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Shit also flows uphill:
Exploring neglected non-hydraulic
flows of faecal pathogens

By

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Declaration of Authorship

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Abstract

- Motivation** Exposure to faecal pathogens is a driver of preventable disease worldwide, with an estimated 3.4 billion people still lacking access to safely managed sanitation (UNICEF, 2025). The sanitation chain protects public health only when it achieves the full separation of faeces from human contact. Failures in Containment, Transport and Treatment release pathogens into the environment, from where they travel along multiple routes to human exposure (Peal *et al.*, 2014).
- Purpose** In the face of such failures, interventions planned without a robust source-pathway-exposure framework risk becoming fragmented and misdirected, with resources channelled into meeting indicators rather than achieving meaningful public health benefits.
- Approach and Methods** The approach was mixed methods and exploratory, combining literature review, fieldwork and modelling. Evidence for source-pathway-exposure linkages for faecal pathogens in the urban context was synthesised. The F-diagram was critically assessed for its usefulness in representing these complex flows, and a new model was proposed: the novel Amplified F-diagram. This diagram was then applied using data collection in Delhi: 180 microbial samples tested for faecal coliforms, 259 household survey participants, over 2000 behaviour observations, six focus group discussions and twelve key informant interviews. The Amplified F-diagram was used to consider how different intervention focus areas would influence public health outcomes.
- Findings** Faecal pathogens are highly mobile across urban environments, creating exposures for communities remote from their source. This underscores the need for systemic city-wide approaches to sanitation interventions. Both empirical and modelled data demonstrate that preventing failures in the Transport stage of the sanitation chain is the most critical for protecting public health. In Delhi, faecal pathogens on the Fresh Produce were traced primarily to herbs grown on urban farms, while Solid Waste had more localised contamination pathways. These non-hydraulic pathways are neglected in both research and in intervention design.
- Contribution and Implications** By conceptualising and analysing source-pathway-exposure linkages, this research expands the traditional F-diagram into a model that more accurately represents urban realities. The Amplified F-diagram provides decision-makers with clearer evidence on which interventions are most likely to disrupt transmission and reduce disease risk. The contribution is therefore both conceptual and empirical: developing a new framework for thinking about urban faecal flows and applying it to case study data from Delhi.

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Abbreviations

Abbreviation	Definition
CFU	Colony Forming Units
FC	Faecal Coliforms
FGD	Focus Group Discussion
FS	Faecal Sludge
FSM	Faecal Sludge Management
JJBs	Jhuggi-Jhompri Basti - the municipality designation of a registered slum community
LMIC	Low- and Middle-Income Countries
QMRA	Quantitative Microbial Risk Assessment
SFD	Shit Flow Diagram
SW	Solid Waste
WASH	Water, Sanitation and Hygiene
WHO	World Health Organization
WW	Wastewater

1 Chapter 1 - Introduction

Exposure to faecal pathogens is a major contributor to preventable disease. An estimated 3.4 billion people remain without access to safely managed sanitation (UNICEF, 2025) leaving large populations at risk of contact with faecal contamination. The sanitation chain protects health only when it fully separates faeces from people, yet failures in containment, transport and treatment routinely allow pathogens to circulate through the environment (Peal *et al.*, 2014). The consequence of this is severe: faecal matter from billions of people enters the environment untreated, contaminating water, soil, food and public spaces. This leads to enteric diseases such as diarrhoea, with consequences that include stunted growth and child mortality (Null *et al.*, 2019). These poor outcomes persist despite decades of investment in water, sanitation and hygiene (WASH). The limited success of household-level interventions in highly contaminated environments (Briscoe, 1984; Ercumen *et al.*, 2018) underscores both the scale and the persistence of the problem.

For decades, observational data had shown a strong association between poor household WASH conditions, enteric infections and childhood stunting. This drew the obvious conclusion that improving WASH at the household level would deliver health improvements. The WASH Benefits and SHINE trials (Null *et al.*, 2019) set out to test that assumption through large interventions in combination with high-contact behaviour change support. The WASH interventions were not associated with any improvement in child stunting rates or community faecal contamination. These findings suggest that localised household interventions cannot overcome the pervasive mobility of faecal matter in highly contaminated urban environments. As a result, it was recommended that further research be done to identify system-level approaches that would radically reduce faecal contamination across the domestic and community environment.

The F-diagram (Wagner and Lanoix, 1958) illustrates the source-pathway-exposure linkages by showing how uncontained faeces contaminate fluids, fields, food, flies and fingers. It was originally titled “Channels of Transmission of Disease from Excreta” and was in a guide for rural sanitation practitioners published by the World Health Organization (WHO) (Figure 1). A version using words beginning with ‘F’ was in common use in WHO documents from the 1980s onwards.

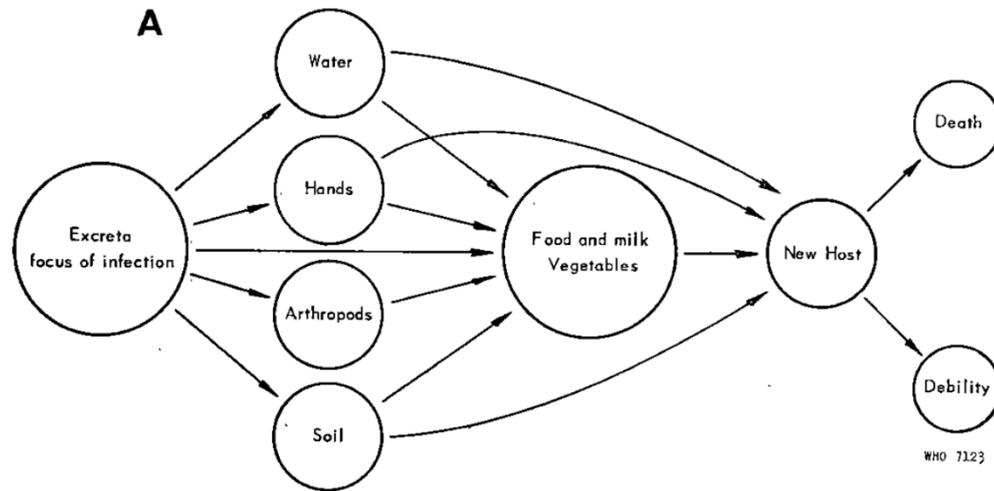


Figure 1 - The original F-diagram showing transmission pathways of excreta-related diseases, titled "Channels of Transmission of Disease from Excreta" in Wagner and Lanoix, 1958.

While influential, this model was originally framed for rural contexts and cannot fully capture the multiplicity of contamination routes in dense urban settings where pathogens are introduced simultaneously from many sources, travel through overlapping pathways, and circulate in systems that defy simple downstream logic.

The challenge for public health is compounded by uncertainty over which sources and pathways are most significant in any given context. Reviews highlight that interventions often reduce non-dominant routes, while leaving others untouched, thereby delivering little measurable health benefit (Shuval *et al.*, 1984; Robb *et al.*, 2017; Mills *et al.*, 2018). This mismatch has led some to question the value of sanitation investments (Cairncross *et al.*, 2010). However, the issue is not whether sanitation matters, but rather that interventions lack precision. In settings with profuse faecal contamination (Ercumen *et al.*, 2017), health gains are unlikely unless dominant transmission pathways are targeted and exposure doses are reduced below infective thresholds (Briscoe, 1984).

The complexity of transmission becomes particularly evident in cities. Urban environments are unbounded systems in which every community is both upstream and downstream, and many places and objects (what might be considered "nodes" in a network) act as both sources, exposures and sinks simultaneously. Faecal contamination may originate locally, for example, from leaking septic tanks or overflowing drains, but may also travel from distant sites via water distribution, food supply chains, Solid Waste, or vectors (Drechsel, 2010a; Ali, 2010). Pathways can be conceptualised as either hydraulic, following gravity through drains and surface water, or non-hydraulic, carried by Solid Waste, fomites and Fresh Produce (fruit

and vegetables eaten raw). Both types operate simultaneously, entangling communities in what can be described as a “faecal catchment” that stretches across entire cities.

Attempts to quantify and manage these risks have generated a range of conceptual and practical tools. Shit Flow Diagrams (SFDs) map the fate of domestic faecal flows (including raw faeces, wastewater, faecal sludge and effluent from sanitation systems) within a city and reveal where sanitation systems fail, but they do not trace subsequent transmission pathways (Peal *et al.*, 2014). SaniPath identifies dominant exposure points for populations, yet lacks information on sources or city-scale flows (Amin *et al.*, 2020). Sanitation Safety Planning (SSP) provides a structured risk assessment framework but relies heavily on qualitative assumptions and expert judgement (Frattarola *et al.*, 2019; Clavijo *et al.*, 2020). Quantitative Microbial Risk Assessment (QMRA) offers detailed dose–response analysis, but the need for extensive data collection and technical analysis often makes it impractical for decision-makers (Mara *et al.*, 2007). Collectively, these tools illuminate parts of the picture but leave major gaps in linking sources, pathways and exposures across scales.

It is important to have an approach that strikes a balance between oversimplification and unnecessary specificity. Enough data needs to be collected to accurately identify risks and priorities, and not rely on excessive assumptions or normalised decisions. Research methods are needed that facilitate progression of intervention norms outside of the legacy practices. This disconnection between system realities and measurement frameworks is visible in the evolution of global sanitation targets.

In 2015, the United Nations agreed on the Sustainable Development Goals (SDG) to be achieved by 2030 (Nations, 2015). This agenda was built on the earlier Millennium Development Goals (United Nations, 2019), for which the goals were to increase household access to improved sanitation (Containment), but with no indicators for Transport and Treatment. The SDGs partially acknowledge this lack by updating the indicator to measure access to safely managed sanitation services. Safely managed *should* mean that the whole sanitation chain is considered; the question of how to look at a toilet and know if it is safely managed (including Transportation and Treatment), or not, has not been fully resolved, and there has been a reliance on proxy measures. While safely managed is a better indicator than just toilet access, it still does not go far enough in ensuring the functional outcomes of protected public health. A more meaningful indicator could be a maximum threshold level of faecal contamination that people are exposed to in their community environment. This thesis contributes to current international discussions on future sanitation targets, demonstrating

that the post-2030 ambitions must move beyond access and community-level assessments and consider equitable protection of public health.

Delhi exemplifies why current frameworks fall short in accounting for both hydraulic and non-hydraulic flows, with its infamy for travellers' diarrhoea (Delhi belly). As one of the fastest-growing megacities in the world, with high population density and overstretched infrastructure, it experiences sanitation failures at every stage of the chain (Lüthi *et al.*, 2010; Diehl, 2015). The Yamuna River, while sacred, functions as a conduit for the city's waste streams (Prashar *et al.*, 2012). Communities along the tributary drainage channels are exposed not only to local sanitation failures but also to contamination from across the wider city.

In such contexts, planning interventions without a robust source-pathway-exposure framework for data collection and risk assessment can lead to fragmented and misdirected interventions. Resources may be directed to fulfil administrative indicator targets and undermine the potential for achieving meaningful public health outcomes.

1.1 Aims and Objectives

The work undertaken that is captured in this thesis addresses that gap. It investigated the extent to which people are exposed to faecal contamination via multiple pathways as described in the aims and objectives (Table 1). In other words, it was an attempt to map what might be called the “faecal catchment” of specific urban communities. To explore this idea, the city of Delhi was taken as a case study. The research explored non-hydraulic pathways, many of them having a source remote from the affected communities, through which faecal matter might travel. These included Fresh Produce distribution and Solid Waste. By conceptualising and analysing source-pathway-exposure linkages in Delhi, the research expanded the traditional F-diagram into a model that better represents urban realities. In doing so, it sought to provide decision-makers with clearer evidence on which interventions are most likely to disrupt transmission and reduce disease risk. The contribution is therefore both conceptual and empirical: developing frameworks for thinking about urban faecal flows and applying them to case study data from Delhi.

