelletisation WTP (**Figure 6.3c**).

The 'baseline' WTP was established by asking participants whether they would be willing to pay 6,000 MWK (approximately $8 USD) for a 50kg bag of HEDF. If they answered 'yes', they were then asked whether they would pay 12,000 MWK for the bag, and if they answered 'no', they were then asked whether they would pay 3,000 MWK for the bag. This allowed the participants to be divided into four groups, according to the highest amount they were willing to pay. The starting bid was pegged to the typical price of a government-subsidised 50kg bag of commercial NPK fertiliser - 6,000 MWK (approximately $8 USD) (Bonilla Cedrez et al., 2020), as this was taken to be a reasonable input cost that all farmers, including the poor, could afford. As 70% of Malawians live on less than $1.90 per day, the affordability of fertiliser in the absence of subsidies is a substantial constraint for most farmers (United Nations Development Programme, 2020; Jew et al., 2020). The other two bids (3,000 MWK and 12,000 MWK) were chosen by halving and doubling the starting bid to create a spread of payment options.

To establish WTP for the two 'added value' attributes (certification and pelletisation) participants were then asked whether they would pay more for the 50kg bag (i.e., above their 'baseline' value) if the HEDF was certified by the Malawi Board of Standards, or if it was pelletised. If they answered 'yes' for either attribute, they were asked how much more they would pay for it.

The survey was carried out with members of the public without remuneration and therefore it was important to keep it short, as a lengthy survey would discourage people from participating. As a result, the questions for determining baseline WTP and WTP for 'added value' attributes were chosen to keep the survey as concise as possible, whilst capturing a range of possible price points. As fertiliser is an essential good which is regularly purchased by smallholder farmers and essential to their food security (Holden and Lunduka, 2012), it can be reasonably assumed that they are aware of its market price and adept at its valuation.

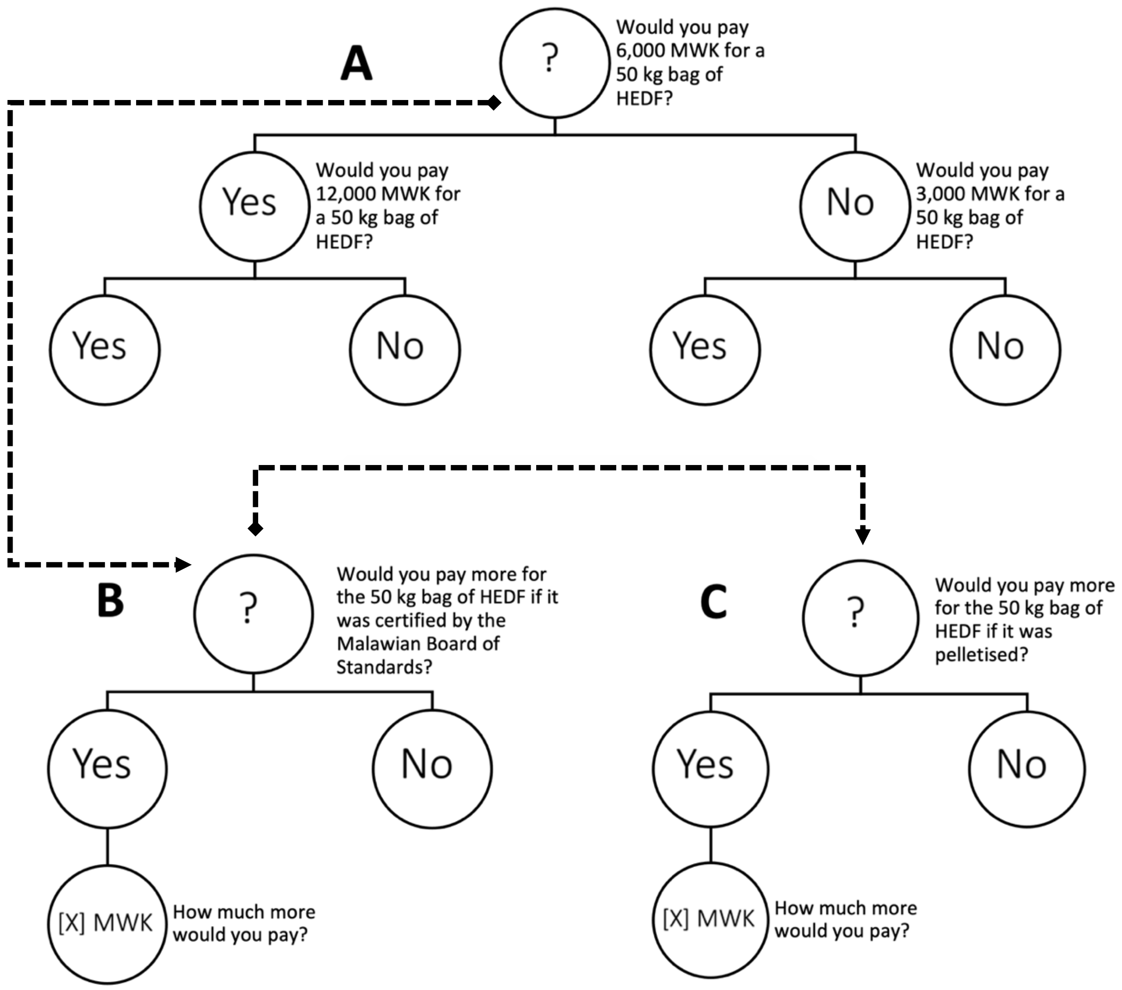

Figure 6.3. Determining **A)** the baseline value for a 50 kg bag of HEDF, and the value added by **B)** certification and **C)** pelletisation. All WTP survey participants were asked **A)**, **B)** and **C)**.

6.3.4 Survey administration and analysis

Data collection was carried out by one male and one female Malawian enumerator, both of whom were fluent in Chichewa and trained in data collection and environmental research methods. They were also residents of Blantyre, and had personal farming experience.

The questionnaire took about 15 minutes to complete, and participants were recruited using time-space sampling across seven fruit and vegetable markets, which were purposefully selected to represent a variety of market sites around the city. Enumerators stood at the entrance to the market sites according to a randomised schedule, and asked every 'n^{th}' person passing if they would like to participate in the survey (‘*n*’ adjusted according to the flow of foot traffic at each market).

The survey data was entered into SPSS (IBM SPSS Statistics Version 23), and associations between variables and WTP for HEDF were tested and characterised using Chi-square tests for independence and odds ratios (for categorical data), and the Mann Whitney U test (for continuous data). Yates’ Correction for Continuity was used for 2 x 2 Chi Square tests in order to compensate for potential overestimation of the Chi square value (Hoffman, 2019). General linear regression models were constructed to assess the predictive power of the demographic and farming variables on WTP for HEDF.

Ethical consent for the interviews and surveys was obtained from the University of Stirling General University Ethics Board (reference numbers: GUEP472 and GUEP544), and from the Malawi National Committee on Research in the Social Sciences and Humanities (reference number: NCST/RTT/2/6), prior to starting the study.

6.4 Results

The demographic characteristics and recruitment locations of WTP survey participants, along with their prior knowledge of HEDF, is shown in **Table 6.1**. There were more female (*n* = 217, 60%) than male (*n* = 142, 40%) participants. Most had received secondary education (*n* = 204, 57%) with a small proportion also having received higher education (*n* = 45, 12%). Almost all participants’ households owned a mobile phone (*n* = 352, 98%) but only 8% (*n* = 27) owned a vehicle. The majority of participants (*n* = 259, 72%) had heard of the idea of using human excreta in agriculture before, with friends being the most common source of information (*n* = 133, 37%). Only a few participants had heard about HEDF from agricultural extension workers (AEWs) (*n* = 18, 5%). The most common HEDF source known to participants was the contents of a disused pit latrine (*n* = 228, 64%). Around a third of participants knew someone who had used HEDF (*n* = 99, 28%) but only one in ten had used it themselves (*n* = 35, 10%).

Survey participants who had grown food in any of the last four rainy seasons were asked about their farming practices (*n* = 282, 79% of total WTP survey participants). Their characteristics are shown in **Table 6.2**. The majority of participants (*n* = 203, 72%) had plots of land 1 hectare or less. Typically, farmed land was owned (*n* = 247, 89%), and was located close to the household plot (*n* = 211, 78%). All but two (*n* = 280, 99%) of the farmers grew maize, and the majority tended to keep and consume the maize that they grew: 82% (*n* = 230) did not sell any maize at all, and only 4% (*n* = 12) sold more than half of their crop. Thus, participants in the WTP survey who engaged in farming activities could be characterised as smallholder subsistence maize farmers.

Table 6.1. Demographic characteristics, recruitment locations, and prior knowledge of WTP survey participants.

Characteristic		WTP survey participants (n = 359)	
Recruitment location	Blantyre central market	72	(20%)
	Chirimba market	31	(9%)
	Limbe market	75	(21%)
	Lunzu market	31	(9%)
	Manje market	29	(8%)
	Ndirande market	85	(24%)
	Zingwangwa market	36	(10%)
Gender	Female	217	(60%)
	Male	142	(40%)
Age	18-29	182	(51.4%)
	30-39	115	(32.5%)
	40-49	45	(12.7%)
	50-59	12	(3.4%)
Relationship to household head	Household head	137	(38%)
	Wife of…	128	(36%)
	Child of…	87	(24%)
	Other	7	(2%)
Highest educational level attended	No education	6	(2%)
	Primary school	103	(29%)
	Secondary school	204	(57%)
	Higher education	45	(12%)
Household asset ownership (wealth proxy)	No assets	7	(2%)
	Mobile only	96	(27%)
	Mobile and TV only	229	(64%)
	Mobile, TV, and vehicle	27	(8%)
Religion	Christian	399	(92%)
	Muslim	19	(7%)
Prior knowledge of HEDF [a]	Had not heard of HEDF before	100	(28%)
	Heard of HEDF before [a]	259	(72%)
	Heard from friends	133	(37%)
	Heard from neighbours	55	(15%)
	Heard from radio	50	(14%)
	Heard from other farmers	33	(9%)
	Heard from school/ university	27	(8%)
	Heard from AEW	18	(5%)
	Heard from WWTW workers	18	(5%)
Prior experience of using HEDF	Have not used HEDF before	324	(90%)
	Used HEDF before [a]	35	(10%)
	Used excavated pit latrine	20	(6%)
	Used wastewater sludge	10	(3%)
	Used UDDT	10	(3%)

Notes
[a] Multiple sub-options possible; values do not sum to 100%.
AEW Agricultural extension worker

WWTW	Wastewater treatment works
UDDT	Urine-diverting dry toilet

Table 6.2. Characterisation of farming practices of WTP survey participants.

Characteristic		Farming participants of WTP survey [a] (*n* = 282; 79% of total WTP survey participants)
Farm size	1 hectare or less	203 (72%)
	1 to 2 hectares	41 (15%)
	Greater than 2 hectares	9 (3%)
Farm ownership	Own all land	247 (89%)
	Rent all land	20 (7%)
	Own part, rent part	12 (4%)
Distance to farmland	At or near household plot	211 (78%)
	Less than one day journey	64 (24%)
	One day journey or more	5 (2%)
Maize harvest from last growing season	25 to 1,000 kg	201 (71%)
	1,001 to 2,000 kg	59 (21%)
	2,001 kg to 15,000 kg	20 (7%)
Amount of maize sold from farmer's last growing season [b]	No maize sold	230 (82%)
	Less than half	26 (9%)
	About half	7 (2%)
	More than half	12 (4%)
	All or almost all	0 (0%)
Fertiliser usage in farmer's last growing season [b]	No fertiliser used	35 (12%)
	Fertiliser used [c]	247 (88%)
	Synthetic fertiliser	237 (84%)
	Plant manure [d]	8 (3%)
	Animal manure	89 (32%)
	Human manure	10 (4%)
Livestock ownership	Don't own animals	94 (33%)
	Own animals [c]	188 (67%)
	Fowl	174 (62%)
	Sheep, goats, or pigs	60 (21%)
	Cows	24 (9%)
Farming practices	Farmed last growing season	221 (78%)
Fertiliser subsidy coupons [c]	Have ever received	123 (44%)
	Received last growing season	47 (17%)

Notes
[a] 'Farming participants' refers to participants who grew food at some point in the last four rainy seasons.
[b] 'Farmer's last growing season' refers to the last time that the participant grew maize.
[c] Multiple sub-options possible; values do not sum to 100%.
[d] 'Plant manure' is the local term used to refer to compost made from plant material and food waste.

The highest baseline values that participants said they would be willing to pay for a 50 kg bag of HEDF is shown in **Figure 5.4**. Almost half of participants (*n* = 167, 47%) would pay a baseline value of 12,000 MWK for a 50 kg bag of HEDF, putting them into the highest payment category. Over a third (*n* = 140, 39%) would pay 6,000 MWK but not 12,000 MWK for the bag. A smaller percentage (*n* = 45, 13%) would pay 3,000 MWK but not 6,000 MWK, and few (*n* = 7, 2%) would not pay 3,000 MWK.

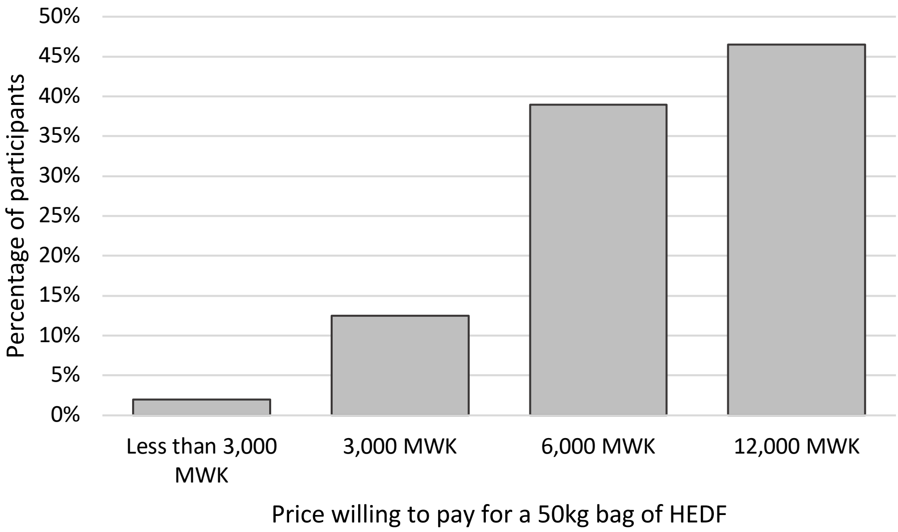

Figure 6.4. Highest baseline payment value for a 50 kg bag of HEDF

Participants were divided into two categories according to their baseline WTP: whether they would, or would not, pay 12,000 MWK for a 50 kg bag of HEDF. This allowed for the creation of sufficiently sized groups to evaluate their WTP against demographic and farming characteristics and their prior knowledge. Using an additional breakpoint of 6000 MWK – the subsidised market price for fertilizer - would not allow for a sufficient number of observations to illustrate any correlation or difference between the respondents.

Attributes which showed statistically significant association with baseline WTP at or close to $p = 0.050$ are shown in **Table 6.3**, alongside selected attributes which did not show statistically significant association but are considered important socio-economic variables (gender, education, and household wealth). Chi square tests are used to test for association between the variables, and odds ratios are presented to show the magnitude of the association. Attributes which showed statistically significant association with the two payment categories were: having heard about HEDF from AEWs ($p = 0.044$, $\chi^2 = 4.058$), having used HEDF before ($p = 0.041$, $\chi^2 = 4.180$), and relationship to household head ($p = 0.002$, $\chi^2 = 14.495$). Having heard about

HEDF from an AEW had the greatest odds ratio, with these participants being 3.157 times more likely to pay 12,000 MWK than those who had not heard about HEDF from an AEW.

A Mann-Whitney U Test identified significant differences in the ages of people who would (Md = 29, $n = 166$) and would not (Md = 30, $n = 188$) pay 12,000 MWK for a 50 kg bag of HEDF (U = 13,250, z = - 2.45, $p = 0.014$, r = 0.13).

Multiple regression was used to assess the ability of variables from **Table 6.3** to predict the baseline WTP value of a 50 kg bag of HEDF (**Table 6.4**). Preliminary analyses were conducted to ensure no violation of the assumptions of normality, linearity, multicollinearity, and homoscedasticity. Three models were constructed: model A (adjusted $R^2 = 0.13$) which contained all variables from **Table 6.3**, model B (adjusted $R^2 = 0.13$) which contained selected variables from **Table 6.3** (chosen after manual experimentation to see which variables could be removed from model A without reducing adjusted R^2), and model C (adjusted $R^2 = 0.11$) which contained variables with significance at $p = 0.050$ only (hearing about HEDF from AEWs, using HEDF before, farmland being at the household plot, and age).

Descriptive statistics calculated from the WTP for value added by certification and pelletisation of HEDF (determined as shown in **Figure 6.3B** and **6.3C**) are shown in **Table 6.5**. The mean WTP increased, with pelletisation valued higher than certification in all price categories. The mean added value (defined where the base price is known, i.e. willing to pay 3,000 / 6,000 / 12,000 MWK) increased with the base price but decreased as a percentage of the base price.

Table 6.3. Relationship between baseline payment category (12,000 MWK or less than 12,000 MWK for a 50kg bag of HEDF) and demographic / farming variables.

Characteristic		< 12,000 MWK (n = 192)		12,000 MWK (n = 167)		Chi square and odds ratio [a]
Heard from AEWs *	Yes No	5 187	(28%) (55%)	13 154	(72%) (45%)	χ^2 = 4.004 p = 0.045 OR = 3.157
Ever used HEDF before *	Yes No	25 167	(71%) (52%)	10 157	(29%) (48%)	χ^2 = 4.253 p = 0.039 OR = 0.425
Grew food last rainy season	Yes No	109 83	(49%) (60%)	112 55	(51%) (40%)	χ^2 = 3.577 p = 0.059 OR = 1.551
Land at plot	Yes No	102 37	(49%) (63%)	109 22	(51%) (37%)	χ^2 = 3.143 p = 0.076 OR = 1.797
Land a day journey	Yes No	40 99	(63%) (48%)	24 107	(38%) (52%)	χ^2 = 3.520 p = 0.061 OR = 0.555
Relationship to household head ***	Household head Wife Child Other [a]	77 79 35 1	(57%) (62%) (40%) (14%)	59 49 52 6	(43%) (38%) (60%) (86%)	χ^2 = 14.495 p = 0.002
Gender	Male Female	77 116	(57%) (54%)	65 101	(43%) (47%)	χ^2 = 0.007 p = 0.934 OR = 1.003
Household asset ownership (wealth proxy)	No assets [a] Mobile only Mobile and TV only Mobile, TV and vehicle	4 55 122 11	(57%) (58%) (53%) (41%)	3 40 107 16	(43%) (42%) (47%) (59%)	χ^2 = 2.545 p = 0.467
Highest education level attended	None [a] Primary school Secondary school Higher education	6 54 110 21	(100%) (52%) (54%) (47%)	0 49 94 24	(0%) (48%) (46%) (53%)	χ^2 = 8.407 p = 0.106

Notes
[a] Odds ratio (OR) calculated for 2 x 2 tables only
[b] Not enough cases in each category to tell for sure
* Difference is significant at $p < 0.050$
*** Difference is significant at $p < 0.005$

Table 6.4. Regression models to estimate baseline WTP value of 50kg bag of HEDF.

Variable description	Units	Model 1 β (SE)	Model 2 β (SE)	Model 3 β (SE)
Heard about HEDF from AEWs	Y = 1, N = 0	2,716 ** (965)	2,743 ** (947)	2,782 ** (946)
Used HEDF before	Y = 1, N = 0	- 1,341 (727)	- 1,829 ** (947)	- 1,893 ** (695)
Grew food last rainy season	Y = 1, N = 0	169 (533)		
Land is at home	Y = 1, N = 0	2,531 (1,330)	1,180 * (523)	1,155 * (526)
Land is a days journey away	Y = 1, N = 0	1,436 (1,332)		
Age	Years	- 83 * (34)	- 68 * (32)	- 94 *** (26)
Is female	Y = 1, N = 0	521 (595)		
Is household head	Y = 1, N = 0	- 2,033 (1,545)	- 2,529 (1,468)	
Is wife of household head	Y = 1, N = 0	- 2,790 (1,498)	- 2,917 * (1,484)	
Is child of household head	Y = 1, N = 0	- 1,373 (1,637)	- 1,417 (1,587)	
Own mobile	Y = 1, N = 0	- 533 (1,635)		
Own TV	Y = 1, N = 0	565 (519)		
Own vehicle	Y = 1, N = 0	344 (955)		
Highest education: primary	Y = 1, N = 0	3,738 * (1,680)		
Highest education: secondary	Y = 1, N = 0	3,319 * (1,684)		
Highest education: higher	Y = 1, N = 0	3,487 (1,862)		
Constant		7,060 * (3,247)	12,005 *** (2,008)	10,451 *** (954)
n		266	266	266
Adjusted R^2		0.13	0.13	0.11

Notes
Y = yes, N = no
Variable is significant at * $p < 0.050$, ** $p < 0.010$, or *** $p < 0.005$

Table 6.5. Value added by certification or pelletisation to 50kg bag of HEDF.

Base payment category	Certified HEDF	Pelletised HEDF
< 3,000 MWK (n = 7)		
Would pay more than base price (n)	3 (43%)	3 (43%)
Price range (MWK)	0 – 3,500	0 – 5,000
Mean price (MWK)	1,143	1,786
Standard deviation of price (MWK)	1,492	2,307
3,000 MWK (n = 45)		
Would pay more than base price (n)	28 (62%)	29 (64%)
Price range (MWK)	3,000 – 10,000	3,000 – 15,000
Mean price (MWK)	3,922	4,984
Standard deviation of price (MWK)	1,310	2,509
Mean added value [a] (MWK)	922	1,984
Mean added value as % of base price	31%	66%
6,000 MWK (n = 140)		
Would pay more than base price (n)	105 (75%)	99 (71%)
Price range (MWK)	6,000 – 20,000	6,000 – 25,000
Mean price (MWK)	7,811	8,729
Standard deviation of price (MWK)	2,369	3,111
Mean added value [a] (MWK)	1,811	2,729
Mean added value as % of base price	30%	45%
12,000 MWK (n = 167)		
Would pay more than base price (n)	126 (75%)	114 (68%)
Price range (MWK)	12,000 – 40,000	12,000 – 30,000
Mean price (MWK)	14,084	15,269
Standard deviation of price (MWK)	3,009	3,553
Mean added value [a] (MWK)	2,084	3,269
Mean added value as % of base price	17%	27%

Notes
[a] Value added to base price by attribute

Attributes which showed a statistically significant association with being willing to pay more for either certified or pelletised HEDF are shown in **Table 6.6**. The attributes showing significant association with being willing to pay more for certified HEDF are using chemical fertiliser (p = 0.005, χ^2 = 7.968) and being female, whilst having used HEDF before (p = 0.005, χ^2 = 7.964) was associated with being unwilling to pay more for certified HEDF. The attributes that showed significant association with being willing to pay more for pelletised HEDF are using chemical fertiliser (p = 0.011, χ^2 = 6.539) and owning cows (p = 0.023, χ^2 = 5.181).

Table 6.6. Relationship between value added and demographic / farming variables.

Characteristic		Would pay more for certified		Chi square and odds ratio	Would pay more for pelletised		Chi square and odds ratio
		Yes	No		Yes	No	
Ever used HEDF before *** [a]	Yes No	18 (51%) 244 (75%)	17 (49%) 80 (25%)	$\chi^2 = 7.964$ $p = 0.005$ OR = 0.347	22 (63%) 223 (69%)	13 (37%) 101 (31%)	$\chi^2 = 0.281$ $p = 0.596$ OR = 0.766
Used chemical fertiliser *** [a] * [b]	Yes No	184 (78%) 24 (56%)	53 (22%) 19 (44%)	$\chi^2 = 7.968$ $p = 0.005$ OR = 2.748	171 (72%) 22 (51%)	66 (28%) 21 (49%)	$\chi^2 = 6.539$ $p = 0.011$ OR = 2.473
Own cows * [b]	Yes No	22 (92%) 187 (73%)	2 (8%) 70 (27%)	$\chi^2 = 3.184$ $p = 0.074$ OR = 4.118	22 (92%) 172 (67%)	2 (8%) 85 (33%)	$\chi^2 = 5.181$ $p = 0.023$ OR = 5.436
Gender * [a]	M F	95 (67%) 167 (77%)	47 (33%) 50 (23%)	$\chi^2 = 3.907$ $p = 0.048$ OR = 1.652	94 (66%) 151 (70%)	48 (34%) 66 (30%)	$\chi^2 = 0.312$ $p = 0.577$ OR = 1.168

Notes
Difference for [a] certification and [b] pelletisation is significant at * $p < 0.050$, ** $p < 0.010$, or *** $p < 0.005$

6.5 Discussion

Almost all participants were willing to pay at least 3,000 MWK for a 50 kg bag of HEDF, and almost half were willing to pay the highest price bracket in the survey: 12,000 MWK (approximately $16 USD). This finding suggests there is substantial demand in Blantyre for HEDF, and even higher price points could potentially be achieved. This high valuation of HEDF could be attributed to dual pressures: year-on-year increases in commercial synthetic fertiliser prices, and the simultaneous reduction of government fertiliser subsidies, leading to alternatives to commercial fertiliser being sought (Nkhoma, 2018). Presenting farmers with a sample to view at the start of the survey influenced their stated valuation, as farmers are known to evaluate the quality, and therefore value, of fertiliser from its appearance (Michelson et al., 2021).

Certain characteristics were associated with higher or lower WTP. Age was negatively correlated with WTP i.e., younger farmers expressed higher WTP than older ones; a similar finding has been reported in Ghana (Agyekym et al., 2014). This finding may reflect younger farmers' greater willingness to take risks, as has been observed elsewhere in Africa and Asia (Ahmad et al., 2019; Kisaka-Lwayo and Obi, 2012). Having used HEDF before (i.e., the participant had prior experience of using HEDF) was also associated with lower WTP. This result might be due to these participants being aware that HEDF can be produced using materials from their own toilets – over three quarters of participants with prior experience with HEDF had sourced it from their pit latrines or urine-diverting dry toilets. Hearing about HEDF from AEWs was associated with higher WTP, which suggests that AEWs are a respected source of farming knowledge; AEW advice has been previously shown to be widely valued by farmers in Malawi (Ragasa and Mazunda, 2018).

Trust is known to play an important role in planning and implementing nutrient recycling programmes (Simha et al., 2017), and therefore finding suitable channels through which to share information about HEDF with farmers is vital. The association between AEWs and higher WTP suggests that they could potentially be an influential channel for promoting HEDF. It is important that farmers receive appropriate support in how to use HEDF correctly for optimum results, as the use of organic fertiliser is different to that of the chemical fertiliser to which most farmers are accustomed (Cai et al., 2019). Incorrect usage of HEDF, whether home-made or commercially produced, could cause reputational damage and discourage usage. If farmers wish to produce HEDF from their own toilets, it would be particularly crucial to provide guidance on the safe production of HEDF at home, as incorrect treatment processes can create health risks for farmers and those who walk on their fields and consume their produce (Cofie et al., 2009). AEW promotion of other types of home-made organic fertiliser, such as compost, has had limited uptake to date, suggesting that innovations in communication and knowledge transfer may be required for success (Cai et al., 2019).

Many variables did not show any significant association with WTP, including socio-economic characteristics such as education and household wealth, and farming practice characteristics such as the size of the farm, ownership of livestock, and ownership of land. This finding suggests that there is little variation in WTP among urban smallholder farmers, regardless of their farming practices or personal circumstances. That said, the proxy measurement for household wealth may have been insufficiently sensitive to detect any association. Even lengthy, complex and sophisticated instruments for measuring household wealth, such as the Demographic Health Survey indicators, cannot always distinguish between differing levels of poverty (Kaiser et al., 2017), as there is a need to balance brevity and accuracy when surveying the general public without offering any compensation for their time.

The lack of association between WTP and many of the variables may also reflect the fact that fertiliser is a basic and fundamental expenditure for smallholder farmers, and as such has relatively low price elasticity (Ogeto and Jiong, 2019). Expanding the survey to cover other types of farmers, such as those with larger land holdings or more commercial activity, may uncover further relationships between farming practice variables, socio-economic variables, and WTP.

Most participants were willing to pay more for HEDF which had been certified or pelletised, which is comparable to farmers surveyed in Uganda (Danso et al., 2017). However, unlike in Uganda, pelletisation was generally attributed greater monetary value than certification, which may reflect lower levels of trust in the national government in Malawi (Maiden et al., 2020), and/or a high value placed on ease of use. Two particular groups of participants were significantly more likely to view certification as adding value: those who had not used HEDF before, and women. This finding may suggest a greater degree of caution among these groups about farming with a substance that humans are typically predisposed to avoid (Curtis, 2011).