Table 1 - Aims and Objectives

Aim:	Develop a better understanding of the principal pathways of faecal contamination in low-income urban communities.
Objective 1	Evaluate the usefulness of the F-diagram as a model to describe pathways of faecal contamination in low-income urban areas and propose an alternative model.
Objective 2	Using an example location, assess the relative significance of different faecal pathogen exposures on health risks in typical low-income urban communities.
Objective 3	Identify and explore the sources and pathways that result in the critical exposures, including those arising beyond the immediate setting of the example location.
Objective 4	Using the results from objectives 1, 2 and 3, evaluate how targeted sanitation interventions might or might not reduce faecal pathogen exposure and thereby enhance public health.

1.2 Thesis Structure

This thesis is organised into nine chapters. Following this introduction, Chapter 2 examines the literature around the impacts of sanitation failures and then develops the conceptual framing by tracing the history and application of the F-diagram. In Chapter 3, the Amplified F-diagram is introduced as a lens through which to consider the sources and pathways leading to faecal exposures in urban communities. Chapter 4 outlines the methodological approach and study context. Chapter 5 presents an integration of microbial and behaviour data to provide an assessment of exposure risk across three study communities. Chapters 6 and 7 then explore two critical exposures in greater depth: Chapter 6 examines the sources and pathways leading to faecal contamination on the Fresh Produce eaten raw. Chapter 7 focuses on qualifying the exposure risk associated with exposure to Solid Waste. Chapter 8 draws

these threads together in a discussion and application of the Amplified F-diagram. The implications for understanding urban sanitation complexities and intervention design are considered. Finally, Chapter 9 reflects on the thesis aims and objectives and further research. This structure is displayed in Figure 2.

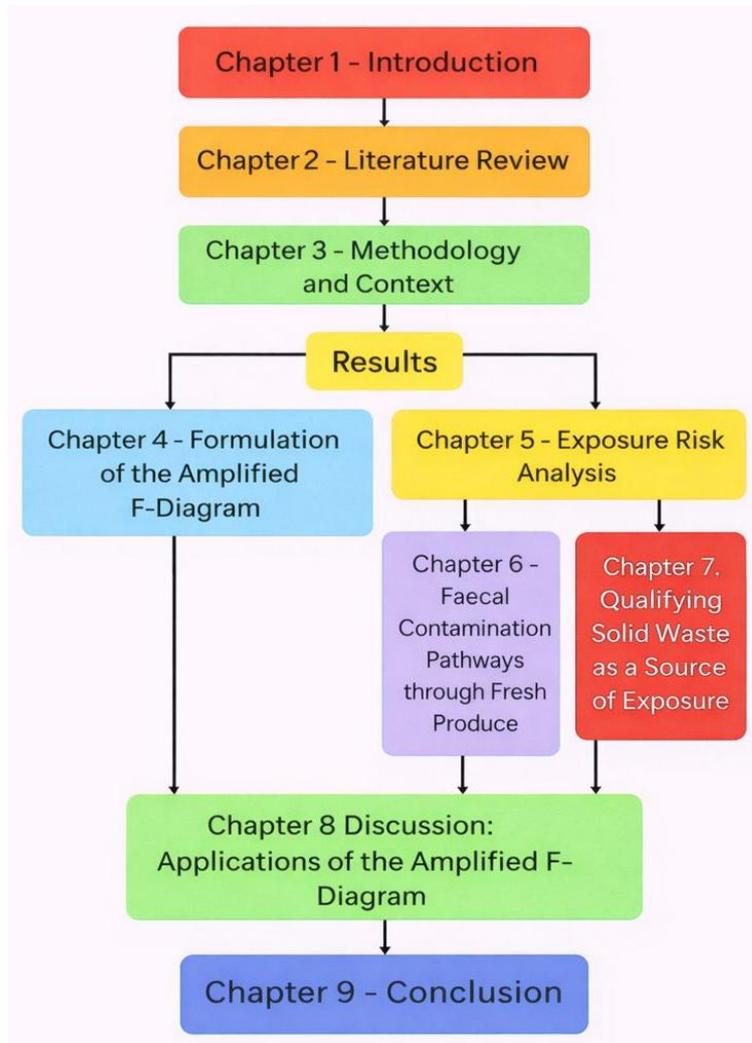


Figure 2 - Thesis structure diagram

2 Chapter 2 - Literature Review

It is important to set the scene with the Shit Flow Diagrams (SFD) (Peal et al., 2014; Peal et al., 2020). There are 332 city-level SFDs published on the data portal from five continents. Each one represents an in-depth assessment of the state of that city's sanitation chain and the failures that are occurring. The online data portal allows a conglomerate SFD to be displayed with all of the 323 global city data points included, shown in Figure 3.

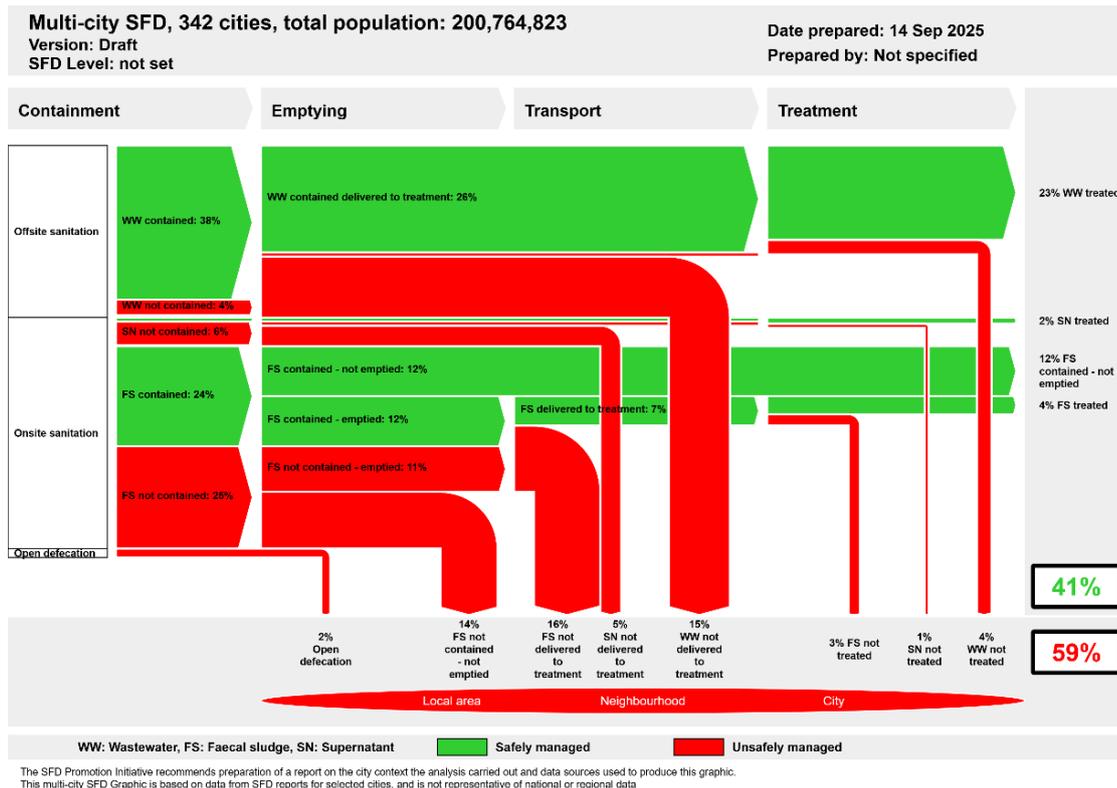


Figure 3 - Shit Flow Diagram depicting the proportion of safely and unsafely managed excreta in 332 cities (susana.org, 2019).

As can be seen in Figure 3, the total amount of faecal waste not safely managed is 59%. Within the Containment stage, the flows (2+4+6+25%) mean that 38% of the faecal waste is not safely contained. Some of this then enters Transportation, but 16% reaches the environment, including the estimated open defecation of 2%. 12% remains safely contained and treated on site. 36% of the faeces reach the environment at the Transport stage.

Not all the faecal sludge, supernatant or wastewater that is produced in a city reaches a Treatment facility. The global urban Shit Flow Diagram portal (susana.org, 2019) makes the optimistic estimate that 33% of the total urban faecal matter reaches a Treatment facility. Of this, 8% is untreated and discharged directly into the environment. Of the faecal matter that is estimated to be treated, the quality of the Treatment may mean that some of the effluent

is still highly contaminated with faecal pathogens when it reaches the environment. These are the three flows of treated green arrows at 23%, 2% and 4% combining to make 29% of the waste.

Therefore, all three stages of the sanitation chain are contributing to the faecal contamination of the environment, and examining the literature for the consequences of this is important.

This literature review is segmented into two sections in support of the attainment of Objective 1. Firstly, taking each segment of the sanitation chain in turn (Containment, Transport and Treatment) to examine the published evidence for the sources and pathways leading to public exposure to faecal pathogens. The full method of the search terms and inclusion and exclusion criteria is included in Appendix A (page 170). Not all the reviewed studies were directly concerned with sources, pathways, and exposures of faecal pathogens; nevertheless, they contained information that was valuable for addressing these questions. Secondly, this chapter examines the development and uses of the F-diagram in the years since its initial publication. The Amplified F-diagram will then be introduced along with some explanation of its development.

2.1 Sanitation failures leading to exposure to faecal pathogens

2.1.1 Review of Containment Failures

After exclusions, 30 papers were identified and reviewed. Of the reviewed articles, most of the articles only specified either the type of failure as the source of contamination or the pathway to exposure mechanism; all but four articles were focused on one aspect only. Many of the articles focused on children's health due to their vulnerability to faecal pathogens and stunted growth.

Records of faeco-oral disease outbreak investigations are limited to high-income countries. One example of this was in the USA, where the cause of the outbreak was animal faeces washed by rain into an unprotected piped water source. However, the authors also identified that there were multiple other sanitation chain failures that could have easily caused an outbreak (Hrudey *et al.*, 2003). Due to the pervasive nature of enteric infections in low and middle-income countries, this type of outbreak investigation has not been carried out. At times, practitioners may attempt to apply findings from studies like this to determine

interventions in other contexts, leading to incorrect allocations of funds and efforts (Amebelu *et al.*, 2021).

2.1.1.1 Sources

The most common Containment failure leading to human faecal exposure was improper siting of sanitation infrastructure that impacts the surrounding ground and surface water, with 11 articles asserting this problem (Hrudey *et al.*, 2003; Howard *et al.*, 2003; Ahmed *et al.*, 2005; Banerjee, 2011; Knappett *et al.*, 2011; Graham and Polizzotto, 2013; Deilami *et al.*, 2017; Back *et al.*, 2018; Gwimbi *et al.*, 2019; Akpataku *et al.*, 2020; Verma *et al.*, 2023). Seven articles identify poor child faeces management (Pokhrel and Viraraghavan, 2004; Kwiringira *et al.*, 2014; Sclar *et al.*, 2016; Mills *et al.*, 2018; Ercumen *et al.*, 2018; Solid Wastearthout *et al.*, 2019; Lin *et al.*, 2020), and 11 remark on direct discharge into the environment and unemptied systems overflowing locally (Howard *et al.*, 2003; Pokhrel and Viraraghavan, 2004; Knappett *et al.*, 2011; Schoen *et al.*, 2014; Kwiringira *et al.*, 2014; Mills *et al.*, 2018; Islam *et al.*, 2018; Peal *et al.*, 2020a; Amin *et al.*, 2020; Manga *et al.*, 2022; Verma *et al.*, 2023).