Whilst the numbers of participants in the highest WTP brackets suggest a strong market for HEDF in Blantyre, it is important to note that the value of HEDF determined by theoretical approaches may produce overestimates (Mallory et al., 2020a). In practice, the value of HEDF is often lower than is suggested by theoretical studies, and value recovery operations can rarely fund the costs of faecal sludge collection and treatment (Mallory et al., 2020b). Although public acceptability studies suggest that there is strong interest in using HEDF (Roxburgh et al., 2020c (i.e., Chapter 5); Moya et al., 2019a), ambiguous regulatory guidelines, particularly around crop exports, also form a barrier to the development of wider markets (Moya et al., 2019b).

Production of HEDF requires faecal sludge feedstock, which in turn requires systematic and regular emptying of pit latrines and septic tanks. However, once full, most urban pit latrines are either abandoned and covered or informally emptied by unlicenced operators who may illegally dump the contents nearby (Water Research Commission, 2015; Holm et al., 2015). These informal sludge disposal mechanisms constitute a serious public health hazard, and the lack of functioning faecal sludge management systems in the context of growing urban populations is nothing less than a time bomb (Yesaya and Tilley, 2021). Demand for pit emptying services exists; however, innovation in the local private sector to meet this need is presently deterred by high costs of capital and logistics of transporting sludge to distant disposal sites (Moya et al., 2019b; Holm et al., 2015). As such, whilst our results suggest that there is potential to sell HEDF to smallholder farmers in Blantyre, there are many more practical and regulatory barriers to creating functioning HEDF markets yet to be overcome.

Further work to improve WTP estimates could involve showing participants a selection of HEDF samples, utilising a variety of post-treatment processing techniques, in a randomised order in order to ascertain the value added more accurately. Qualitative work could be used to establish why participants value certain characteristics more than others, and a wider range of price bids can be used to establish if WTP extends further than the maximum bid of 12,000 MWK used in this survey. The survey population could also be expanded to include commercial farmers, and farmers of non-food crops.

6.6 Conclusion

This study has established that the highest tested valuation point of 12,000 MWK is an acceptable price for a 50 kg bag of HEDF among almost half of surveyed smallholder farmers, and certification or pelletisation adds further value to the product. Few relationships were detected between demographic or farming-related variables and WTP categories, suggesting that WTP is widespread across the different smallholder farmers surveyed, rather than particular groups being strongly associated with higher or lower payment categories. The only relationships detected were in the case of younger farmers and those who had heard about HEDF from agricultural extension workers, who were likely to have higher WTP, whilst those who had used HEDF before were likely to have lower WTP, reflecting the influences of risk aversion, trust, and personal experience on their valuations.

The results suggest that there is an opportunity to promote HEDF in Blantyre as a confluence of chemical fertiliser subsidy withdrawals and price rises have generated a more pronounced WTP for organic alternatives. It would be beneficial to conduct further research investigating how small-scale HEDF enterprises can be best supported to grow, and how farmers can be guided to use HEDF effectively, with AEWs identified as a conduit for particularly effective promotion. Importantly, the theoretical results here, the stated WTP values, should be tested in the market to determine if, and how close the stated values are to the actual, or revealed WTP values that can only be measured by actual purchases.

The economic and pragmatic barriers to functioning HEDF markets are numerous and require synergistic change (Mallory et al., 2020b). However, not only does there appear to be widespread and strong WTP for HEDF in Blantyre among smallholder farmers, but combined pressures on existing resources, environmental sustainability, and public health create substantial impetus for system-wide reframing in how human waste nutrients are viewed in relation to agriculture (Harder et al., 2020). There is a pressing need to rehabilitate intensively farmed soils, both in Africa and around the world, and organic soil amendments such as HEDF are proven to improve soil structure and productivity (Tadele, 2017; Eden et al., 2017; Oldfield et al., 2018). There is also an urgent need to develop safe and sustainable management systems for faecal sludge in dense urban settlements, whereby sludge is emptied from pits and taken to centralised treatment plants on a regular and affordable basis (Yesaya and Tilley, 2021). Furthermore, as scarce phosphorus resources become increasingly concentrated in geopolitically fragile regions, HEDF is likely to become an important part of agricultural production around the world in coming years (Chowdhury et al., 2017; Iwaniec et al., 2016). In urban and peri-urban areas, where large quantities of excreta are generated in close proximity to farming land, processing faecal sludge into agricultural products has potential to tackle all of these challenges in a particularly efficient way.

Chapter 7 | General discussion

The implementation of safe and sustainable faecal sludge management (FSM) systems is vital to achieving adequate sanitation for the billions of people around the world that rely on non-sewered sanitation (Berendes et al., 2017). FSM can prevent the introduction and dispersal of human pathogens into the environment, lessen the burden of faeco-oral diseases, and contribute to environmental sustainability (Strande, 2014a). Furthermore, treated faecal sludge can be used in agriculture as an organic soil amendment, which in turn facilitates sustainable nutrient recycling, improves soil health, and reduces dependence on commercially mined nutrients (Harder et al., 2019). In sub-Saharan Africa (SSA), high proportions of people use pit latrines in densely populated urban areas, and so the safe management of faecal sludge from these facilities is particularly critical (Thye et al., 2011; Berendes et al., 2017). However, FSM has so far proved difficult to implement in practice for a variety of social, technical, and economic reasons.

The overarching aim of this thesis is to examine the opportunities and barriers to FSM and agricultural reuse of faecal sludge in SSA at three points in the sanitation service chain: containment, treatment, and reuse. The specific research objectives are:

- To quantify the extent to which menstrual waste enters the sanitation service chain and identify the socio-cultural processes that drive and sustain this behaviour and how they might be adapted;
- To investigate the efficiency of a novel biological faecal sludge management technology - black soldier fly larvae - on removing faecal indicator microorganisms from faecal sludge with and without the addition of additional organic waste; and
- To assess public acceptability and willingness to pay for human-excreta-derived fertiliser (HEDF) and identify potentially effective strategies for promoting HEDF usage.

This chapter presents critical reflections on this aim, and the three main objectives of the thesis. The main opportunities and barriers explored and discussed in the thesis are summarised in **Figure 7.1**. First, empirical contributions are presented whereby the main findings of the chapters are briefly recapped in the context of the objectives, and then their theoretical and practical implications are discussed. A reflection on the limitations of the work is presented, along with recommendations for future work, and concluding remarks.

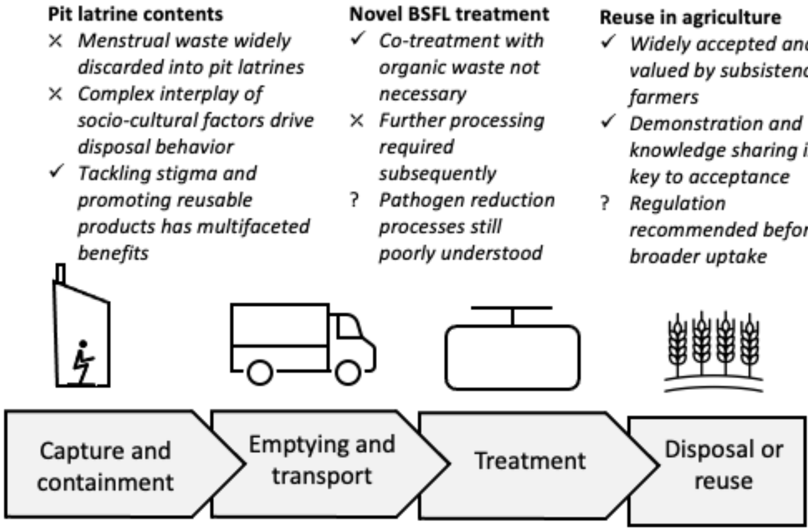

Figure 7.1. Opportunities and barriers in the sanitation service chain.

7.1 Objective 1: Quantify the extent to which menstrual waste enters the sanitation service chain and identify the socio-cultural processes that drive and sustain this behaviour and how they might be adapted

7.1.1 Empirical contribution

Chapter 3 demonstrated that over half of menstrual absorbents are ultimately discarded into pit latrines in urban areas of SSA. In volumetric terms, disposable pads appear to constitute the larger flow since they are discarded after a single use, but menstrual cloth can potentially be more detrimental to the emptying process since textiles are prone to entangling with pump blades (Sisco et al., 2017). Cloth users were shown to display a wide diversity of practices, with some appearing to discard menstrual cloths after just a few uses and others reusing their cloths for decades. Despite the substantial volumes of menstrual waste that enter pit latrines, there is a distinct lack of specific attention paid to menstrual waste within pit emptying literature. Studies which examine pit contents frequently discuss solid waste and identify particular items within it, but the composition is usually described in terms of material type such as ‘plastic’ or ‘textiles’ (e.g., Tembo et al., 2019), perhaps because the decomposition process renders any more specific identification difficult, but more likely because the methods and labour required to disaggregate such waste would be messy, hazardous, and unpalatable. However, it is important to understand and identify the particular waste streams that are entering pit latrines in order to consider how alternative waste management behaviours might be encouraged.

Burning is the other predominant disposal route for menstrual waste identified in Chapter 3; however, this is constrained by the necessity for privacy. Women living in informal settlements are more likely to discard their absorbents in pit latrines, because the high population density means that burning is difficult to perform unnoticed. By contrast, burning is more popular than pit latrine disposal in more rural areas. Unfortunately, this pattern does not benefit faecal sludge management interests, because unlike dense urban areas, rural areas tend to have more space available to dig new pit latrines when they become full (Peal et al., 2014). Thus, pit latrines in areas where they are most likely to require emptying are also most likely to contain menstrual waste. It would therefore be helpful for future research on menstrual waste to concentrate on urban high-density informal settlements, because these spaces have the most critical management issues. In extremely poor informal settlements, cloth may be reused for long periods and disposable pad use may be uncommon due to their cost (Kambala et al., 2018), and therefore the problem may be less severe than in dense settlements with slightly higher incomes: it is here that the challenge of menstrual waste in pit latrines will be most acute.

Modernisation and globalisation processes are causing rapid and profound change in many aspects of African life (Agugua, 2018), and menstruation is no exception. Chapters 2 and 3 revealed clear differences in behaviours and attitudes between older and younger generations, and particularly between those with more or fewer years of formal education. Use of disposable pads and reusable cloth are strongly associated with younger / older age groups, and having more / fewer years of education, respectively; therefore, projected demographic shifts in population and expansion of educational opportunities means that the volume of menstrual waste generated is likely to grow. The diversity of menstrual product choice has increased in the last decade with options such as tampons and reusable pads becoming more commonly available, however, the growth in their uptake is slow compared to that of disposable pads. The need to discard menstrual waste discreetly can place a heavy burden on young pad users; and cause stress and anxiety by having to secretly dispose the taboo waste on a daily basis when suitable facilities are not available (Kambala et al., 2018).

Chapter 2 revealed that the shame associated with menstruation was a powerful driver for all participants' attitudes and behaviours, as has been identified in many other parts of the world (Mason et al., 2013; Scorgie et al., 2016). Menstrual blood was widely viewed as disgusting, and some participants explained how perceptions of disgust can extend to the menstruating woman as well. The menstruating woman was also sometimes perceived as dangerous and destructive, i.e., touching crops might cause them to fail, or eating food prepared by them might cause a person to become sick, leading to certain restrictions on household activities during menstrual periods. An interesting and contrasting perception of menstrual blood, however, was found among some participants who used it in traditional medicine practices. Many participants were aware of the purported healing properties of menstrual blood and a few had used it themselves, whilst others had never heard of the practice before, so it was difficult to establish how widespread it actually was. Whilst similar practices have been reported in ancient history (Buckley and Gottlieb, 1988), no other reports of this kind have been identified in SSA.

Another factor discussed in Chapter 2 was the fear of witchcraft, which significantly affected participants' behaviours in relation to menstrual absorbents. Although participants differed in how severe they felt this threat was, almost all of them perceived a danger from 'rituals' that might be performed using their menstrual absorbents and cause them personal harm; it was a widely accepted fact of life and has been similarly identified as such in other parts of SSA (Scorgie et al., 2016; Chinyama et al., 2019). Among the older participants, and those with fewer years of formal education, the fear was extremely powerful. The rituals described by participants had harmful consequences such as causing indefinite menstrual bleeding and becoming infertile, although other less threatening kinds of rituals were occasionally mentioned, e.g., bringing prosperity in business activities. The threat of witchcraft competed against other factors, such as practicality and shame, as women made choices about how to dispose of their menstrual absorbents and often faced unresolvable tension between them. Discarding menstrual waste into a pit latrine - which was quick, easy, discreet, and protected it from being taken for use in witchcraft – often satisfied these competing needs better than other methods and explains in part why pit latrine disposal is so common.

To summarise the empirical contributions of Chapters 2 and 3, the most common menstrual absorbents used in Blantyre, their most common disposal methods, and the socio-cultural drivers that affect their disposal, are illustrated in **Figure 7.2**.

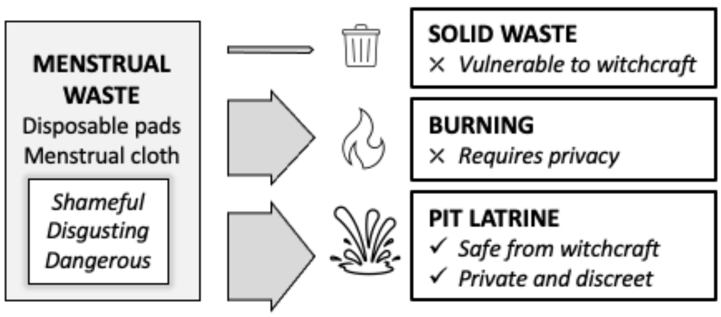

Figure 7.2. Socio-cultural drivers of menstrual waste disposal.

7.1.2 Theoretical discussion

The performative absence of menstruation from public life provides an interesting example of the theoretical 'backstage' discussed by Goffman (1959). Whilst on the front stage of public life, menstruation is carefully hidden, this performance is only possible through extensive work 'backstage' to collect and dispose of menses discreetly. Through these efforts, the front stage retains its utopian façade of clean, non-menstruating bodies, whilst the messy fluids and leaky bodies (and the accompanying labour of managing them) are concealed. There is a sad irony in how certain efforts to maintain this façade of hygienic, non-menstruating bodies can ultimately lead to unhygienic practices and sick bodies, e.g., using damp menstrual cloths which have not been dried properly in sunshine (because they would be seen by others) can result in vaginal infections (Kambala et al., 2020). Most relevant to the future of faecal sludge management, however, is how the emptying of a latrine can suddenly turn a backstage setting into the front stage. One participant from Chapter 2 recounted how she had disposed of her pads in the family's urine-diverting dry toilet after it was first built, but then suffered terrible embarrassment on the day that her father came to empty the toilet's chamber and found her pads accumulated there. The emptying of a latrine in a crowded area may create an uncomfortable reversal of social norms when menstrual waste is visibly present within the sludge. This potential for shame is further amplified by pit emptiers being ubiquitously male, as the importance of keeping signs of menses particularly well-hidden from men was mentioned repeatedly by participants.