Animal faeces in the household environment was cited by 12 articles as a source of faecal contamination, and while not directly related to sanitation chain failures, is worth noting due to being so commonly mentioned and causing similar health issues (Howard *et al.*, 2003; Pokhrel and Viraraghavan, 2004; Knappett *et al.*, 2011; Kwiringira *et al.*, 2014; Ercumen *et al.*, 2017; Mills *et al.*, 2018; Ercumen *et al.*, 2018; Solid Wastearthout *et al.*, 2019; Gwimbi *et al.*, 2019; Lin *et al.*, 2020; Budge *et al.*, 2022; Verma *et al.*, 2023).

Nine articles also mentioned general failures such as “inadequate sanitation”, “lack of sanitation access”, and “poor maintenance” (Kamat and Malkani, 2003; Pokhrel and Viraraghavan, 2004; Graham and Polizzotto, 2013; Schoen *et al.*, 2014; Kwiringira *et al.*, 2014; Mills *et al.*, 2018; Back *et al.*, 2018; Peal *et al.*, 2020a; Manga *et al.*, 2022).

There is some concern among eight authors about the reality of the situation where sanitation is designated as ‘improved’ or ‘safely managed’, but even when sanitation meets these standards, it does not always effectively prevent the escape of faecal pathogens. These issues could lead to metrics like SFDs having inflated safety percentages (Pokhrel and Viraraghavan, 2004; Graham and Polizzotto, 2013; Schoen *et al.*, 2014; Kwiringira *et al.*, 2014; Mills *et al.*, 2018; Back *et al.*, 2018; Ercumen *et al.*, 2018; Peal *et al.*, 2020a). Four authors draw attention to unsafe on-site sanitation emptying practices spreading contamination

(Schoen *et al.*, 2014; Kwiringira *et al.*, 2014; Mills *et al.*, 2018; Peal *et al.*, 2020a) but did not quantify how much of a regular or significant contributor this flow would be.

2.1.1.2 Exposures

The most commonly identified pathway to exposure was through contamination of water sources, be it for drinking, as mentioned by 12 (Hrudey *et al.*, 2003; Howard *et al.*, 2003; Clasen and Bastable, 2003; Eshcol *et al.*, 2009; Graham and Polizzotto, 2013; Sclar *et al.*, 2016; Deilami *et al.*, 2017; Back *et al.*, 2018; Islam *et al.*, 2018; Gwimbi *et al.*, 2019; Goddard *et al.*, 2020; Verma *et al.*, 2023), or for bathing or recreational use, as mentioned by six (Ahmed *et al.*, 2005; Knappett *et al.*, 2011; Schoen *et al.*, 2014; Islam *et al.*, 2018; Gwimbi *et al.*, 2019; Peal *et al.*, 2020a).

The next most commonly mentioned pathway to exposure was general contamination of the environment, hand contamination and surface contamination. For the purposes of this study, this has been collected together under the topic of fomite exposure and mentioned by 13 articles (Kamat and Malkani, 2003; Knappett *et al.*, 2011; Schoen *et al.*, 2014; Kwiringira *et al.*, 2014; Sclar *et al.*, 2016; Ercumen *et al.*, 2017; Mills *et al.*, 2018; Islam *et al.*, 2018; Ercumen *et al.*, 2018; Solid Wastearthout *et al.*, 2019; Lin *et al.*, 2020; Goddard *et al.*, 2020; Verma *et al.*, 2023). Six studies mentioned contamination of food preparation areas, specifically (Eshcol *et al.*, 2009; Sclar *et al.*, 2016; Solid Wastearthout *et al.*, 2019; Lin *et al.*, 2020; Goddard *et al.*, 2020; Verma *et al.*, 2023). From the literature, it is clear that the pathways for environmental contamination are less clearly understood than the pathways leading to water-based contamination, with more unspecific language used.

Hygiene, including handwashing, safe water storage and cooking practices, can mitigate some of this exposure, but these rely on with behaviour change adherence (Sclar *et al.*, 2016; Ercumen *et al.*, 2018; Solid Wastearthout *et al.*, 2019; Lin *et al.*, 2020; Goddard *et al.*, 2020). It would seem logical that just asking people to be more hygienic alone, while living in a highly contaminated environment, will be less effective than also reducing the environmental contamination from an infrastructural approach.

2.1.1.3 Sources to exposures

Sclar *et al.*, (2016) carried out a review of Containment failures and found these results: poorly sited, poor-quality Containment, issues with child faeces disposal, open defecation and flies leading to contamination of water and surfaces. Graham and Polizzotto (2013) carried out a review about the impact of pit latrines on groundwater and identified the issue

of poor siting and soil conditions increasing the likelihood of contamination in drinking water. Goddard et al (2020) also carried out a systematic review focused on flies but also found that poor quality and poor maintenance of household sanitation, plus unmanaged child faeces, led to faecal waste entering the living environment. Kyu et al (2024) did a review analysis of the global burden of diarrhoeal disease and concluded that faeces enter the environment due to failure to contain it with adequate sanitation, either due to open defecation or sanitation that was failing. The pathogens then moved through groundwater used for drinking or washing, or around the environment in other ways, leading to exposures by water, surfaces and food.

2.1.2 Review of Transport Failures

Transport is the part of the system that moves faecal waste from the point of production to Treatment or discharge. It comprises pipes, channels or motor vehicles. It is challenging to define the exact boundary between direct discharge from 'Containment' and some discharges associated with 'Transport'. For this review, effluent flowing directly into a water body or the wider environment from was considered as Containment (i.e. an outlet from a sealed tank) as a Containment failure; but any flow that subsequently enters a pipe or open channel prior to discharge into the environment is defined as a Transport failure. After exclusions, 14 papers were reviewed.

2.1.2.1 Sources

The most commonly reported mode of Transport failure, with seven articles, was pipes (sewers), drains or ditches leaking or directly discharging faecal matter into waterbodies and the environment (Lara *et al.*, 2011; Lam *et al.*, 2015; Mills *et al.*, 2018; Islam *et al.*, 2018; Peal *et al.*, 2020a; Amin *et al.*, 2020; Manga *et al.*, 2022). This can be by design, by use of Open Drains (which do not safely contain faeces) or through leaking and broken systems. One study mentioned the possibility of aerosolisation of faecal pathogens from open waste streams (Rocha-Melogno *et al.*, 2022).

The second most often reported mode of Transport failure, with six articles, is sewer overflow and leakage (Xagorarakis *et al.*, 2014; Schoen *et al.*, 2014; Mills *et al.*, 2018; Peal *et al.*, 2020a; Manga *et al.*, 2022; Salubi *et al.*, 2025). Sewer failures can be exacerbated by intense rainfall and flooding events, often associated with climate change, as discussed in seven articles (Chambers *et al.*, 2008; Lara *et al.*, 2011; Xagorarakis *et al.*, 2014; Lam *et al.*, 2015; Islam *et al.*, 2018; Amin *et al.*, 2020; Salubi *et al.*, 2025).

The third most common mode of Transport failure, with four articles, is waste not taken to Treatment but dumped into waterbodies or the environment (Chambers *et al.*, 2008; Lara *et al.*, 2011; Mills *et al.*, 2018; Peal *et al.*, 2020a). Emptying of on-site sanitation can be a costly and technically challenging service. There is widespread use of informal and unregulated emptying services. Sewage sludge and wastewater, along with untreated effluent from Containment, is used in agriculture and aquaculture as described in five articles (Lara *et al.*, 2011; Xagorarakis *et al.*, 2014; Lam *et al.*, 2015; Mills *et al.*, 2018; Manga *et al.*, 2022).

2.1.2.2 Exposures

The most commonly referenced exposure from the Transport failures was direct contact through drinking, playing in, bathing in or travelling through contaminated water, including surface water, Open Drains and flood waters, mentioned by 11 articles (Chambers *et al.*, 2008; Lara *et al.*, 2011; Xagorarakis *et al.*, 2014; Schoen *et al.*, 2014; Mills *et al.*, 2018; Islam *et al.*, 2018; Crank *et al.*, 2019; Peal *et al.*, 2020a; Amin *et al.*, 2020; Manga *et al.*, 2022; Salubi *et al.*, 2025).

The second exposure type was through consumption of contaminated foods, such as vegetables and fish, with six articles (Lara *et al.*, 2011; Xagorarakis *et al.*, 2014; Schoen *et al.*, 2014; Lam *et al.*, 2015; Mills *et al.*, 2018; Manga *et al.*, 2022). The third common exposure with six articles, type was the contact with the contaminated environment, such as soil and toys, which was particularly a concern for children (Chambers *et al.*, 2008; Lara *et al.*, 2011; Graham and Polizzotto, 2013; Amin *et al.*, 2020; Manga *et al.*, 2022; Salubi *et al.*, 2025).

2.1.3 Review of Treatment Failures

Thirdly, the evidence for failed 'Treatment' as a source of human exposure to faecal contamination is investigated. After exclusions, 13 papers were reviewed.

2.1.3.1 Source

There can be many reasons that Treatment plants are not working as intended. This is a commonly cited reason for faecal pathogens reaching the environment. This includes sludge mismanagement which is discussed in four articles (Strauss, 1995; Xagorarakis *et al.*, 2014; Chernicharo *et al.*, 2015; Nguyen *et al.*, 2021), neglected post-Treatment infrastructure in two (Chernicharo *et al.*, 2015; Capodaglio *et al.*, 2017), overflow and bypass during storms in three (Oliveira and Von Sperling, 2008; Chernicharo *et al.*, 2015; Capodaglio *et al.*, 2017) and other failures such as fouling of membranes and filter overloads in seven (Chong *et al.*, 2012;

Xagorarakis *et al.*, 2014; Chernicharo *et al.*, 2015; Capodaglio *et al.*, 2017; M. Wang *et al.*, 2017; Kehrein *et al.*, 2020; Amin *et al.*, 2020).

Other Treatment works can function as intended, but still not remove pathogens sufficiently to protect human health. This is usually to do with the design not including disinfection or post Treatment as described by six articles (Oliveira and Von Sperling, 2008; Wen *et al.*, 2009; Rijal *et al.*, 2011; Li *et al.*, 2014; Chernicharo *et al.*, 2015; Capodaglio *et al.*, 2017). Other issues include misrepresented indicators in two articles (Wen *et al.*, 2009; Li *et al.*, 2014), and bacterial and antimicrobial resistant bacteria regrowth in four (Strauss, 1995; Surbeck *et al.*, 2010; Xagorarakis *et al.*, 2014; Nguyen *et al.*, 2021).

2.1.3.2 Exposure

In these articles, there is no data collected on human exposures or health risks, and in some, they are not discussed at all (Oliveira and Von Sperling, 2008; Wen *et al.*, 2009; Li *et al.*, 2014; M. Wang *et al.*, 2017; Kehrein *et al.*, 2020; Nguyen *et al.*, 2021). Some conclusions are reached based only on the authors' opinion on the likely transmission pathways.

The most common exposure type, in seven articles, was through contact with or consumption of contaminated crops and seafood (Strauss, 1995; Chong *et al.*, 2012; Xagorarakis *et al.*, 2014; Chernicharo *et al.*, 2015; Capodaglio *et al.*, 2017; M. Wang *et al.*, 2017; Nguyen *et al.*, 2021). Five articles named contact with contaminated water as the pathway to faecal pathogen exposure (Strauss, 1995; Surbeck *et al.*, 2010; Rijal *et al.*, 2011; Xagorarakis *et al.*, 2014; Capodaglio *et al.*, 2017). Three studies mentioned exposure through aerosols (Rijal *et al.*, 2011; Xagorarakis *et al.*, 2014; Nguyen *et al.*, 2021).

2.1.4 Conclusion of Literature Review

This review has identified that failures are occurring across the sanitation chain, and this is leading to faecal pathogen exposure for people and communities. The majority of the literature focuses on the impacts on surface and groundwater and the resultant exposures through drinking, bathing and recreation. Additionally, exposures can be through Fresh Produce and fish contaminated by the impacted water. The second theme was around general contamination and exposure to fomite transmission, but the sources and pathways for this are less clearly defined.

2.2 Review of the F-diagram and its uses

Here, the usefulness and uses of the F-diagram (Wagner and Lanoix, 1958) to represent sources of human exposure to faecal pathogens is explored. After exclusions, 33 papers were reviewed. These had a wide range of different aims and objectives, but were included because they all used the F-diagram as an underpinning for their work, either in practice, research, or theoretical development.

The F-diagram has been used as a valuable tool from 1958 until the present day, and it has conceptual acceptance and familiarity. F-diagrams are also extensively used in grey literature with a range of examples referenced here: Clean Water for Laymen, 2015; Samaritan’s Purse Canada, 2018; UNICEF, 2020;ñ Water1st, 2021; Baidoa Research Training and Consultancy Centre, 2022; RCUES Mumbai, 2022; Centre for Science and Environment, 2025; The Water Project, n.d.; Verma et al., n.d.; Sweeney, n.d.; UNICEF, n.d.; Maksimenko, n.d..

From the academic literature searches, eight papers were found to include the classic F-diagram concept with a variety of stylisations and graphics, but no major conceptual alterations (Curtis *et al.*, 2000a; Brown *et al.*, 2013; Guiteras, 2015; Wolfe *et al.*, 2018; Aliyu and Dahiru, 2019; Ntajal *et al.*, 2020; Ketema *et al.*, 2022; Fatima *et al.*, 2025). Two examples of these diagrams are shown in Figure 4 and Figure 5.

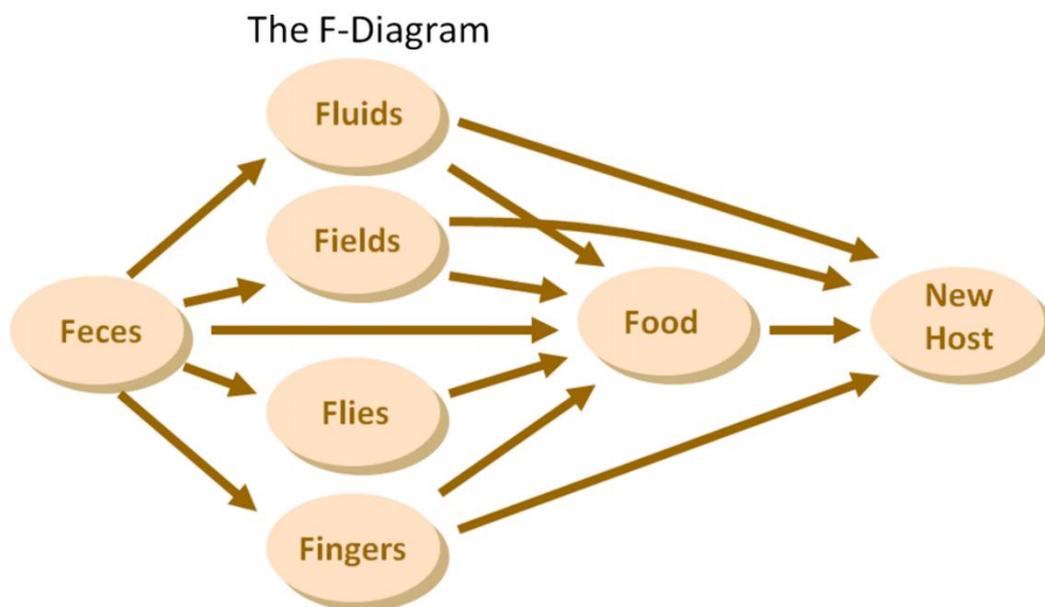


Figure 4 - Iteration of the F-diagram showing transmission pathways of excreta-related diseases using words beginning with 'F' (Brown *et al.*, 2013).

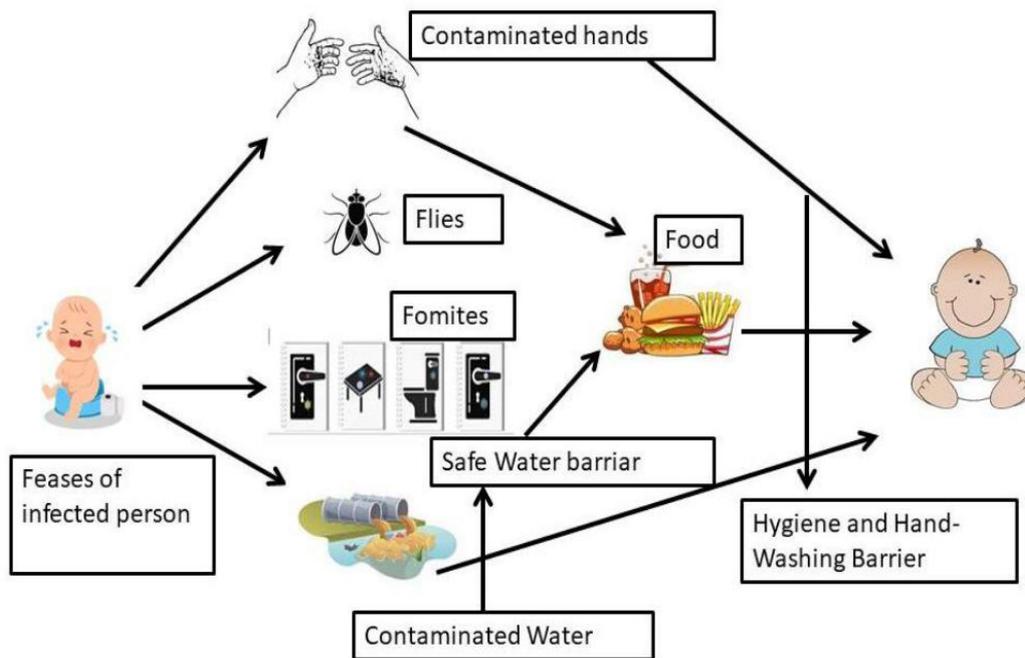


Figure 5 - Iteration of the F-diagram depicting faecal-oral transmission of infection from an infected person and points of interventions (Fatima *et al.*, 2025).

In four articles, the F-diagram was used as an underpinning concept, but the visual figure was not included (Odai *et al.*, 2008; Boisson *et al.*, 2014; Ali, 2020; Fatima *et al.*, 2025).

Many authors, even when using the F-diagram as a bedrock of their work, approach it critically, and some went on to suggest or create updated versions. While some of the usefulness of the F-diagram is its simplicity, many authors also found it to be over-simplified or missing key complexities (Curtis *et al.*, 2000a; Humphrey, 2009; Mbuya *et al.*, 2015; Penakalapati *et al.*, 2017; Wolfe *et al.*, 2018; Wang *et al.*, 2018; Ngure *et al.*, 2019; Whitley *et al.*, 2019; Mensah, 2020; Ntajal *et al.*, 2020; Zerbo *et al.*, 2021; Budge *et al.*, 2022; Zerbo *et al.*, 2022; Niven *et al.*, 2023; Wright *et al.*, 2024; Niven *et al.*, 2025).

Some authors made minor amendments to the F-diagram to provide altered emphasis depending on the purposes of the article (Hjalmarsson, 2012; Van Seventer, 2017; Rose and Jiménez Cisneros, 2019).

Figure 6 shows the amendments Nordin (2010) made (picture taken from Hjalmarsson, 2012) which keeps the structure and purpose of the original diagram, adding some more detail about primary and secondary Treatment, faecal reuse practices and food hygiene.

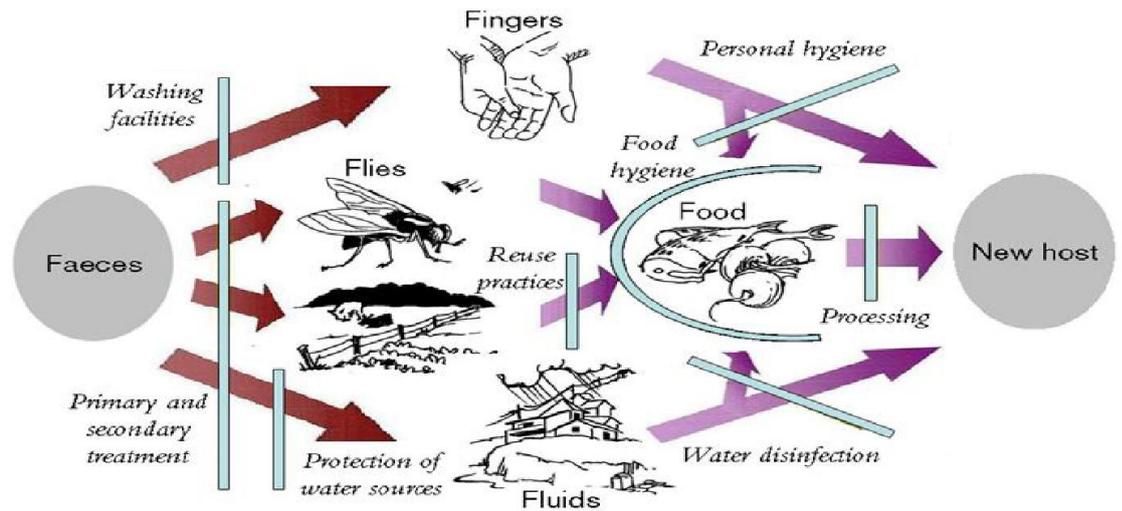


Figure 6 - Amended F-diagram illustrating faecal transmission pathways with added detail on treatment, reuse and food hygiene (Hjalmarsson, 2012).

Figure 7 shows amendments made by Van Seventer (2017) to add labels for primary and secondary barriers, and emphasise where water, sanitation and hygiene interventions would be applicable.