Substances that cross human bodily boundaries, such as menstrual blood, are typically subjected to particular societal regulation and control (Douglas, 1966). They are also sometimes perceived as powerful and magical, as exemplified in the case of menstrual blood being used in witchcraft rituals and traditional healing practices described in Chapter 2. However, further dimensions can underpin societal understandings of menstrual blood in the traditional beliefs of agricultural societies, as in the case of the Chewa – the most widespread Malawian ethnic group (whose language, Chichewa, is the de-facto national language). Under traditional Chewa beliefs, the careful management of body fluids is viewed in parallel to the careful seasonal management of the land (Kaspin, 1996). The rhythms of rain, drought, and fire, which are carefully utilised by farmers in a delicate balance between heat/cold/moisture to reap food and sustain life, are thought to be mirrored in reproductive processes, and must be managed similarly in order to protect society and fertility. In keeping with this view, menstrual blood is seen as 'hot', akin to the fires used to clear dead vegetation before the next rainy season. Menstruating women are expected to stay away from 'cool' persons, such as very young children, and refrain from sexual intercourse to avoid harming others with their 'heat' (Kaspin, 1996). As such, menstrual blood is perceived as a very dangerous fluid which can cause serious illness, particularly in men (Zulu, 2001); these perceptions likely form some of the roots from which the perceptions of power and magic surrounding menstrual blood have grown today. Either way, the rituals around menstrual blood would benefit from further study as they provide an example of anthropological interest *par excellence* in the regions of dirt, disgust, gender, and the human body.

7.1.3 Practical implication

Human beings are social by biological inheritance, and shame is an inherently social emotion (Scheff, 2003). As such, shame constitutes a powerful driving force in human relations and society at large. The shame attached to menstruation as a result of the complex processes described above, place an extremely unfair burden on women and girls, who must obey the 'rules' of menstrual secrecy whilst simultaneously contending with inadequate infrastructure and supplies to do so (Moffat and Pickering, 2019). Tackling shame-based menstrual stigma is vitally important and a growing number of menstrual activists have brought attention to this cause over the last half decade (Weiss-Wolf, 2017). This remarkable global effort has seen campaigns, educational programmes, and legislation rolled out around the world with the aim of improving women's menstrual experience. However, the roots of menstrual stigma will be neither quick nor easy to dismantle, and many women, particularly those who are older or do not attend school, will not be easily reached by school-focussed reproductive health educational programmes. As such, whilst the highly laudable aim of tackling menstrual stigma has made progress, efforts to design alternative menstrual waste disposal methods will need to work within the constraints of menstrual stigma for the foreseeable future. Menstrual waste disposal infrastructure, such as bins or incinerators, must therefore be discreet to use but keep waste inaccessible to others, or else they will not be used (Mchenga et al., 2020).

Reusable pads are a menstrual absorbent with particular relevance to SSA as they have potential for significant advantages. High-quality reusable pads can offer the benefits and innovations of modern textiles technology, including significantly greater absorbability, comfort, ease of washing and speed of drying over traditional absorbents (Hennegan et al., 2017). Using reusable instead of disposable pads could therefore not only provide a more comfortable menstrual experience and cost less over the long term, but also significantly reduce volumes of menstrual waste produced. Use of reusable pads have similarities to traditional practices of washing and reusing cloth and therefore may be preferred to relatively unfamiliar reusable products like menstrual cups, as was found to be the case in Zimbabwe (Tembo et al., 2020). However, reusable pads can vary significantly in construction and quality; poorly made reusable pads can be uncomfortable to use and even cause skin irritations, and such experiences can discourage potential users (Kambala et al., 2020). In Malawi, reusable pads (and the materials to make them) are not widely available and tend to be produced by small-scale cottage industries rather than retailed by international brands (Kambala et al., 2020). Whether reusable pads are mass- or locally produced, regulation to control their quality would improve their safety and comfort, which may in turn encourage more women to use them. However, any regulatory interventions may have the downsides of increasing costs, being difficult to enforce, and creating a secondary market in low-quality pads, and should therefore be approached with caution. Whilst wider availability and uptake of reusable pads could have multifaceted benefits, it is also important that women have access to a variety of menstrual absorbents, as many women prefer to use disposable options, particularly when travelling or if the user has limited access to water and privacy in order to wash reusable absorbents.

Ultimately, it is difficult to say whether it would be better to try and prevent the disposal of menstrual waste in pit latrines by promoting other disposal options (such as with solid waste or incineration) and reusable menstrual absorbents, or whether to accept the status quo and focus on creating cheap and powerful maceration pumping devices to cope with a mixed composition of faecal sludge and menstrual waste. The pervasiveness of menstrual waste disposal in pit latrines, and the deep and complex socio-cultural drivers that cause it, suggest that both approaches may be required simultaneously as neither are likely to be entirely successful on their own. Whilst diverting menstrual waste from pit latrines entirely is likely to be impossible, reducing the volume will make it easier to cost-effectively remove and recover value from faecal sludge. One particular challenge of this issue, however, is that most diversion tactics lie outside the domain of the current boundaries of the FSM sector. Education initiatives delivered through schools on tackling menstrual stigma and promoting reusable pads are more likely to be carried out by specialists in reproductive health, education, and gender equality, whilst wider promotion of reusable pads is a challenge better suited for entrepreneurs and business/market specialists. Designing solid waste services and incineration devices that are socio-culturally and practically suitable for the disposal of menstrual absorbents lies within the realm of solid waste management professionals. Therefore, apart from designing better pumping machines, many of the most promising remedies lie within disciplines other than FSM. This fragmentation highlights the importance of working in tandem with related sectors, the hindrance of disciplinary silos, and might also explain why the subject of menstrual waste within FSM has received little attention until now despite a proliferation of scholarship in both areas over the last few years.

7.2 Objective 2: Investigate the efficiency of black soldier fly larvae on removing faecal indicator organisms from faecal sludge with and without the addition of organic waste

7.2.1 Empirical contribution

In Chapter 4, BSF larvae grown on a mixture of human faeces and vegetable waste grew heavier with higher proportions of vegetable waste, as has been similarly observed elsewhere (Nyakeri et al., 2017; Nyakeri et al., 2019). However, co-treatment with vegetable waste did not result in greater reductions of *Escherichia coli* or *Enterococcus faecalis*; in contrast, persistence and proliferation of these bacteria was greater in the faecal substrates containing vegetable waste compared to the substrate containing just faeces. This was hypothesised to be due to differences in the moisture contained within the material. The substrate containing just faeces was particularly prone to drying out in the simulated tropical temperatures, which caused concentrations of *E. coli* to rapidly decline, with or without the addition of BSFL.

The concentration of *E. coli* was significantly affected by BSFL feeding, for both substrates (i.e., with and without vegetable waste). BSFL feeding appeared to accelerate die-off of *E. coli*, particularly in the substrate containing faeces only. In contrast, *E. faecalis* concentrations did not show any statistically significant differences between material with or without BSFL, for either substrate. This suggests that the mechanisms by which BSFL feeding activity supresses and reduces concentrations of pathogens in the material are effective against *E. coli* but ineffective against *E. faecalis*, as previously observed in substrates of human faeces, pig manure, and dog food (Lalander et al., 2013; Lalander et al., 2015a), and this may be caused by differing resilience of these microorganisms to environmental stresses in the substrate.

To summarise the empirical contributions of Chapter 4, the general trends in *E. coli* and *E. faecalis* concentration change in both faeces and vegetable substrates are illustrated in **Figure 7.3**.

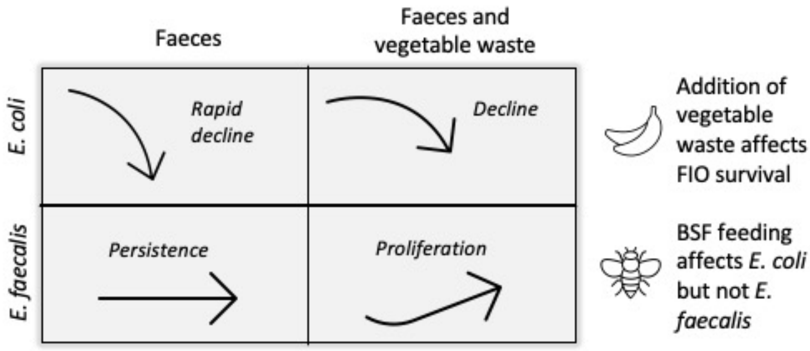

Figure 7.3. Effect of BSFL feeding activity on *E. coli* and *E. faecalis* in substrates of faeces and vegetable waste.

7.2.2 Theoretical discussion

Neither of the processes by which pathogen concentrations were affected – drying of the feedstock and BSFL feeding activity – are particularly well understood (Oliver and Page, 2016; Gold et al., 2018). The effects of BSFL feeding activity on microorganisms within faeces is at an early stage of knowledge development, having only been studied intensively in the last few years. However, the mechanisms of *E. coli* die-off within the faecal matrix under various environmental conditions are highly complex and remain elusive despite decades of investigation (Oliver et al., 2016; Porter et al., 2019).

The faecal matrix can be considered as a structure of organic particles (namely, microbial biomass and undigested macronutrients) intermixed with water and (increasingly, as the material dries) air, with the physio-chemical properties of the organic matter dependent on diet and digestive system of the animal in question (Rose et al., 2015). The presence of moisture in particular is known to have an important effect on die-off of *E. coli* (Oliver et al., 2016; Porter et al., 2019), and is usually measured and discussed in terms of moisture content (i.e., the ratio of the mass of water to the total dry mass). Although moisture content is a relatively simple measurement to take, it does not necessarily distinguish between the different ways in which water can be bound and available within a material.

As faeces dries and moisture content decreases, it can be hypothesised that the remaining moisture forms menisci in the voids between the organic particles. The matric suction forces resulting from surface tension in the menisci draw the particles tightly together (as can be visibly observed when drying faeces shrivels and becomes hard). The high organic matter content of faeces, and correspondingly diverse shapes, sizes, shear, and tensile strengths of the particles, will affect how tightly they can be pulled together. The relationship between moisture content and matric suction is not linear, but rather follows a hysteresis curve (Lu and Likos, 2004). Therefore, matric suction is higher in drying substances than wetting substances, even for the same moisture content.

Unlike bacteria in other substrates like soil, which may be accustomed to regular wetting and drying cycles (Zhou et al., 2016), bacteria in human faeces are primarily adapted to the conditions of the human gut. Whilst *E. coli* might be well adapted to tolerate the shear stress of fluids passing along the intestinal wall (Persat et al., 2015), they may not be resilient against the specific experience of drying stress, and particularly the strong tensile forces that may occur within the menisci of material pores. If matric suction forces within the pores reach a critical level, this may begin to impose stress on the gut bacteria, either destroying them or decreasing their resistance to other threats. Thus, the size of pores within the substrate and whether the material is in a progressive state of becoming wetter or dryer may affect the survival and proliferation of bacteria, as both these properties relate to the strength of matric suction (i.e., matric potential). This theory could potentially explain the different rates of bacterial proliferation and decline between the two substrates tested in Chapter 4, despite their moisture contents being relatively similar. Although pore size was not measured in the experiments, the substrates had visually different fluidities (i.e., the degree to which they flowed to fill the shape of the container), and the addition of pulverised vegetables to faeces (i.e., adding moisture) would potentially mean that the substrate containing vegetable waste had a lower matric suction than the substrate containing faeces alone, even for the same degree of saturation (as a result of the hysteresis relationship between matric suction and water content). How organisms respond to these changing forces is likely to depend on their particular characteristics, and also their preferred location within the faecal matrix. For instance, *E. faecalis* prefers to reside within the solid fractions of the material, whilst *E. coli* is more often found in the liquid fractions (Guber et al., 2007), which may explain why *E. coli* appeared to be more vulnerable to the effects of desiccation.

The physical effects of BSFL feeding activity further affect the complex relationship between moisture, air, material structure, and microbial proliferation. BSFL tunnel through their substrate, consuming and excreting, thereby modifying the structure of organic particles whilst simultaneously aerating, moistening, and mixing (Dortmans et al., 2017; Gold et al., 2020). The activity of the larvae could therefore potentially reduce the concentration declines of gut bacteria which occur from desiccation but induce concentration declines in other different ways. Ingestion by BSFL may inactivate bacteria via gut pH and digestive enzymes, as has been shown to be the case for *E. coli* in other fly species (Mumcuoglu et al., 2001), whilst the BSFL gut microbiome also introduces new, competing species of bacteria to the material (Gold et al., 2020). Another mechanism by which BSFL are hypothesised to reduce concentrations of certain microorganisms in the substrate is through their production of antibacterial agents. These have been extensively examined to assess their potential for combatting antibiotic resistance (Choi et al., 2012; Park et al., 2014, 2015; Park and Yoe, 2017a, 2017b), and notably appear to be effective against gram-negative bacteria but not gram-positive bacteria (Choi et al., 2012). The difference between gram-positive and gram-negative bacteria relates to their cell wall composition; the former has thick cell walls composted of peptidoglycan (a polymer of sugars and amino acids), while the latter has a thin layer of peptidoglycan and an outer membrane of lipopolysaccharide molecules (Alberts et al., 2014). *E. coli* is an example of a gram-negative bacteria, while *E. faecalis* is gram-positive, and the increased die-off rate of *E. coli* but not *E. faecalis* in Chapter 4 may be due to this mechanism.

7.2.3 Practical implication

The experiments presented in Chapter 4 suggest that it is not necessarily advantageous to co-treat faecal sludge with other kinds of organic waste from a pathogen reduction viewpoint; in fact, it can be disadvantageous as pathogenic organisms appeared to persist for longer in the moister and more fluid substrate containing vegetable waste. However, subsequent processing techniques would be required to facilitate reuse in agriculture, as pathogenic bacteria such as *E. faecalis* appear to be unaffected by BSFL feeding activity, and this may form part of a wider pattern of gram-positive bacteria being unaffected by BSFL antibacterial agents (Choi et al., 2012). Even though subsequent processing adds further steps to the faecal sludge treatment process, these are likely to be greatly simplified by the reduction in mass and odour of the material (Lalander et al., 2013). The wider benefits of BSFL feeding activity, such as improving the quality and maturity of the compost produced and seeding the material with beneficial microorganisms (Liu et al., 2019; Poveda, 2021), mean that BSFL treatment can still be an attractive prospect for producing high-quality HEDF despite having a limited effect on pathogen concentration reductions. Furthermore, the production of valuable by-products from the BSFL treatment process (i.e., larvae and their derivatives such as chitin and oil) could potentially provide an economic incentive for the complex process; this ultimately depends on the local availability of suitable markets for these products.