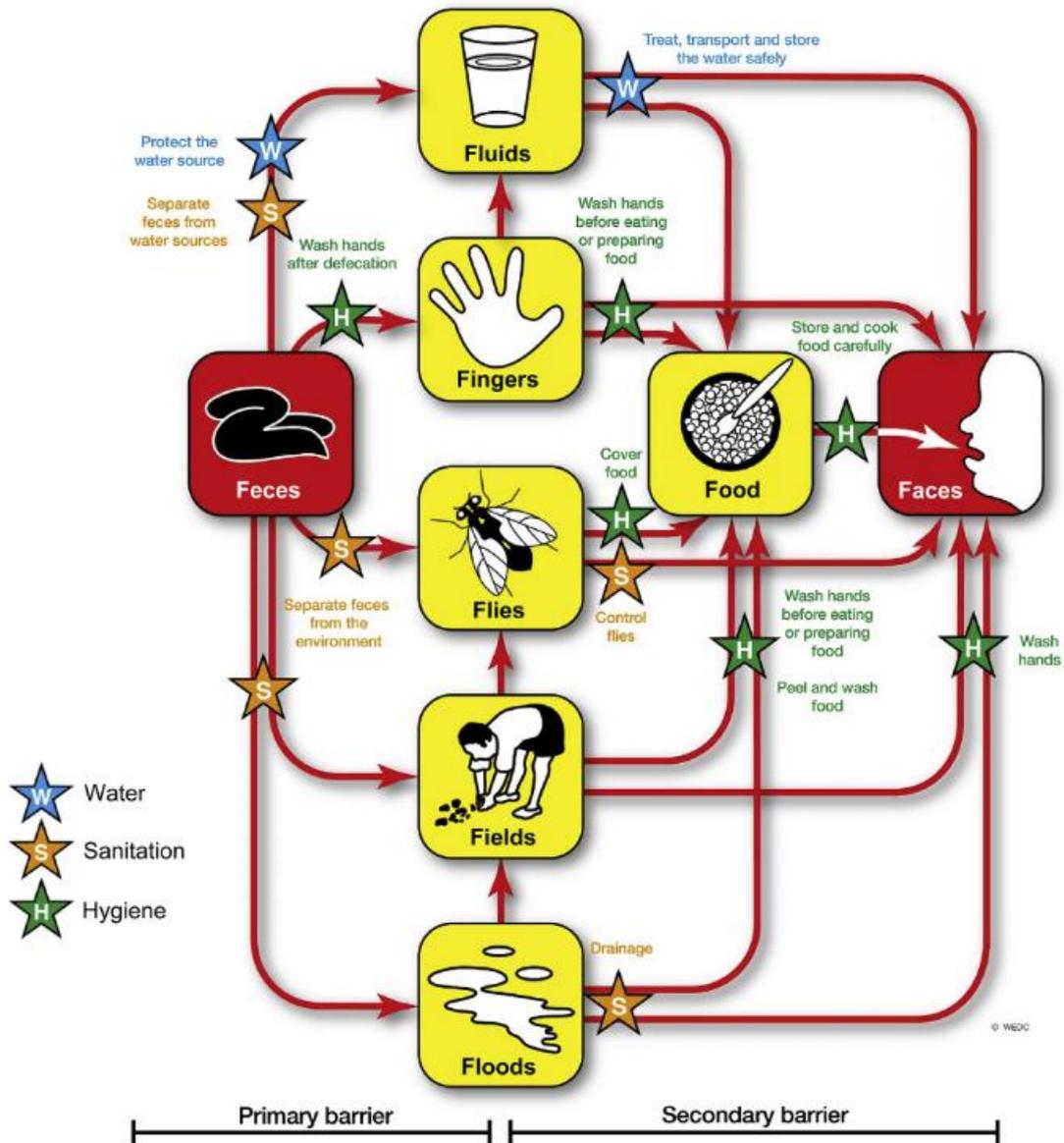


Figure 7 - Amended F-diagram to show primary and secondary barriers to faecal-oral transmission and intervention points for water, sanitation and hygiene (Van Seventer, 2017).

Figure 8 shows minor amendments to the F-diagram to include hand-drawn icons and some more specificity to the barriers (Rose and Jiménez Cisneros, 2019).

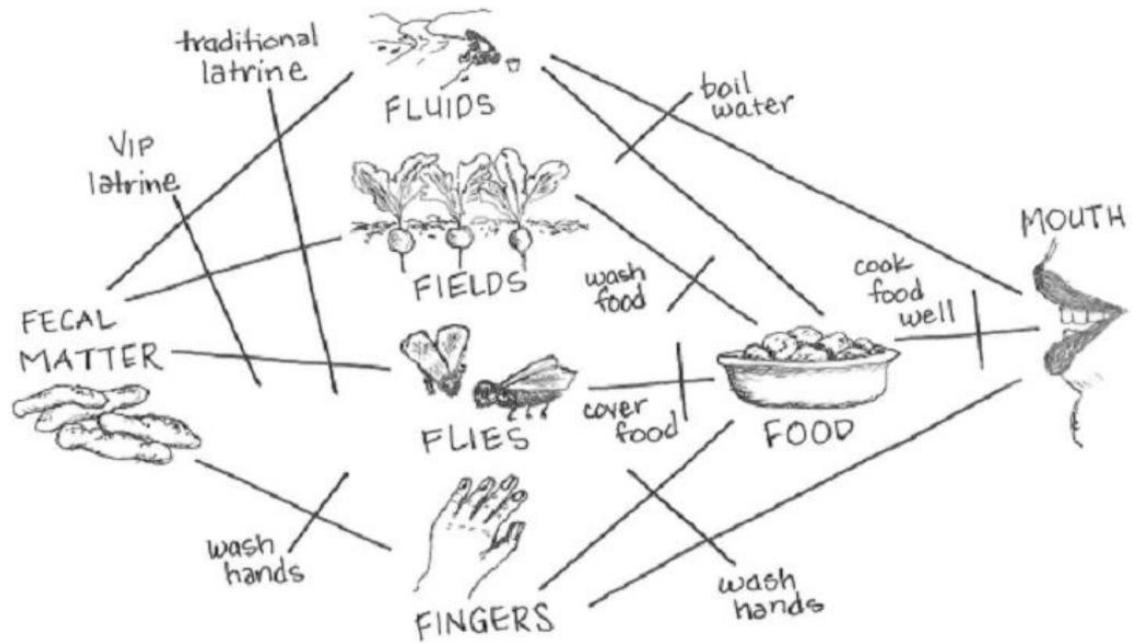


Figure 8 - Amended F-diagram with transmission routes blocked by latrines and hygiene interventions (Rose and Jiménez Cisneros, 2019).

Other authors made major revisions that departed from the original F-diagram to a greater extent, while still drawing ideas from the premise of a diagram that shows the flow of faecal pathogens (Eisenberg *et al.*, 2007; Humphrey, 2009; Campos *et al.*, 2015; Penakalapati *et al.*, 2017; Wang *et al.*, 2018; Whitley *et al.*, 2019; Okaali *et al.*, 2022; Zerbo *et al.*, 2022; Jensen *et al.*, 2023; Wright *et al.*, 2024).

Humphrey (2009), shown in Figure 9, took a version of the f-diagram and developed it to demonstrate how faeces in the environment lead to tropical enteropathy and problems with healthy child development. This diagram is a useful contribution, but it does not show the intricacy of the sanitation failures, as it has just a box for 'no toilet'.

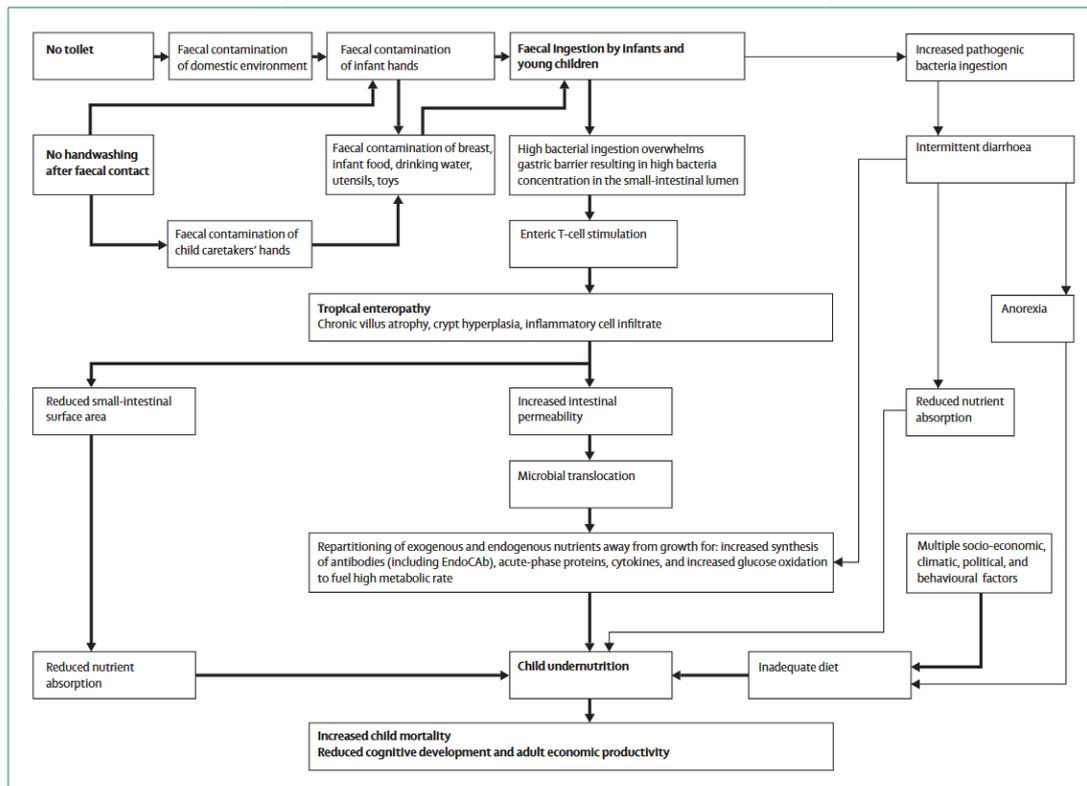


Figure 9 – Adapted F-diagram illustrating how environmental faecal exposure contributes to tropical enteropathy and impaired child development (Humphrey, 2009).

Campos et al. (2015) developed a diagram shown in Figure 10, to show how hazardous events cause failure of the sanitation system, leading to the transmission routes, and that social factors exacerbate vulnerability. This does not expand on the original F-diagram and, in fact, reduces the complexity while adding those important additional considerations.

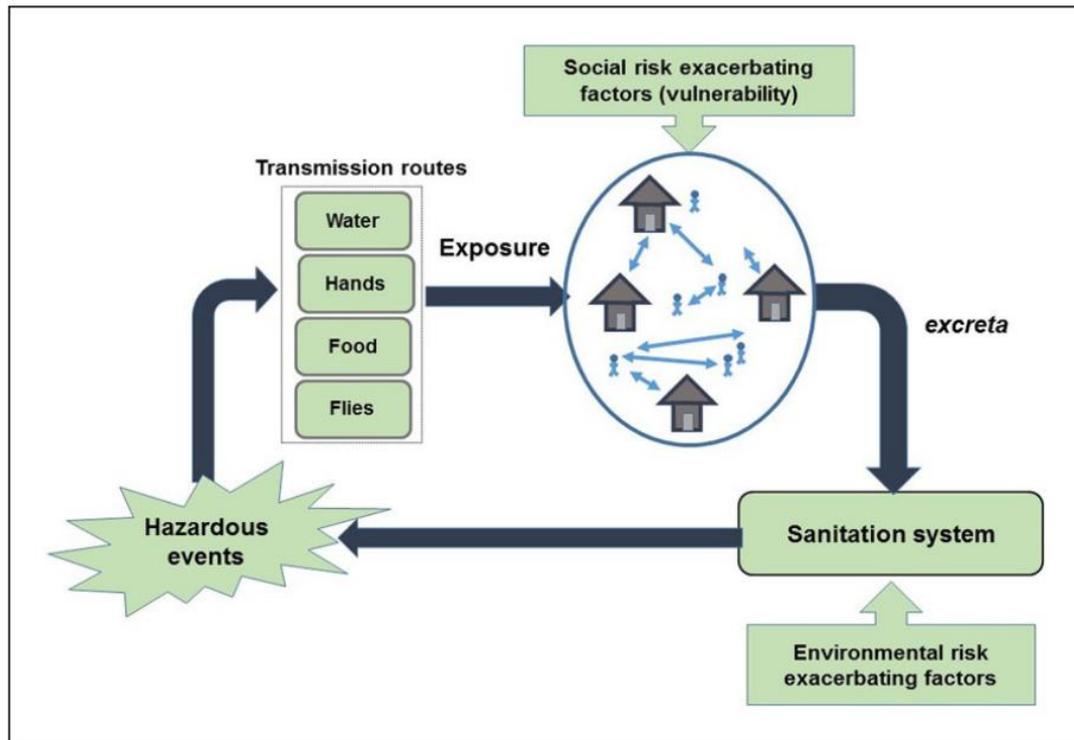


Figure 10 – Diagram illustrating how hazardous events and social factors contribute to sanitation system failure and increased vulnerability to disease transmission (Campos et al., 2015).