7.3 Objective 3: Assess public acceptability and willingness to pay for human-excreta-derived fertiliser (HEDF) and identify potentially effective strategies for promoting HEDF usage

7.3.1 Empirical contribution

Chapter 5 demonstrated that the degree of public acceptance of HEDF depends on two critical factors: whether or not people were able to view a sample of composted, granulated faecal sludge for themselves, and whether or not they had heard about the idea of using human excreta in agriculture before. For those participants who had heard of HEDF before and were shown a composted, granulated sample, 96% were willing to buy maize grown in it. For those participants who were not shown the sample and had never heard of it before, only 30% were willing to do so. This sharp division in opinion prompted (in part) by the methodological process of showing or not showing a sample helps to explain why previous studies have found such different results in measuring acceptability (e.g., between Appiyah-Effah et al. (2015) and Moya et al. (2019a)), and also demonstrates the importance of grounding participants' opinions in their prior knowledge and experiences. There are many different levels of treatment and post-treatment processing that faecal sludge can undergo to become 'HEDF', and without firmly rooting the discussion to a particular example (demonstrated visually to the participants with a physical sample) it is not possible to know exactly how potential users understand the term and ascertain their opinion accordingly.

The almost universal acceptance of HEDF by participants who fulfilled the two critical criteria (i.e., saw a sample of composted, granulated HEDF, and had heard of it before) should not be entirely surprising. Farmers are generally aware of the need to apply organic matter for optimum soil health and understand the benefits of animal manure in particular (Dawoe et al., 2012; Ndambi et al., 2019). Using visual cues from colour and texture to assess the quality of soil and fertiliser is common practice among farmers (Dawoe et al., 2012; Michelson et al., 2021). The presentation of the composted, granulated HEDF sample (which was dark, crumbly, and odourless – essentially appearing as a fertile, organic-rich substance) was therefore a powerful way to demonstrate its beneficial properties. This broad acceptance of HEDF, along with the historic use of HEDF in agriculture by civilisations around the world, shows that faeces are not widely considered disgusting once they have been appropriately transformed (Ferguson, 2014).

When collecting data for Chapter 5, semi-structured interviews were initially used to gain information on what farmers thought of HEDF, how they understood it, and the language used to describe it. The interviews were intended to explore the reasons why farmers chose to use HEDF on their own land or not, and why it was considered disgusting or not. Whilst the interviews were successful in determining the vernacular terms used to describe HEDF ('human manure') and revealed a great diversity of opinion among farmers on its merits, they were not very helpful in establishing the reasons why farmers felt as such. Also, it was not easy for the farmers themselves to distinguish the reasons for their feelings and opinions when asked; the same was found in studies of the Ghanaian general public (Buit and Jansen, 2016). At this point in the research process, the sample of composted, granulated HEDF had not yet been acquired, and a sample of dried sewage sludge (acquired from the local wastewater treatment plant and used by local farmers in their fields) was shown to the farmers to illustrate the concept of 'HEDF'. Perhaps if the more visually appealing sample had been available earlier, then the same patterns would have been identified in the interviews that were later found in the survey. But, as the mechanisms for disgust are primarily subconscious and invisible (Curtis et al., 2011), it may be that the interviews were just not a good tool for answering this particular question. By contrast, the survey of the general public whereby some participants were shown samples of HEDF, and some were not, proved a highly effective (albeit accidental) method to shed light on the underlying mechanisms of HEDF acceptability.

Chapter 6 revealed that there was substantial willingness to pay for HEDF among farmers, with over half of farmers willing to pay the highest tested payment category (12,000 MWK) for a 50kg bag of HEDF. This was unexpected, and in retrospect it would have been preferable to test even higher payment categories. WTP was surveyed alongside public acceptability in the same questionnaire, and therefore at that point the higher acceptability due to showing the sample of composted, granulated HEDF to participants was only just being revealed. Given that acceptability is linked to WTP (Buit and Jansen, 2016), it is understandable that WTP was higher than anticipated in the light of being shown the more visually appealing sample. Interestingly, however, in contrast to the results from the public acceptability survey, prior experience of using HEDF *decreased* WTP, which was thought to be a result of these participants being aware that they could make HEDF from their own excreta. Overall, there appeared to be a pressing public interest in alternatives to commercial fertiliser, which is likely to be the result of government subsidies being scaled down and increasing retail prices (Nkhoma, 2018). During the surveys and interviews, farmers often pressed the data collectors for additional information on how to use and make HEDF.

To summarise the empirical contributions of Chapters 5 and 6, the main drivers of public acceptance and valuation of HEDF are illustrated in **Figure 7.4**.

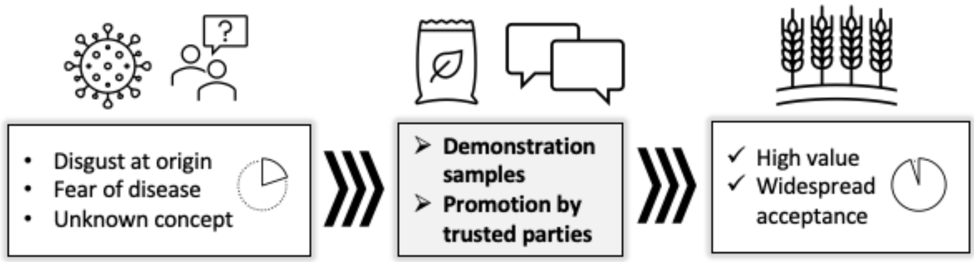

Figure 7.4. Acceptability and valuation of HEDF among subsistence farmers.

7.3.2 Theoretical discussion

Literature regarding the use of HEDF often refers to a phenomenon termed ‘faecophobia’. The ‘faecophobia’ argument, as it relates to SSA, purports that many farmers in this region were historically semi-nomadic and are therefore predisposed to feel particular fear – ‘faecophobia’ - at the sight of human faeces which signify the presence of other people. This is contrasted with cultures and civilisations of East Asia, which are termed ‘faecophillic’ due to well-documented practices of returning excreta to agriculture, and this is speculated to be the result of their greater population density. This argument was first speculatively coined by Winblad and Simpson-Hébert (2004) in a book about ecological sanitation and has been repeated many times subsequently in discussions about the acceptability of reusing human excreta (e.g., Dellström Rosenquist, 2005; Nawab et al., 2006; Jewitt, 2011). However, there are several immediate issues with the idea of ‘faecophobia/philia’; firstly, the lack of extensive documentation regarding excreta reuse in SSA does not mean that it did not occur; in fact, there are documented examples of excreta reuse (e.g., Rugalema et al., 1994). Secondly, there is no evidence presented that people of semi-nomadic heritage are necessarily more fearful of faeces than anyone else. Finally, the portrayal of East Asian populations as ‘faecophilic’ (which Winblad and Simpson-Hébert describe as having ‘no problems talking about [faeces], smelling it, or handling it’), does not concur at all with in-depth anthropological studies of Vietnamese farmers who use HEDF, who frequently expressed disgust at excreta, particularly when it is odorous (Knudsen et al., 2008). However, the widespread repetition of this narrative appears to nonetheless cast doubt on the public acceptability of HEDF in SSA, despite data presented in Chapter 5 suggesting that Malawian subsistence farmers can be widely receptive to HEDF.

In contrast to the assertions discussed above, there is no documented empirical evidence to suggest that some cultures are indeed naturally more disgusted by faeces than others. Disgust is a powerful behavioural driver which functions as an evolved psychosocial system to protect against infectious diseases (Curtis et al., 2011). Although disgust-evoking objects and practices vary widely across places and cultures, and even between individuals, human faeces are almost universally reviled. However, as HEDF was so quickly and universally accepted by farmers and consumers in Chapter 5, it seems that even the most extreme disgust reactions can potentially be modified with relative ease. In contrast, the behavioural drivers of shame and fear which cause menstrual waste to be deposited in pit latrines would appear to be much more complex and less easy to change. Perhaps an explanation can be found in the differences between disgust and shame: the function of disgust is to protect us (as individuals) from infection or harm, and so once the sensory triggers of disgust (i.e., appearance, odour) are removed through material transformation, disgust naturally diminishes (Buit and Jansen, 2016). By contrast, shame is a social phenomenon (Scheff, 2003), and therefore it may be harder to influence an individual's sense of shame, but rather it must be removed from an entire community (or at least, from a large enough group) in order to make major differences to any single individual.

The role of faeces and HEDF within Douglas's theory of dirt, which is conceived as 'matter out of place', is interesting to contemplate in this context (Douglas, 1966). The relationality of dirt is easily apparent within the examples presented by Douglas, e.g., shoes on the floor are fine, but shoes on the table are dirty. With faeces, though, the argument can be harder to understand. Faeces might be considered extremely dirty on the carpet, but are they dirty when visible in the toilet? What about faeces in the sewer, or the sewage treatment plant? Despite being in the 'right' place, many people would likely still feel disgust at the sight of faeces in any of these locations. Van der Geest added a further layer to conceptions of dirt and faeces with his observation that the faeces of others is considered dirtier than our own or that of our close relations (van der Geest, 2007), which fits understandings of disgust as a disease-protection mechanism (the faeces of others is far more dangerous to us than our own) (Curtis et al., 2011). It is striking, therefore, that when presented with a dark, crumbly, fertile-looking HEDF sample that is produced from other people's faecal matter, there is an absence of disgust, and instead even a strong interest in purchasing it. If dirt really is 'matter out of place', then perhaps the fact that human faeces is no longer considered disgusting once it has been dried, decomposed, and returned to the soil, shows that we subconsciously believe this is the place it is 'meant' to be.

7.3.3 Practical implication

The two factors correlating with high acceptance of HEDF discussed in Chapter 5 (i.e., prior knowledge of HEDF, and viewing a composted, granulated sample of HEDF) suggest that wider promotion – and in particular, the use of demonstration samples - can be very effective in increasing acceptability and uptake. Agricultural extension workers (AEWs) were identified as potentially being effective channels through which to do this; other options for HEDF promotion could include farmer radio stations, local community leaders, or the national school curriculum, which has a significant agricultural component (Chirwa and Naidoo, 2014). Some of these organisations may be more receptive to HEDF initially than others; reaching out to local NGOs (who may be particularly agile and open minded) to conduct pilot projects may be a good way to build an initial evidence base before eventually approaching larger, more centralised organisations. A long-term vision of integrating HEDF usage into official AEW programmes (which are under the control of the Ministry of Agriculture) may take some time to achieve.

Whilst the findings of Chapters 5 and 6 that suggest HEDF could be broadly accepted and valued by the general public are encouraging with regards to faecal sludge reuse and value recovery, they also raise new concerns. The evolved psychological mechanisms that cause disgust at human faeces exist primarily to keep people safe from disease, however, HEDF which is odourless and looks 'safe' can nonetheless still contain harmful pathogenic organisms, particularly helminths (Curtis et al., 2011; Kengne et al., 2014). If farmers do not feel any natural caution when using HEDF because it looks 'safe' and is widely accepted as such by the farming community, this could make them (and potentially the wider public) vulnerable to the health risks from improperly treated HEDF. As such, any HEDF promotion efforts would need to be accompanied by appropriate regulation of HEDF-producing enterprises, together with monitoring and enforcement (Bassan, 2014). The results of Chapter 6 suggest that there may be considerable interest from farmers in producing HEDF at home, and support from extension workers would help to ensure that correct storage periods and procedures are followed.

Treatment standards for reusing faecal sludge in agriculture have a difficult balance to strike. Whilst they must protect farmers and consumers, they also must not be so stringent that few HEDF enterprises would be able to comply (Strande, 2014b). The World Health Organization recommends a risk-management approach to determining appropriate regulation for HEDF which takes account of the crop it is used on and how the produce is cooked and consumed (World Health Organization, 2006). As shown in Chapter 5, people generally consider HEDF to be most suitable for use on maize, where the edible part of the plant has virtually no contact with the soil and is processed before eating, and this could be accounted for in treatment standards accordingly. Whatever treatment standards are determined, they must be appropriately reflected in usage guidelines and instructions on the product packaging, for instance recommending farmers to wear shoes when applying the product and for a certain number of days afterwards when walking on the field.

7.4 Aim: Identify key opportunities and barriers to implementing faecal sludge management systems and value recovery in urban sub-Saharan Africa

Efforts to deliver FSM services to rapidly urbanising spaces in SSA involve a variety of specialist services, stakeholders, and complex chains of responsibility and finances (Bassan, 2014). It is a socio-technical process requiring infrastructure and technology that are not only designed around the physical requirements of the waste streams, but also around the cultural preferences of the users (Berendes et al., 2017). This complexity draws together a variety of diverse academic fields under the umbrella of 'waste management', and as a result, scholarship has often been focussed on a particular part or aspect of the sanitation chain as opposed to examining the process as a holistic whole. However, the absence of an overarching view has led to certain aspects of challenge of the chain being relatively overstated, whilst others receive little attention despite being arguably more important.

For instance, the socio-cultural acceptability of reusing human waste, and willingness to pay for it, has long been recognised as an important consideration for achieving nutrient recovery from sanitation systems (Ricard and Rico, 2019). However, despite decades of study, a 2020 literature review of the topic nonetheless asked: 'Why do we know so much and yet so little?' (Gwara et al., 2020). The uncritical repetition of ideas such as 'faecophobia' and 'faecophilia' has persisted in giving the impression of certain cultures being innately more or less accepting of HEDF whilst less attention has been paid to variation in individual acceptance. As such, practical and useful information about how HEDF can be promoted and marketed in practice has remained elusive. This thesis has proposed the simple but powerful explanatory idea that acceptance is linked to personal experience, and suggested that survey methods (i.e., whether a sample of HEDF was shown to participants and the nature of that sample) may have a larger share of responsibility for different patterns of acceptability than any innate cultural difference. In practice, it appears that there may be a simple and widely replicable method to encourage acceptability and uptake of HEDF: demonstration. The obstacle of cultural acceptability, despite being widely approached with trepidation, may not be so challenging to surmount after all.

In contrast, the subject of how solid waste and faecal sludge can be effectively disentangled for more appropriate management has received very limited attention in the academic literature, despite being an extremely important obstacle that practitioners must contend with daily (Elledge et al., 2018). This may be due in part to the topic falling into the disciplinary cracks between not only solid waste management and sanitation, but also between anthropology and engineering. As a result, in comparison to the challenge of HEDF socio-cultural acceptability, waste in pit latrines may prove a more complex and difficult challenge to solve with a smaller evidence base to support it. This highlights the importance of research being closely guided and led by practitioners so that effort can be focussed on what is most relevant to practical operational obstacles rather than abstract theoretical issues. Holistic interdisciplinary reviews provide a useful opportunity to assess which challenges have acquired a body of evidence pointing to solutions and which are yet to be solved.

Examination of the economics of FSM in this thesis has been limited to the willingness to pay study in Chapter 5, as the main research focus has related to socio-technical aspects of the sanitation chain. However, it is a vitally important topic with interconnections to all three research objectives. The entanglement of solid waste with faecal sludge has a substantial impact on the cost-effectiveness of FSM endeavours because sludge and waste mixtures are not only more difficult to extract from pit latrines, but also more costly to transport and harder to valorise into high quality products (Sisco et al., 2017; Tembo et al., 2019). Thus, there are important interconnections between waste separation and the financial sustainability of FSM - particularly when considering a circular economy approach, which must be considered in evaluations. Financial viability is critical to all public and private service endeavours, and important questions remain about whether FSM can aspire to be a self-financing operation or whether some degree of public subsidy is required (Mallory et al., 2020b). There are also choices to be made about whether value recovery efforts and HEDF promotion are approached as a ‘social good’ enterprise or a profitable business venture. For example, the former might have the objective of improving availability of organic fertilisers to resource-poor farmers at affordable prices but necessitate subsidies elsewhere to recover the costs of pit emptying and treatment. The latter might focus on providing a premium fertiliser product to higher paying customers, therefore not providing much improvement in food security to poor farmers but have the benefit of less input being required from public finances.

For this thesis, all fieldwork was conducted in the Southern Malawian city of Blantyre. Although Blantyre typifies many of the challenges and processes affecting rapidly urbanising African cities, the degree to which conclusions can be generalised from specific places to different contexts and regions is important to consider. It is widely recognised that solutions cannot be simplistically transplanted from one place to another, however, it is also important not to underestimate the cultural similarities that can exist across countries and regions. Contemporary national borders can obscure the pre-colonial boundaries of powerful dynasties and centuries of movement of ethnic groups. For instance, between the 16th and 19th century, most of the present-day country of Malawi formed part of the Maravi Kingdom, spanning from Zambia to the coastline of Mozambique, creating economic and cultural ties across the region (Newitt, 2016; Morris, 2006). Similarly, in the modern day, substantial economic migration of both men and women from southern and central Africa to the regional economic powerhouse of

South Africa creates interconnections and exchanges of ideas and ways of life (Magidimisha, 2018). In the case of menstrual waste management, one of the most important considerations - belief in and fear of witchcraft - has been documented elsewhere across the continent in southern Africa (South Africa), central Africa (Zambia), and west Africa (The Gambia) (Scorgie et al., 2016; Chinyama et al., 2019; Shah et al., 2019), which suggests that it is a widespread cultural phenomenon.

The city of Blantyre is rapidly expanding and densifying due to rural-to-urban migration and population growth, demonstrating a pattern typically seen in urban spaces across SSA and in other developing country contexts (Awumbila, 2017). Expansion of the municipal services required to sustain sanitary environments in urban conditions have not kept up with these developments, and vast informal settlements – usually characterised by informal land tenure, lack of basic services, and poverty – can be found across SSA as a result (Niva et al., 2019). Whilst these settlements may exhibit diversity in their physical characteristics, they nonetheless almost all require effective management of decentralised sanitation facilities. Pit latrines are ubiquitous, and despite cosmetic differences in superstructure design and technical variations in pit lining, they all have broadly similar requirements in terms of FSM in an urban setting. These commonalities suggest that FSM insights or solutions developed using case studies may well have wider applicability, although careful consideration of potentially important differences is required before implementing in new contexts.

The widespread presence of BSF across the African continent also implies that technology developed to utilise larvae in waste processing may be widely applicable, although heating may be necessary during colder months in some locations (Kaya et al., 2021; Spranghers et al., 2017). Preferably, flies and larvae should be locally sourced wherever possible, as they are more likely to have adaptations to cope with local climatic conditions. Foreign strains, particularly those which are widely found in commercial farms North America, Europe, and East Asia, should not be imported for use as this could threaten the genetic diversity of local wild populations (Kaya et al., 2021).

Achieving Sustainable Development Goal (SDG) 6, which aims to eliminate open defecation and ensure universal access to 'safely managed' sanitation by 2030, will be a substantial task (Mara and Evans, 2018). However, improvements in sanitation facilities can also cause a far-reaching cascade of positive effects that relate to other important development targets. As such, delivery of sustainable FSM services not only relates to SDG 6, but also to goals relating to improving food security and promoting sustainable agriculture (SDG2), health and well-being (SDG3), safety and sustainability of cities (SDG11), and conservation of ecosystems (SDG15) (United Nations, 2015). Improvements to menstrual waste management are not only vital to delivering efficient FSM systems, but to widening girls' access to education (SDG4) and gender equality (SDG5) (United Nations, 2015). These complex interconnections can present both opportunities and challenges in FSM due to their significance to a range of fields and stakeholders, and holistic analysis approaches are vital to understand and capitalise on them.

7.5 Limitations of thesis

Over 250 women in Blantyre city were recruited to take part in the menstrual waste material flow survey; this number of participants was required in order to have a sufficiently large sample so as to be representative of the city population at large. In order to achieve this within the limitations of time and resources, the survey relied on self-reported behaviour. Self-reporting can induce social desirability bias when it involves activities such as hand washing, where people might be widely aware of the need to perform a particular activity but in practice do it less often, and therefore report a slightly exaggerated account of their true behaviour (Chidziwisano et al., 2020). In the case of the menstrual flow data, it is likely that some pathways, such as discarding menstrual waste into the environment or into bins, were somewhat underreported as these are not viewed as 'respectable' methods of disposal, and some participants may have felt too embarrassed to admit to doing this. However, these flows are not anticipated to have been *significantly* underreported, as during the qualitative phase in Chapter 2 (during which the interviewer had time to develop a rapport with participants over multiple interviews and lessen the risk of social desirability bias), it became apparent that they were infrequently used due to the threat of witchcraft. Burning and throwing menstrual waste into pit latrines were widely societally acceptable methods of disposal, and therefore not likely to be underreported.

The self-reporting method also may have induced inaccuracies in that the women would be unlikely to accurately remember the exact proportions of different menstrual absorbents used, and the ways in which they were disposed. This challenge was mitigated to some extent by the skill of the field workers, who would carefully discuss the participant's practices with them in order to determine an estimate. Importantly, the menstrual waste flow volumes presented in Chapter 3 must be viewed as an indicative, rather than a precise, illustration of how menstrual waste moves in the city. Whilst it would be misleading to quote precise percentages of flows with certainty, particularly for the less widely used absorbents, it is nonetheless valid to conclude that *substantial volumes* of pads and cloth are either burned or thrown into pit latrines. Improvements to data accuracy could be made by triangulating self-reported behaviour with more rigorous methods such as use of diaries (whereby participants record what menstrual absorbents are used and how they are disposed during their periods), or by examining the contents of participants' pit latrines. Whilst use of diaries may allow participants the chance to volunteer further information that they would not be comfortable doing face-to-face (e.g., as shown by Maclean et al. (2020)), the identification of pit latrine contents may make some participants uncomfortable. Naturally, such data collection methods are more time-intensive to collect and analyse, and use of diaries in particular would exclude or be difficult for those who are not fully literate.

The discovery of how showing samples of composted, granulated HEDF to participants dramatically increased their acceptance of HEDF (discussed in Chapter 5) was essentially made by accident. During the piloting of the survey, participants were either shown or not shown a sample of HEDF in the form of dried excreta, which was acquired from a local treatment plant and used by local farmers on their fields (no significant difference in responses to the pilot survey were found between participants shown and not shown the dried sample). By the time of the main survey, however, the composted granulated sample had been acquired from a local business, and it was decided that this should be shown to participants instead as it provided a better representation of what commercialised HEDF would look like. Upon comparing the results of the pilot and main survey, it became immediately apparent that presentation of the composted granulated HEDF sample had significantly and dramatically influenced participants views on HEDF. Whilst the difference between the results of the two surveys lent substantial weight to this hypothesis, it would nonetheless have been preferable to repeat the survey in a controlled manner, randomly assigning participants to either be shown no sample, the dried sample, or the composted granulated sample.

Whilst WTP studies have been shown to consistently overvalue HEDF (Mallory et al., 2020a), the presentation of the composted, granulated sample to participants should raise confidence in the WTP values presented in Chapter 6. This is because farmers elsewhere have been shown to judge the value of fertiliser from its appearance (Michelson et al., 2021), and Chapter 5 clearly demonstrated the transformative impact that the composted, granulated sample had on confidence in HEDF. However, it nonetheless raises concern as to whether the particular values presented for pelletised HEDF can be considered accurate, given that participants were not actually shown a pelletised sample. It would also have been preferable to utilise a broader range of bids and more sophisticated survey methods, such as initial bid randomisation, as these have been shown to influence participant responses (Ndau and Tilley, 2018).

Further methodological limitations with the HEDF acceptability and WTP surveys lie in the recruitment procedure. Participants were recruited during the weekday hours at market sites across the city which were chosen to represent a diverse selection of neighbourhoods. This may have biased the sample to an extent by excluding those who are at their workplace during the day, or those who only shop at supermarkets. Attempts were made to mitigate this by extending the start and finishing hours of the data collection to capture people who may have been on their way to/from work, as the markets were located next to major intercity transport hubs, but nonetheless this strategy may have excluded certain kinds of workers. It does, however, represent an improvement over survey strategies that recruit participants exclusively at home during daytime hours, which would exclude those working or studying away from home during the day completely.

Finally, whilst the experiments in Chapter 4 demonstrated the disadvantages of co-processing faecal sludge and organic waste with regards to pathogen concentrations, they nonetheless did not conclusively determine whether providing BSFL with a more nutritious diet of organic waste affected their ability to influence faecal indicator organism concentrations in the material. To do so would have required raising the larvae on a diet of varying proportions of faecal sludge and vegetable waste, and then when the larvae had grown sufficiently, removing them and placing them in a uniform substrate inoculated with faecal indicator organisms and measuring the subsequent concentrations. This procedure would have removed the interfering effect that the differing moistures in the substrates had on bacterial survival and isolated the particular effect that larger and fitter BSFL might have had on subsequent pathogen reduction.

7.6 Recommendations for future research

High-density informal settlements in SSA are particularly critical in terms of the intersections of menstrual waste and FSM as they are the locations where pit latrines are most likely to contain menstrual waste and are also most likely to be in need of emptying; it would be beneficial to direct future research efforts on MHM towards this problem, which has been understudied to date. Participatory and action-based research methods could be used effectively to examine how other methods of discarding menstrual waste, such as through community-level incinerators or innovatively designed waste collection systems, could fit the needs of communities. For instance, involving women from affected communities in the diagnosis of their menstrual waste challenges, and in the design, testing, and evaluation of solutions, would facilitate ownership as well as ensuring that the interventions are appropriate and effective. If used sensitively, creative research techniques such as participatory theatre or art could also be an effective and interesting way of subverting the menstrual taboo by bringing conversations about menstruation into the public realm and encouraging buy-in and development of solutions at a community level. Partnering with existing grassroots networks dedicated to women's empowerment or menstrual health can increase reach and effectiveness whilst building trust with participants and incorporating practitioner experience. Close collaboration with pit emptying entrepreneurs to identify low-cost methods for handling excess trash in pit latrines and develop locally manufactured and robust pit emptying devices is another area where participatory research could be particularly effective.

Understanding the barriers to wider uptake of reusable pad use is another important area for future research; potential avenues include determining appropriate standards for reusable pads, willingness-to-pay studies to determine price points, and experimentation with different incentive schemes that might allow reusable pads to compete with disposable pads. A particularly innovative line of potential enquiry would be to consider how wider views of menstruation and waste in communities and societies, such as in traditional narratives of menstruation or rising concerns about environmental sustainability, can be understood and used effectively to promote better menstrual waste management and reusable solutions. However, this must not be approached evangelically, but rather within a broader appreciation of the importance of personal choice. Each woman's personal circumstances determine what is the most appropriate menstrual absorbent for her to use, within the constraints of socio-cultural norms and infrastructure, and it is therefore vital that a variety of menstrual products (both disposable and reusable) are locally available at suitable price points. At present, not enough women are offered the option of *choosing* high-quality reusable pads, and this is the challenge to be addressed.

There is an urgent need to design legislative and regulatory guidance to facilitate a safe marketplace for HEDF. It is particularly important to design treatment guidelines for faecal sludge reuse which are carefully considered and appropriate for the local setting. Use of quantitative microbial risk analysis (QMRA) to calculate appropriate treatment standards based on what faeco-oral pathogens are endemic to the area, how HEDF is applied to the soil by farmers, and what is grown in it, are pertinent contributions that researchers could make. Further research with farmers containing a strong participatory component, such as by providing volunteers with HEDF to use on their crops for free in return for providing data on their crop growth, practices, and user experience, could help to identify their particular needs for support in order to use HEDF safely and effectively. Future studies could also explore in greater detail what attributes of HEDF add the most value for farmers and identify where the highest value could be returned for HEDF businesses, whilst detailed insights into farmer's consumer behaviour (e.g., preferred purchase volumes, outlet locations, delivery options, and seasonality of requirements), could be usefully integrated into FSM business plans. Practical research into low-cost processing methods to treat, granulate, and pelletise HEDF would also be beneficial.

There is much that remains to be understood in the process of treating faecal sludge with BSFL. Commercial use of BSFL is extremely secretive, and it is therefore important for BSFL researchers to continue to make their results publicly available in order to broaden expansion of the technology. Understanding more about the mechanisms by which BSFL reduce pathogen concentrations in feed substrates, and whether this can be optimised and refined by environmental conditions and/or breeding programmes, would be beneficial. However, as part of this process, it will also be helpful to understand how bacteria survive and die in the faecal matrix under the pressures of other environmental changes, which is complex and remains poorly understood.

7.7 Concluding remarks

Ultimately, it is difficult for any particular intervention – whether technological (e.g., pit emptying strategies), infrastructural (e.g., solid waste management systems), or policy-based (e.g., subsidies for reusable pads) – to make a meaningful impact on faecal sludge management without a comprehensive understanding of the cultural norms, beliefs, and behaviours of beneficiaries. The siloed nature of sanitation and solid waste management in particular has led to interconnections between the fields being misunderstood and underappreciated, whilst assertions lacking evidence, such as 'faecophobia', have persisted for too long. This thesis has used an interdisciplinary approach to examine both socio-technical interactions and technological innovations, transcending traditional academic barriers between the study of waste management infrastructure and the people who use it, and found novel insights into the state of the faecal sludge management chain. Holistic examinations of sanitation systems, with particular regard to their socio-cultural context, continue to play an important role in supporting the implementation of safe and sustainable faecal sludge management.