Two authors (Penakalapati et al., 2017; Whitley et al., 2019) considered that including only human faeces was not a complete picture, and also included animal faeces as an important contribution, as shown in Figure 11 and Figure 12. Aside from this addition, there are barely any changes to the original F-diagram.

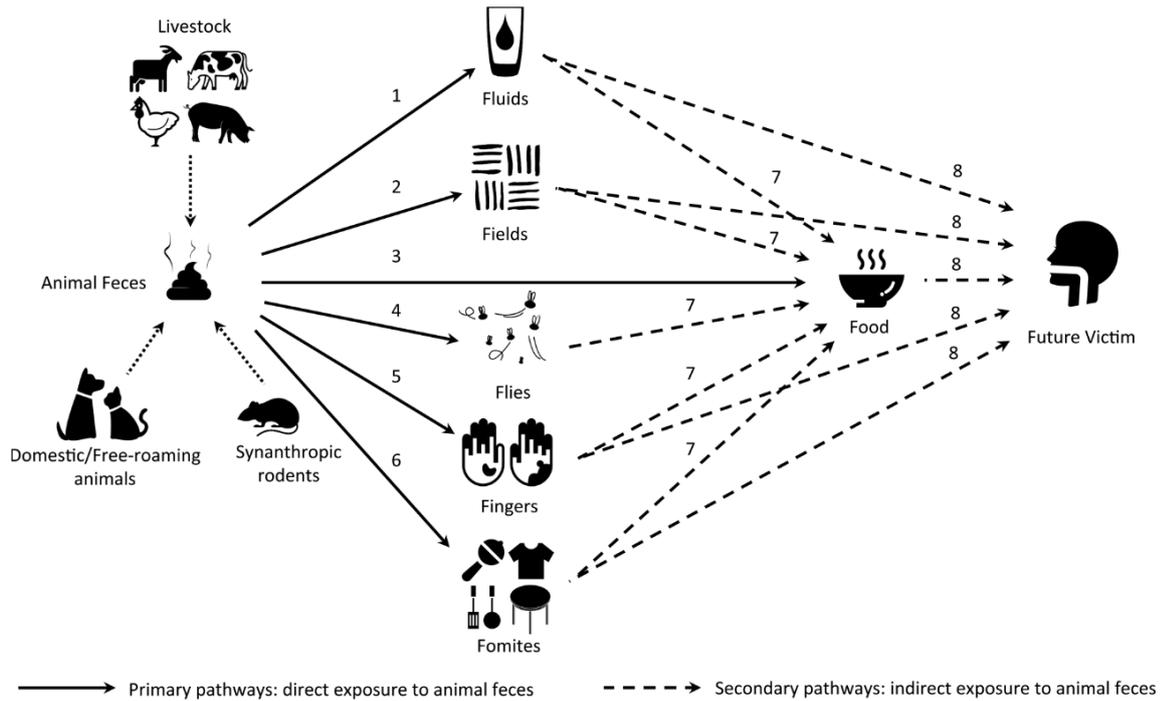


Figure 11 – Amended F-diagram incorporating both human and animal faeces as sources of environmental contamination (Penakalapati et al., 2017).

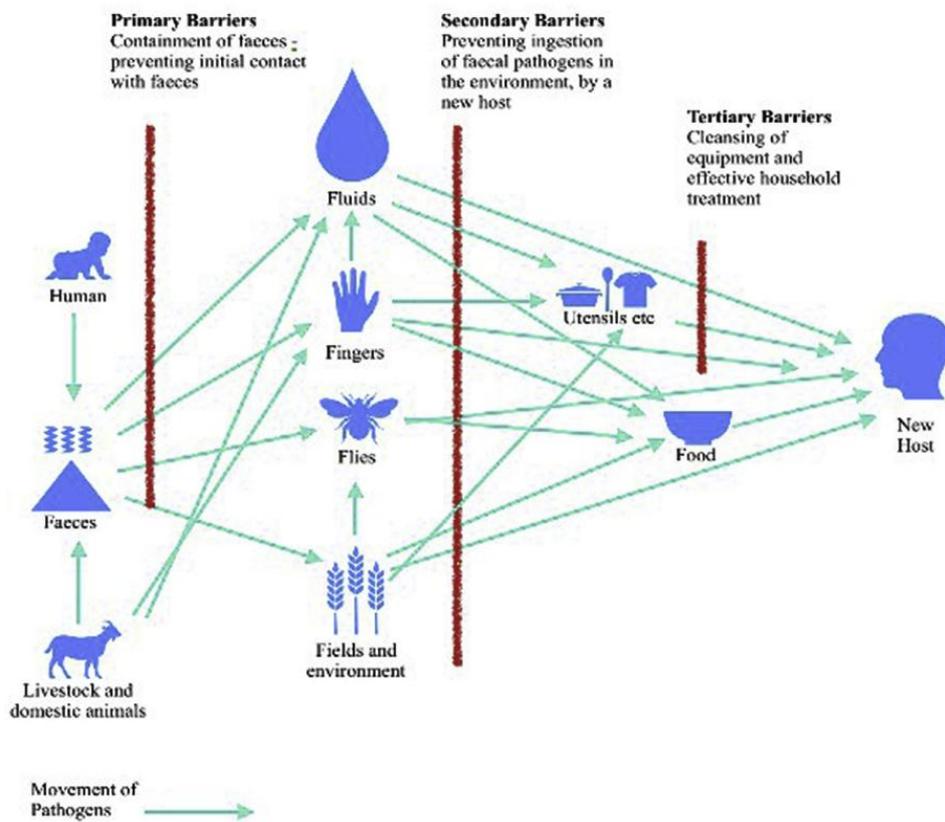


Figure 12 – Adapted F-diagram illustrating the role of animal faeces along with human faeces in faecal-oral transmission pathways (Whitley et al., 2019).

One author (Wright *et al.*, 2024), used a diagram based on the F-diagram (Figure 13) to show how the sanitation system failures, storm drain issues and clean water sources interact with Solid Waste management issues. This is useful to include often-ignored issues such as flying toilets (bagged faeces) and disposable nappies/diapers, but does not include any nodes regarding human exposure to the pathogens.

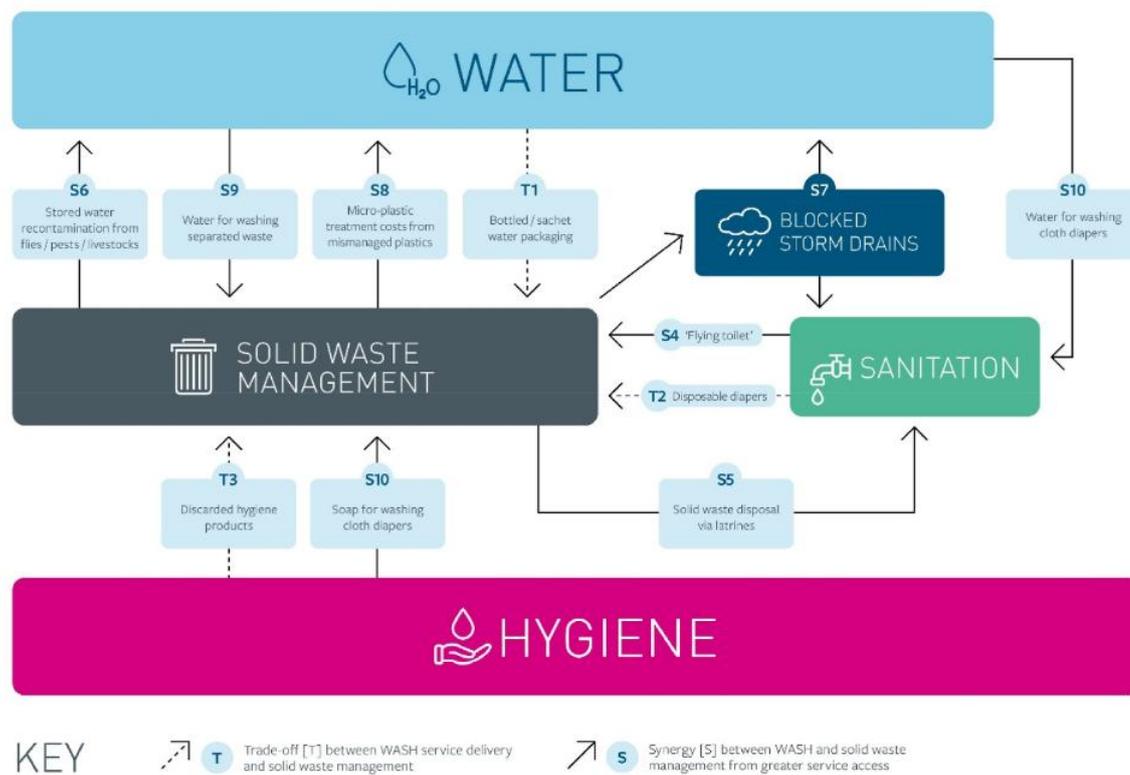


Figure 13 – Synergies and trade-offs between Solid Waste management and WASH for urban households (Wright *et al.*, 2024).

Okaali *et al.*, (2022) expanded on the F-diagram in Figure 14 to attempt to explain the complexities of the sanitation chain failures and shows the failed sanitation leading to contamination of surface water, but does not include any other ways that people can be exposed to faecal contamination other than through water.

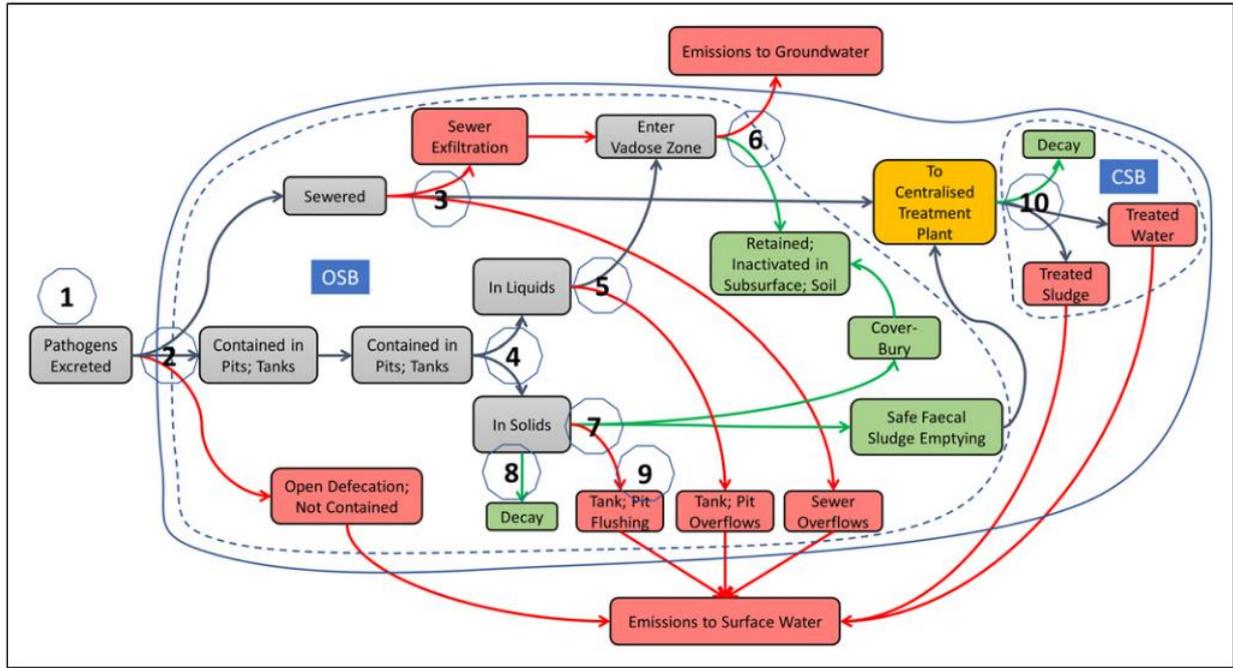


Figure 14 – Expanded F-diagram illustrating sanitation chain failures leading to surface water contamination as a primary exposure pathway (Okaali et al., 2022).