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Appendices

Appendix 1: Supplementary information

Table S1: Final destinations of menstrual waste.

Disposal method	Anticipated destination of receptacle	Participants *n* (%)	
Pit latrine (*n* = 158)	Abandoned	67	42%
	Emptied by a gulper or machine and taken away	27	17%
	Emptied with a bucket and taken away	10	6%
	Emptied and buried nearby	38	24%
	Missing	16	10%
Bin (*n* = 7)	Removed by BCC	3	43%
	Burned	2	29%
	Thrown into the environment	2	29%
Pit (*n* = 5)	Left there	2	40%
	Burned	2	40%
	Missing	1	20%

Table S2: Omnibus Chi Square tests for associations between absorbent use / disposal method and demographic / infrastructural characteristics.

Characteristics		Using pads		Using cloth		Burning		Throwing in latrine	
		n (%)	Chi Square test	*n* (%)	Chi Square test	*n* (%)	Chi Square test	*n* (%)	Chi Square test
Recruitment location	Bangwe Blantyre Chigumula Chirimba Machinjiri Mbayani Ndirande	38 (62%) 7 (47%) 19 (63%) 17 (45%) 21 (64%) 29 (63%) 26 (74%)	$p = 0.211$ $\chi^2 = 8.4$	32 (53%) 8 (53%) 14 (47%) 26 (68%) 14 (42%) 21 (46%) 15 (43%)	$p = 0.293$ $\chi^2 = 7.3$	27 (44%) 8 (53%) 18 (60%) 12 (32%) 15 (46%) 21 (46%) 17 (49%)	$p = 0.418$ $\chi^2 = 6.0$	44 (72%) 6 (40%) 11 (37%) 32 (84%) 15 (46%) 30 (65%) 20 (57%)	*** $p < 0.001$ $\chi^2 = 26.0$
Recruitment location	At home Public space	74 (61%) 83 (61%)	$p = 1.000$ $\chi^2 = 0.0$	65 (54%) 65 (47%)	$p = 0.378$ $\chi^2 = 0.7$	50 (42%) 68 (50%)	$p = 0.260$ $\chi^2 = 1.3$	79 (50%) 79 (50%)	$p = 0.260$ $\chi^2 = 1.6$
Waste collection by BCC	Never < 2 x month > 2 x month	79 (60%) 28 (56%) 34 (69%)	$p = 0.368$ $\chi^2 = 2.0$	66 (50%) 27 (54%) 22 (45%)	$p = 0.658$ $\chi^2 = 0.8$	60 (46%) 20 (40%) 26 (53%)	$p = 0.425$ $\chi^2 = 1.7$	75 (57%) 36 (72%) 28 (57%)	$p = 0.167$ $\chi^2 = 3.6$
Household toilet	Pit latrine	134 (60%)	$p = 0.406$ $\chi^2 = 0.7$	122 (54%)	* $p = 0.015$ $\chi^2 = 5.9$	97 (43%)	* $p = 0.024$ $\chi^2 = 5.1$	149 (97%)	*** $p < 0.001$ $\chi^2 = 16.2$
	Flush	42 (75%)	* $p = 0.017$ $\chi^2 = 5.7$	16 (29%)	*** $p < 0.001$ $\chi^2 = 14.5$	31 (55%)	$p = 0.119$ $\chi^2 = 2.4$	30 (54%)	$p = 0.166$ $\chi^2 = 1.9$
Age	18-29 30-39 40-49 50-59 60+	102 (71%) 36 (51%) 14 (54%) 5 (39%) 0 (0%) [a]	** $p = 0.001$ $\chi^2 = 18.2$	60 (42%) 38 (54%) 17 (65%) 10 (77%) [a] 4 (100%) [a]	** $p = 0.005$ $\chi^2 = 14.7$	53 (37%) 34 (49%) 21 (81%) 8 (62%) 1 (25%) [a]	** $p = 0.001$ $\chi^2 = 19.7$	102 (71%) 36 (51%) 8 (32%) 9 (69%) [a] 3 (75%) [a]	** $p = 0.001$ $\chi^2 = 19.3$

Highest educational level attained	None Primary Secondary Technical college University	1 (20%) [a] 13 (27%) 82 (66%) 29 (71%) 31 (84%)	*** $p < 0.001$ $\chi^2 = 37.9$	5 (100%) [a] 41 (85%) 64 (52%) 13 (32%) 4 (11%) [a]	*** $p < 0.001$ $\chi^2 = 57.4$	4 (80%) [a] 20 (42%) 50 (40%) 24 (59%) 18 (49%)	$p = 0.137$ $\chi^2 = 7.0$	1 (20%) [a] 35 (73%) 79 (64%) 19 (46%) 22 (60%)	* $p = 0.032$ $\chi^2 = 10.5$
Main source of personal income	Piecework Business or farming Employment Husband Family / friends	8 (32%) 54 (59%) 50 (69%) 12 (48%) 33 (77%)	** $p = 0.002$ $\chi^2 = 17.0$	19 (76%) 49 (53%) 25 (34%) 18 (72%) 19 (44%)	** $p = 0.001$ $\chi^2 = 19.8$	9 (36%) 43 (47%) 36 (49%) 10 (40%) 20 (47%)	$p = 0.789$ $\chi^2 = 1.7$	18 (72%) 55 (60%) 42 (58%) 18 (72%) 25 (58%)	$p = 0.538$ $\chi^2 = 3.1$
Marital status	Never married Married Previously married	67 (78%) 73 (59%) 16 (35%)	*** $p < 0.001$ $\chi^2 = 23.8$	26 (30%) 68 (55%) 35 (76%)	*** $p < 0.001$ $\chi^2 = 27.1$	33 (38%) 53 (43%) 30 (65%)	** $p = 0.009$ $\chi^2 = 9.4$	82 (66%) 57 (66%) 19 (41%)	** $p = 0.007$ $\chi^2 = 9.9$
Household asset ownership	No assets Mobile TV Motorbike Car or truck	1 (11%) [a] 24 (44%) 83 (68%) 9 (69%) [a] 39 (74%)	*** $p < 0.001$ $\chi^2 = 22.6$	7 (78%) [a] 40 (73%) 60 (49%) 6 (46%) [a] 14 (26%)	*** $p < 0.001$ $\chi^2 = 26.1$	5 (56%) [a] 28 (51%) 57 (46%) 3 (23%) [a] 22 (42%)	$p = 0.402$ $\chi^2 = 4.0$	4 (44%) [a] 27 (49%) 82 (67%) 9 (69%) [a] 33 (62%)	$p = 0.172$ $\chi^2 = 6.4$

Notes
Significant differences within groups detected by Chi Square test (with Yates' Correction for Continuity for 2 x 2 tables).
* $p < 0.05$ ** $p < 0.01$ *** $p < 0.005$
[a] There were not enough observations to determine whether the difference was significant.

Table S3: Post hoc testing for absorbent use and demographic / infrastructural characteristics.

Characteristics		Using pads			Using cloth		
		n (%)	Post hoc Chi Square test	Bonferroni corrected α	*n* (%)	Post hoc Chi Square test	Bonferroni corrected α
Age	18-29 30-39 40-49 50-59 60+	102 (71%) ** 36 (51%) 14 (54%) 5 (39%) 0 (0%) [a]	$p < 0.001$, $\chi^2 = 13.1$ $p = 0.052$, $\chi^2 = 3.8$ $p = 0.424$, $\chi^2 = 0.6$ $p = 0.085$, $\chi^2 = 3.0$ $p = 0.011$, $\chi^2 = 6.4$	0.05 → 0.005	60 (42%) * 38 (54%) 17 (65%) 10 (77%) [a] 4 (100%) [a]	$p = 0.002$, $\chi^2 = 10.0$ $p = 0.423$, $\chi^2 = 0.6$ $p = 0.103$, $\chi^2 = 2.7$ $p = 0.048$, $\chi^2 = 3.9$ $p = 0.044$, $\chi^2 = 4.0$	0.05 → 0.005
Highest educational level attained	None Primary Secondary Technical college University	1 (20%) [a] 13 (27%) *** 82 (66%) 29 (71%) 31 (84%) *	$p = 0.056$, $\chi^2 = 3.7$ $p < 0.0001$, $\chi^2 = 28.9$ $p = 0.114$, $\chi^2 = 2.5$ $p = 0.171$, $\chi^2 = 1.9$ $p = 0.002$, $\chi^2 = 9.3$	0.05 → 0.005 0.01 → 0.001 0.001 → 0.0001	5 (100%) [a] 41 (85%) *** 64 (52%) 13 (32%) 4 (11%) [a] ***	$p = 0.023$, $\chi^2 = 5.2$ $p < 0.0001$, $\chi^2 = 30.0$ $p = 0.575$, $\chi^2 = 0.3$ $p = 0.001$, $\chi^2 = 26.3$	0.05 → 0.005 0.01 → 0.001 0.001 → 0.0001
Main source of personal income	Piecework Business or farming Employment Husband Family / friends	8 (32%) * 54 (59%) 50 (69%) 12 (48%) 33 (77%)	$p = 0.002$, $\chi^2 = 9.7$ $p = 0.596$, $\chi^2 = 0.3$ $p = 0.114$, $\chi^2 = 2.5$ $p = 0.165$, $\chi^2 = 1.9$ $p = 0.019$, $\chi^2 = 5.5$	0.05 → 0.005	19 (76%) 49 (53%) 25 (34%) * 18 (72%) 19 (44%)	$p = 0.007$, $\chi^2 = 7.29$ $p = 0.490$, $\chi^2 = 0.5$ $p = 0.001$, $\chi^2 = 10.6$ $p = 0.023$, $\chi^2 = 5.2$ $p = 0.373$, $\chi^2 = 0.8$	0.05 → 0.005
Marital status	Never married Married Previously married	67 (78%) *** 73 (59%) 16 (35%) ***	$p < 0.0001$, $\chi^2 = 15.7$ $p = 0.509$, $\chi^2 = 0.4$ $p < 0.0001$, $\chi^2 = 16.1$	0.05 → 0.008 0.01 → 0.002 0.001 → 0.0002	26 (30%) *** 68 (55%) 35 (76%) ***	$p < 0.0001$, $\chi^2 = 21.1$ $p = 0.168$, $\chi^2 = 1.9$ $p = 0.0001$, $\chi^2 = 14.82$	0.05 → 0.008 0.01 → 0.002 0.001 → 0.0002
Household asset ownership	No assets Mobile TV Motorbike	1 (11%) [a] * 24 (44%) * 83 (68%) 9 (69%) [a]	$p = 0.001$, $\chi^2 = 10.1$ $p = 0.002$, $\chi^2 = 9.7$ $p = 0.064$, $\chi^2 = 3.4$ $p = 0.562$, $\chi^2 = 0.3$	0.05 → 0.005	7 (78%) [a] 40 (73%) ** 60 (49%) 6 (46%) [a]	$p = 0.091$, $\chi^2 = 2.9$ $p < 0.001$, $\chi^2 = 14.3$ $p = 0.660$, $\chi^2 = 0.2$ $p = 0.764$, $\chi^2 = 0.1$	0.05 → 0.005 0.01 → 0.001

	Car or truck	39 (74%)	$p = 0.044$, $\chi^2 = 4.0$		14 (26%) **	$p < 0.001$, $\chi^2 = 15.1$	

Notes
* $p < 0.05$ ** $p < 0.01$ *** $p < 0.005$ where α has been adjusted by the Bonferroni correction
[a] There were not enough observations to determine whether the difference was significant.

Table S4: Post hoc testing for disposal method and demographic / infrastructural characteristics.

Characteristics		Burning			Throwing in latrine		
		n (%)	Post hoc Chi Square test	Bonferroni corrected α	*n* (%)	Post hoc Chi Square test	Bonferroni corrected α
Recruitment location	Bangwe	NA	NA	NA	44 (72%)	$p = 0.046$, $\chi^2 = 4.00$	0.05 → 0.004
	Blantyre				6 (40%)	$p = 0.082$, $\chi^2 = 3.03$	
	Chigumula				11 (37%) *	$p = 0.003$, $\chi^2 = 8.64$	
	Chirimba				32 (84%) *	$p = 0.002$, $\chi^2 = 9.92$	
	Machinjiri				15 (46%)	$p = 0.047$, $\chi^2 = 3.96$	
	Mbayani				30 (65%)	$p = 0.542$, $\chi^2 = 0.37$	
	Ndirande				20 (57%)	$p = 0.589$, $\chi^2 = 0.29$	
Age	18-29	53 (37%) *	$p = 0.002$, $\chi^2 = 10.1$	0.05 → 0.005	102 (71%) **	$p < 0.001$, $\chi^2 = 12.11$	0.05 → 0.005
	30-39	34 (49%)	$p = 0.549$, $\chi^2 = 0.4$	0.01 → 0.001	36 (51%)	$p = 0.042$, $\chi^2 = 4.12$	0.01 → 0.001
	40-49	21 (81%) **	$p = 0.001$, $\chi^2 = 14.5$		8 (32%) **	$p < 0.001$, $\chi^2 = 11.49$	
	50-59	8 (62%)	$p = 0.234$, $\chi^2 = 1.4$		9 (69%) [a]	$p = 0.555$, $\chi^2 = 0.4$	
	60+	1 (25%) [a]	$p = 0.407$, $\chi^2 = 0.7$		3 (75%) [a]	$p = 0.575$, $\chi^2 = 0.3$	
Highest educational level attained	None	NA	NA	NA	1 (20%) [a]	$p = 0.056$, $\chi^2 = 3.7$	0.05 → 0.005
	Primary				35 (73%)	$p = 0.064$, $\chi^2 = 3.4$	
	Secondary				79 (64%)	$p = 0.417$, $\chi^2 = 0.7$	
	Technical college				19 (46%)	$p = 0.033$, $\chi^2 = 4.5$	
	University				22 (60%)	$p = 0.818$, $\chi^2 = 0.1$	
Marital status	Never married	33 (38%)	$p = 0.112$, $\chi^2 = 2.5$	0.05 → 0.008	82 (66%)	$p = 0.285$, $\chi^2 = 1.1$	0.05 → 0.008
	Married	53 (43%)	$p = 0.424$, $\chi^2 = 0.6$		57 (66%)	$p = 0.159$, $\chi^2 = 2.0$	0.01 → 0.002
	Previously married	30 (65%) *	$p = 0.003$, $\chi^2 = 8.9$		19 (41%) **	$p = 0.002$, $\chi^2 = 9.9$	

Notes
NA Not applicable because omnibus Chi square test did not detect significant differences between groups.
* $p < 0.05$ ** $p < 0.01$ *** $p < 0.005$ where α has been adjusted by the Bonferroni correction
[a] There were not enough observations to determine whether the difference was significant.