Shit Flow Diagrams (Peal et al., 2014; Peal et al., 2020b) as has already been mentioned, are a tool for understanding the sanitation failure in the city, as shown in the master diagram in Figure 15. While the SFD gives some indication as to the potential exposure routes and domains along the bottom of the diagram, it does not attempt to go into detail on these and the subsequent pathways leading to exposure.

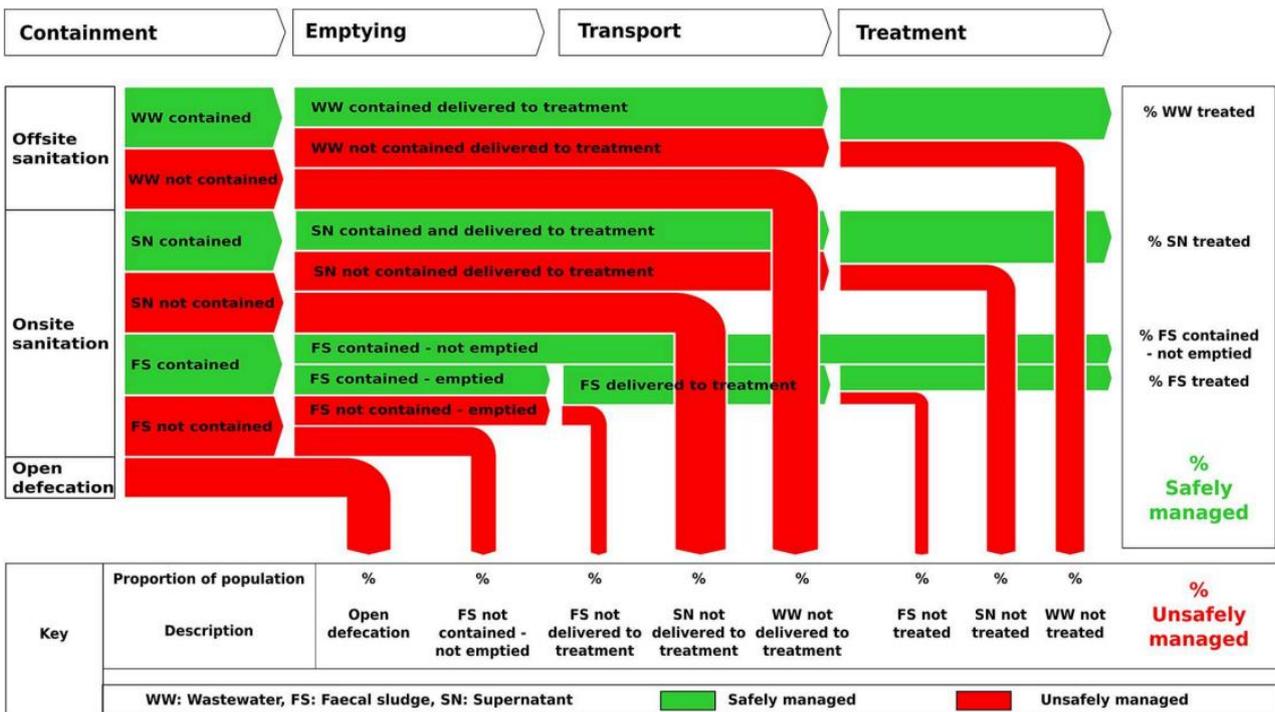


Figure 15 – Master Shit Flow Diagram depicting all the possible flows of safely and unsafely managed excreta (Peal et al. 2014).

Three authors attempted to update the F-diagram to include a consideration of spatial domains (Eisenberg et al., 2007; Zerbo et al., 2021; Jensen et al., 2023). Eisenberg et al., (2007) updated the diagram to include a consideration of the within and between household transmission routes, added a node for animal faeces, and added a line to show the circularity of infections, as shown in Figure 16. This figure does not improve the representation of the multiple contamination connections happening at once and does not explain much about the purpose behind separating the domains.

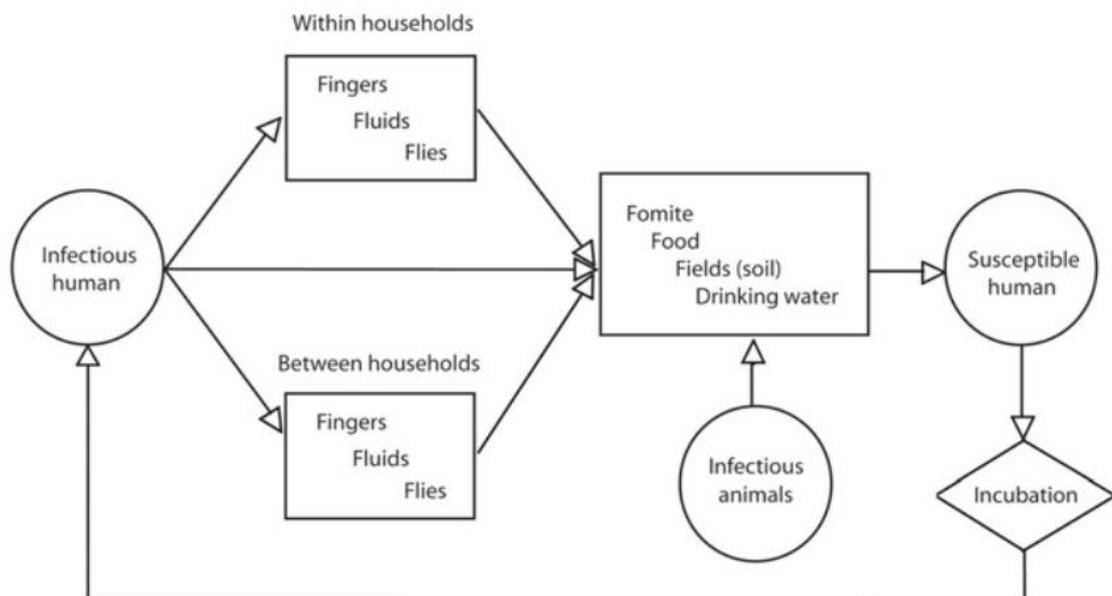


Figure 16 – Updated F-diagram incorporating within and between household transmission, animal faeces and the circularity of infections (Eisenberg et al., 2007).

Jensen et al., (2023) developed this idea further with the clear diagram shown in Figure 17. This diagram adds much to F-diagrams' usefulness by making it clearer how each transmission happens, but keeps the source of faeces to one node of 'latrine'. The shift of direction from the source being on the left and the exposures being at the top decreases the intuitive ease of this F-diagram.

A team at Emroy University did research to quantify the routes of exposure to faecal pathogens for children under 5 years old. They described their findings in two papers (Wang et al., 2017; Wang et al., 2018) but the part of the work that is most comparable to the F-diagram is included here in Figure 19. This diagram is, as intended, focused on the final pathway to exposures and does not attempt to describe sanitation failures or the pathways leading to the point of exposure.

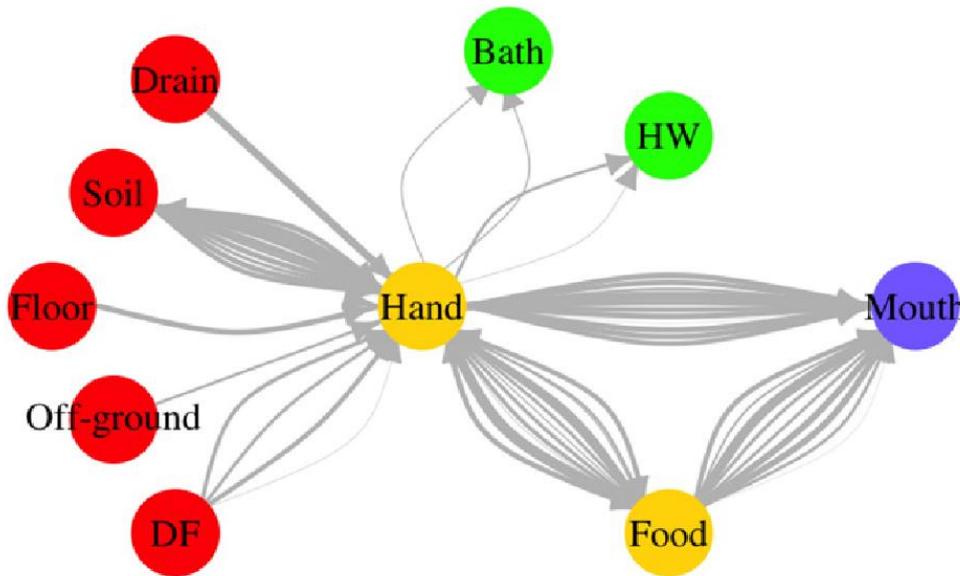


Figure 19 - Wang et al., 2017: Faecal microbe transfer network for a typical child day. DF = direct contact with own faeces, HW = handwashing. The thickness of the connections is proportional to the log₁₀ number of microbes transferred. Red = sources; yellow = vehicles; green = sink; purple = ingestion.

This aligns with the SaniPath research at the same university (Raj et al., 2020), which is a methodological approach designed to quantify population exposure to faecal contamination by integrating microbiological measurements from environmental samples with detailed behavioural observations. The SaniPath framework estimates exposure by combining the results of measures of faecal indicator bacteria concentrations at specific environmental compartments (such as open drains, food, soil, and water) with observed frequencies and durations of human contact at these points. In doing so, it provides comparative insight into which exposure pathways dominate at the community level. This can support prioritisation of interventions based on relative exposure burden. However, the approach is inherently Exposure-focused, rather than tracing contamination back to Pathways or Sources. Consequently, while SaniPath is highly effective for identifying high-risk exposure points, it offers limited insight into how those exposure points are generated through interconnected failures elsewhere in the city, or how contamination may spread spatially beyond the immediate sampling sites.

2.3 Research Gaps Identified in the Literature

The F-diagram has long been a foundational and useful schematic for describing how pathogens travel from uncontained human faeces to new hosts by environmental pathways. However, a growing body of literature has criticised its simplicity, particularly in the context of low income urban environments characterised by infrastructural complexity, overlapping exposure routes and simultaneous contact with multiple contaminated exposure points.