Table S5: Logistic regression models for pad and cloth use with five variables.

Variable	B	S.E.	Wald	df	*p*	Odds ratio	95.0% C.I. for odds ratio	
							Lower	Upper
Logistic regression model: Pad use, five variables								
Age	- 0.036	0.018	3.794	1	0.051	0.965	0.931	1.000
Highest education:								
None/primary			14.534	3	0.002			
Secondary	1.092	0.430	6.436	1	0.011	2.980	1.282	6.926
Tech college	1.532	0.557	7.579	1	0.006	4.629	1.555	13.783
University	2.529	0.705	12.858	1	< 0.001	12.536	3.147	49.934
Main income source:								
Piecework			7.571	4	0.109			
Business/farm	1.073	0.606	3.139	1	0.076	2.925	0.892	9.591
Employment	0.823	0.631	1.703	1	0.192	2.278	0.662	7.841
Husband	0.655	0.718	0.833	1	0.362	1.925	0.472	7.857
Family/friends	1.760	0.673	6.845	1	0.009	5.811	1.555	21.714
Marital status:								
Married			5.139	2	0.077			
Never married	0.329	0.456	0.522	1	0.470	1.390	0.569	3.397
Previously married	- 0.820	0.423	3.753	1	0.053	0.440	0.192	1.010
Wealth category: [a]								
Low			1.154	2	0.562			
Middle	0.394	0.389	1.028	1	0.311	1.483	0.692	3.177
High	0.128	0.529	0.059	1	0.808	1.137	0.403	3.207
Constant	- 0.644	0.848	0.577	1	0.447	0.525		
Logistic regression model: Cloth use, five variables								
Age	0.061	0.023	6.812	1	0.009	1.063	1.015	1.112
Highest education:								
None/primary			23.103	3	< 0.001			
Secondary	- 1.126	0.501	5.041	1	0.025	0.324	0.121	0.867

Tech college	- 2.169	0.612	12.557	1	< 0.001	0.114	0.034	0.379
University	- 3.514	0.808	18.890	1	< 0.001	0.030	0.006	0.145
Main income source:								
Piecework			3.801	4	0.434			
Business/farm	- 1.098	0.680	2.607	1	0.106	0.334	0.088	1.265
Employment	- 0.991	0.700	2.009	1	0.156	0.371	0.094	1.462
Husband	- 0.369	0.826	0.190	1	0.663	0.697	0.138	3.518
Family/friends	- 0.789	0.692	1.268	1	0.260	0.459	0.118	1.782
Marital status:								
Married			6.453	2	0.040			
Never married	- 0.564	0.488	1.339	1	0.247	0.569	0.219	1.479
Previously married	0.953	0.488	3.820	1	0.051	2.593	0.997	6.744
Wealth category: [a]								
Low			2.387	2	0.303			
Middle	- 0.235	0.417	0.318	1	0.573	0.791	0.349	1.789
High	- 0.833	0.554	2.260	1	0.133	0.435	0.147	1.288
Constant	0.732	1.007	0.528	1	0.467	2.080		

Notes:
The ‘Household asset ownership’ index was reclassified into three ‘wealth’ categories in order to generate three groups each containing more than 50 participants. The ‘low wealth’ category contains participants whose households either owned none of the ‘household assets’ or a mobile. The ‘middle wealth’ category contains participants whose households owned a TV. The ‘high wealth’ category contains participants whose household owned a car or truck.

Appendix 2: Survey documentation for menstrual waste flow data

A1	Have you reached menopause?	1	Yes
		0	No
No → A3			
A2	Did you reach menopause in the last two years?	1	Yes
		0	No
A3a	Which of these materials did you use during your last period? (tick all that apply)		Cloth
A3b			Disposable sanitary pads
A3c			Homemade sanitary pads (cotton)
A3d			Tampons
A3e			Reusable sanitary pads
If more than one material is selected → A4 **If only disposable sanitary pads is selected → A5** **If only cloth is selected → A6**			
A4a	During your last period, please indicate what percentage of time was spent using different materials (e.g. 50% cloth, 50% disposable sanitary pads).	%	Cloth
A4b		%	Disposable sanitary pads
A4c		%	Homemade disposable sanitary pads ("cotton")
A4d		%	Tampons
A4e		%	Reusable sanitary pads
Go to B1			
A5	How many pads do you use in a typical period?		
Go to B1			
A6	Last year, how many menstrual cloths did you discard?		

B1a	For **disposable pad users**, please indicate where these were disposed of during your last period. If a mixture of methods were used please indicate the % of waste that ends up at each destination (e.g. 50% pads burned, 50% pads thrown in pit latrine).	%	Buried
B1b		%	Burned
B1c		%	Thrown in pit latrine
B1d		%	Thrown in rubbish bin
B1e		%	Thrown into environment
B1f		%	Other (describe)

B2a	For **cloth and reusable pad users**, please indicate where these are generally disposed of when they are worn out and no longer functional. If a mixture of methods are used please indicate the % of waste that ends up at each destination (e.g. 50% cloth burned, 50% cloth thrown in pit latrine).	%	Kept for other uses
B2b		%	Buried
B2c		%	Burned
B2d		%	Thrown in pit latrine
B2e		%	Thrown in rubbish bin
B2f		%	Thrown into environment
B2g		%	Other (describe
B3a	For **tampon users**, please indicate where these were disposed of during your last period. If a mixture of methods were used please indicate the % of waste that ends up at each destination (e.g. 50% tampons burned, 50% tampons thrown in pit latrine).	%	Buried
B3b		%	Burned
B3c		%	Thrown in pit latrine
B3d		%	Thrown in rubbish bin
B3e		%	Thrown into environment
B3f		%	Other (describe)
B4	If any waste is disposed of in a pit latrine, what will happen to this pit latrine when it fills up?	1	The toilet is abandoned when its full
		2	The toilet is emptied by a gulper or a machine and taken away
		3	Toilet is emptied with a bucket and taken away
		4	Toilet is emptied and buried nearby
		5	Other (describe)
		6	I don't know
B5	If any waste is disposed of in a rubbish bin, what happens to this rubbish bin next?	1	Emptied regularly by local council
		2	Emptied regularly by other organisation
		3	Burned by household
		4	Dumped by household
		5	Don't know
		6	Other (describe)

C1	How old are you?		
C2		1	Yes

	Think back to 10 years ago, when you were ……….. years old. Were you menstruating then?	0	No
No → A10			
C3a	At that time, which of these materials did you mainly use? (tick all that apply)		Cloth
C3b			Disposable sanitary pads
C3c			Homemade sanitary pads (cotton)
C3d			Tampons
C3e			Reusable sanitary pads

D1	What is the name of the ward where you live?		
D2	What is the highest education level you have completed?	1	None
		2	Primary
		3	Secondary
		4	Vocational / technical
		5	University
D3	Do you have a personal source of income?	1	Yes
		0	No
D4	What is your main personal source of income?	1	Informal sector activities
		2	Employment in formal sector
		3	Remittance from family or friends
		4	Other (describe)
D5	Are you married?	1	Yes
		2	No, never married
		3	Formerly married
D6a	Does anyone in the **household** own any of the following? (tick all that apply)		Mobile telephone
D6b			Television
D6c			Car or truck

Appendix 3: Survey documentation for HEDF acceptability and WTP data

A1	Have you ever heard about human manure before?	1	Yes
		0	No
NO → A8			
A2a	Where did you hear about this? (tick all that apply)		Family
A2b			Friends
A2c			Neighbours
A2d			Radio
A2e			Chief
A2f			Agricultural extension workers
A2g			School / university
A2h			Farmers
A2i			WWTW workers
A2j			Other people (non-specific)
A2k			Other (describe)
A3a	What sources of human manure have you heard about? (tick all that apply)		Excavating pit latrine
A3b			UDDT
A3c			Sludge from WWTW
A3d			Don't know
A3e			Other (describe)
A4	Do you know any person who uses human manure on their farm or garden?	1	Yes
		0	No
A5	Have you ever used any kind of human manure on any garden or farm yourself?	1	Yes
		0	No
NO → A8			
A6a	What sources of human manure have you used? (Tick all that apply)		Excavating pit latrine
A6b			UDDT
A6c			Sludge from WWTW
A6d			Other (describe)
A7a	If you no longer use human manure on your garden or farm, what is the reason for this? (Tick all that apply)	1	Don't like using it
A7b		2	Crops don't grow well
A7c		3	Can't find it
A7d		4	Can't afford it
A7e		5	Other (describe)
A8	How would you feel if somebody got on a bus with you carrying a bag of human manure like this?		0. Don't know 1. Would be very bothered 2. Would be bothered a bit 3. Would not be bothered at all
A9	How would you feel if your neighbours used human manure like this?		

A10	How do you think other people would feel if you got on a bus carrying a bag of human manure like this?			0. Don't know 1. Would be very bothered 2. Would be bothered a bit 3. Would not be bothered at all
A11	How do you think your neighbour would feel if you used human manure like this?			
A12	Can you describe a person who uses human manure like this in 1 word in your own personal opinion?			
A13	Would you buy these crops from the market if you knew that they had been grown in human manure like this?	Maize	1	Yes
			0	No
A14		Pumpkins	1	Yes
			0	No
A15		Tomatoes	1	Yes
			0	No
A16		Leafy greens	1	Yes
			0	No
A17		Beans and pigeon peas	1	Yes
			0	No
A18		Potatoes	1	Yes
			0	No
A19	Is it possible that your household might grow food of any kind in next 5 years?		1	Yes
			2	Maybe
			3	No
NO → E1				

B1	Would you be willing to use human manure like this on your farm or garden, if it was cheaper than chemical fertiliser?	1	Yes
		2	Maybe
		3	No
YES → B4			
B2	Would you be willing to use human manure like this on your farm or garden, if it was certified by the Malawi Bureau of Standards as organic compost?	1	Yes
		2	Maybe
		3	No
YES → B4			
B3a	What are the reasons why you might be concerned about using human manure like this, even if it was cheaper than chemical fertiliser and certified by Malawi Board of Standards? (Tick all that apply)		Worried about health risk
B3b			Feeling disgusted
B3c			People will say I am poor
B3d			People will say I am going to use it for ritual
B3e			People would say other bad things about me
B3f			Couldn't sell crops grown with it

B3g	IF 'NO' TO B2, GO TO C1			It would be hard to transport
B3h				Other (describe)
B4a	What are the reasons why you might want to use human manure like this, if it was cheaper than chemical fertiliser? (Tick all that apply)			Good for bumper harvest
B4b				Good for soil fertility
B4c				Cheaper than chemical fertiliser
B4d				To see how it performs
B4e				Other (describe)
B5	Would you use human manure like this on these crops to grow and eat them?	Maize	1	Yes
			0	No
B6		Pumpkins	1	Yes
			0	No
B7		Tomatoes	1	Yes
			0	No
B8		Leafy greens	1	Yes
			0	No
B9		Beans and pigeon peas	1	Yes
			0	No
B10		Potatoes	1	Yes
			0	No
B11	Would you pay 6,000 kwacha for a 50kg bag of human manure like this from this market?		1	Yes
			0	No
YES → B13				
B12	Would you pay 3,000 kwacha for a 50kg bag of human manure like this from this market?		1	Yes
			0	No
YES OR NO → B14				
B13	Would you pay 12,000 kwacha for a 50kg bag of human manure like this from this market?		1	Yes
			0	No
B14	Would you pay more for the 50kg bag if it was certified by the Malawi Bureau of Standards as organic compost?		1	Yes
			0	No
NO → B16				
B15	What is the highest price you would pay?			
B16	Would you pay more for the 50kg bag if it was made into pellets?		1	Yes
			0	No
NO → C1				
B17	What is the highest price you would pay?			

C1	Did your household grow food of any kind this last rainy season?	1	Yes
		0	No

YES → D1			
C2	Did your household grow food of any kind in the last 4 rainy seasons?	1	Yes
		0	No
NO → E1			

D1	Thinking of the last time you grew food, what was the farm / garden size?		m x m
			Hectares
D2	Did you or your family own the land that you grew food on?	1	Yes
		2	No
		3	Own part, rent part
D3a	How far was the land from where you live? (tick all that apply, if there are multiple farms/gardens)		At or near the household plot
D3b			Less than 1 day journey
D3c			1 day journey or more
D4	How much maize did the household harvest last time? (In 50kg bags)		
D5	Did the household sell any of the food that was last grown?	0	Yes
		1	No
NO → D8			
D6	How much did you sell?	1	Sell less than half
		2	Sell about half
		3	Sell more than half
		4	Sell all / almost all
D7a	How many 50kg bags of these fertilisers were used the last time you grew food?		Chemical fertilizer
D7b			Plant manure
D7c			Animal manure
D7d			Human manure
D7e			No fertiliser used
D8a	Does the household own livestock? How many?		Chickens
D8b			Sheep or goats
D8c			Cows
D8d			Other (describe)

E1	Gender of respondent	1	Female
		0	Male
E2	What is your age?		
E3	What district do you live in?	1	Blantyre City
		2	Blantyre Rural
		3	Thyolo District
		4	Chiradzulu District

		5	Elsewhere
E4	What is the name of the ward where you live? (or village)		
E5	What is your relationship to the household head?	1	Respondent is household head
		2	Wife
		3	Child
	Respondent is the …. of the household head.	4	Sibling
		5	Parent
		6	Extended family member
		7	Friend
		8	Other
E6	What is the highest education level you have completed?	1	None
		2	Primary
		3	Secondary
		4	Vocational / technical
		5	University
E7	What is your ethnic group?	1	Chewa
		2	Lomwe
		3	Yao
		4	Ngoni
		5	Tumbuka
		6	Nyanja
		7	Sena
		8	Tonga
		9	Ngonde
		10	Other (state)
E8	What is your religion?	1	Christian
		2	Muslim
		3	Hindu
		4	Other
E9a	Does anyone in the **household** own any of the following? (tick all that apply)		Mobile telephone
E9b			Television
E9c			Car or truck
E10	Have you ever received a fertiliser subsidy coupon?	1	Yes
		0	No
	NO → GO TO E13		
E11	When did you last receive a fertiliser subsidy coupon?		Rainy seasons ago
E12	How many bags of chemical fertiliser did you get with your last fertiliser subsidy coupon?		50kg bags
E13	Would you like to find about more about where to purchase human manure?	1	Yes
		0	No