As identified in the literature review above, numerous authors have proposed extension or modifications to the F-diagram to address specific limitations, including the incorporation of flooding events (Campos *et al.*, 2015), spatial and domain areas (Eisenberg *et al.*, 2007; Zerbo *et al.*, 2022), animal faeces (Penakalapati *et al.*, 2017; Whitley *et al.*, 2019), Solid Waste (Wright *et al.*, 2024) and other updates (Humphrey, 2009; Wang *et al.*, 2018; Okaali *et al.*, 2022).

While these contributions have advanced understanding of particular contextual factors, none fully resolve the central challenge the F-diagram was originally intended to address: describing how uncontained faecal matter enters and moves through environmental Pathways that interact and overlap. Existing adaptations tend to remain compartmentalised, address individual modifiers rather than capturing the dynamic distribution of faecal contamination across interconnected systems.

The lack of an integrative conceptual tool represents a key gap in the sanitation and exposed literature. In particular, there is no tool to link upstream Sources and Pathways to downstream Exposure points in a way that supports comparative assessment and intervention prioritisation in complex urban settings. This gap directly informs Objective 1 of this thesis, which evaluates the usefulness of the traditional F-diagram and proposes an alternative conceptual model that can better represent these dynamics.

In addition, much of the existing literature focuses on Exposure at discrete points of context, without assessing the relative significance of the different exposure Pathways within the same community, or considering how dominant risks emerge through system-level interactions. This limitation underpins Objectives 2 and 3, which assess the relative significance of different faecal pathogen Exposure and identify the Sources and Pathways, including those arising beyond the immediate household environment or locality.

Together, these gaps provide the rationale for the development of the Amplified F-diagram, introduced in Chapter 4, and its subsequent application to empirical microbial and behavioural data in Chapter 8. By integrating conceptual modelling with exposure assessment and systems thinking, this thesis seeks to address the limitations identified in the literature and contribute a more pragmatic framework for understanding and intervening in urban faecal contamination pathways.

3 Chapter 3 - Methodology and Context

This chapter will describe the methodology adopted by the researcher in meeting the objectives as described above (Table 1) which were designed to address the literature gaps identified in Chapter 2, particularly the lack of integrative exposure assessment and system-level analysis. The process of designing the work, including the paradigms, models, and approaches, is outlined. Getting this right is important in order to ensure that this research addresses the topic in the most robust way, considering the weight and importance of the subject matter and public health outcomes. The process of thinking that led to the PhD and, subsequently, how each piece of work informed the next is outlined, followed by consideration of ethics, risk and positionality. The relationship between these approaches is outlined in Figure 20.

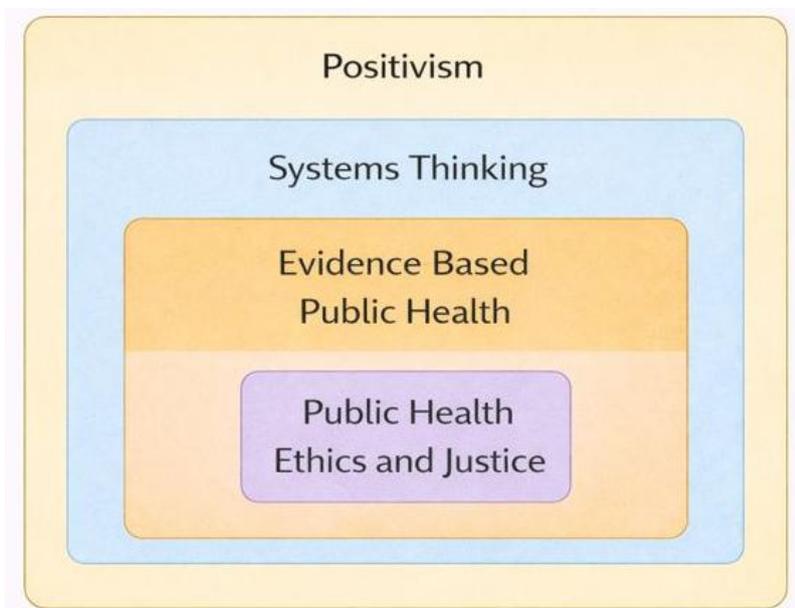


Figure 20 - Relationship between approaches

3.1 Research Paradigm – Positivism

Research paradigms play a crucial role in shaping the research process, from identifying questions to designing investigative methods. Positivism is widely used in all physical sciences and is systematic in its approach (Payne and Payne, 2004). It derives from a belief that there is a truth that can be identified and that everything around us can be explained and described, and is governed by patterns, principles or laws (Mukherji and Albon, 2023). Positivist science suggests that explaining and describing the causation of observed patterns

enables solutions (Romero et al., 2013; Sultana, 2020). The aim of this thesis is to develop a better understanding of the principal pathways of faecal contamination in low-income urban communities, and to add knowledge which will contribute to solving problems relating to the health impacts of failed sanitation.

Positivist research consists of looking for a pattern, planning an investigation, investigating the pattern, analysing the results, and finally coming to a conclusion about the reasons behind the pattern (Mukherji and Albon, 2023). The positivist approach is generally accepted in application to science, but is criticised when applied to questions relating to investigating attitudes and feelings in social science (Payne and Payne, 2004). For this thesis, the positivist approach is an appropriate paradigm for investigating faecal pathogens pathways in the urban environment using mainly quantitative methods.

Positivist research can be confirmatory with a formal hypothesis about the causation behind the pattern or exploratory with a broad idea about why the observed pattern occurs (Johnson and Christensen, 2024). The lack of peer-reviewed, analytical work and preexisting models on this topic, as explored in Chapter 2, necessitated an inductive approach to be used here. Each stage of this work was developed in response to the previous step, and therefore, it was not appropriate to form a hypothesis. This inductive analysis process is crucial as it allows this exploratory data collection to draw conclusions on the big-picture reasons behind the observed patterns, based on the balance of probability that the conclusion is true (Romero et al., 2013; Mukherji and Albon, 2023), highlighting the necessity of this research.

While the positivist approach is well-suited to this research, it is important to acknowledge that any scientific study set in the real world does not exist in isolation from human behaviour, individual impacts and contextual factors; therefore, these must be considered in the design and interpretation of the data collection and analysis to ensure that the design is accurately testing what it sets out to test (Mukherji and Albon, 2023).

Based on this summation, the researcher chose this approach as appropriate for meeting the research objectives. In this mixed methods research, focus group discussions, key informant interviews and observations are carried out to triangulate data on behavioural patterns (Park *et al.*, 2020). The focus remains on physical contamination processes rather than on the subjective lived experience or opinion of the participants; therefore, positivism remains the best approach.

3.2 Evidence Based Public Health

I am originally a health scientist, then trained in engineering, and now working on public health in the School of Civil Engineering. Public health has overlaps with medical research, but has a different focus; instead of the individual patient, the emphasis is on the community (Brownson *et al.*, 2009). My experience allows me to bring my expertise from both disciplines: the engineered systems around water and sanitation intersecting with the considerations of health, pathogens and transmission prevention.

Evidence-based medicine is referred to as the gold standard approach in all medical interventions on the individual scale. It is based on Cochrane's observations that, in the past, medical Treatments did not have evidence of their effectiveness, and so he sought to change that by ensuring that all interventions were backed up by appropriate data (Cochrane, 2004).

There have been several models of Evidence Based Public Health (EBPH) formulated over the years, but a common factor is that scientific evidence should be used in decision-making with a sound understanding of the context and resources available. This commits the public health professional to make decisions according to the best scientific evidence, collected in the most robust way. This has the benefit of more successful disease prevention and effective use of public and private funds. The EBPH action cycle is to generate evidence, synthesise the evidence, communicate with the public, and make policy recommendations for decision-makers (Lhachimi *et al.*, 2016). This does not mean that common sense and anecdotal evidence should be disregarded, but that these cannot be the only things on which thousands or even millions of people's lives and large financial investment decisions are relying. There must be a balance between objective and subjective evidence to move forward from repeating status quo approaches that do not fit the context applied.

The last decade has seen some movement towards applying the same principles used in the Treatment of the individual by a medic to inform public health scale actions (Lhachimi *et al.*, 2016). This is the case, whether or not the term evidence based public health is being used (Brownson *et al.*, 2009). Evidence-based medicine favours rigorous, randomised, controlled epidemiological trials. Public health evidence usually relies on case study approaches and quasi-experimental designs. This means it is problematic to assert direct causality between the action and the result for public health than for medicine. However, natural experiments can provide invaluable data when an intervention is carried out in a set area and not in the surrounding areas (Brownson *et al.*, 2009). For evidence-based approaches to be possible, there needs to be evidence (Brownson *et al.*, 2009). This raises the question of how to gather

accurate community and population-level health data, and what constitutes good evidence (Kaplan, 2019). Research is plentiful in some topic areas, but there are still many subjects where data is sparse, and more work is needed.

The objectives of using evidence-based public health approaches are to ensure high-quality data and analysis precede action, to bring a higher likelihood of successful programmes with long-lasting benefits and resources being more efficiently used. Public Health interventions in practice can lack systemic assessments of peer-reviewed evidence of the best approaches and instead respond to crises. Hindsight reviews have concluded that the population interventions which significantly increased life expectancy in the USA are clean water, sanitation, adequate clean food, smoking policies, injury prevention strategies and immunisation (Brownson *et al.*, 2009). However, another review found that at the time of carrying out a project, the public health benefits are only known for 4.4% of population-level interventions (Thacker *et al.*, 2005), making it clear that a true assessment of the efficacy of public interventions is rare. This means that interventions are carried out and repeated without certainty of the best approach. This research aims to use the evidence-based approach to bring rigour and expansion to somewhat oversimplified narratives and status quo approaches to improving public health regarding faeco-oral diseases.

3.3 Systems thinking

Systems thinking is an oft-mentioned, nebulous concept that describes something so basic and fundamental that it can be hard to define. At its core, however, it is the recognition of the complexity surrounding any given issue, and the understanding that the wider system must be included to make analyses useful and interventions effective. It is important to be forthright about it because it can be easy in science to forget about the context and concentrate on answering our research questions as if we are looking at a test tube in a laboratory. Systems thinking for public health encourages transdisciplinarity, contextual understanding, acknowledgement of complexity, and the acceptance that changes in one part of the system can have intended and unintended consequences elsewhere in the system (Leischow *et al.*, 2008).

Infectious diseases have a wide range of entrenched and systemic physical and social determinants. Public health actions focus on three key areas: preventing exposure to pathogens, reducing vulnerability of groups, and ensuring preparedness for responses when hazards do occur (Beauchamp, 1976). Many complex factors lead to some populations having

better health outcomes and some having worse health outcomes; this is a fundamental root and branch of other inequalities, such as poverty. Within this level of complexity, successfully designing interventions to change these inequitable determinants at the population level is proving challenging, even with a myriad of academic and practice groups dedicated to this cause. Engaging with the intricacy of the systems that health exists within is an evolving field, as interdisciplinary research and working across silos are slowly becoming more accepted and encouraged (Canadian Academy of Health Sciences, 2016). Nutritional status is a large protective factor against the effects of faeco-oral diseases; poor nutrition, water and sanitation is often associated with other intersectional issues such as gender, caste, poverty, living situation, location, employment, work type, migrant status, age and disability (Null *et al.*, 2018).

Working on the Bill and Melinda Gates Foundation-funded Phase III Shit Flow Diagram (Centre for Science and Environment, 2020) programme gave me a deep dive into understanding that city-level sanitation system analysis is complex. This is not just from an engineering perspective of understanding the infrastructure that exists, but also that complexity exists within political, policy, and environmental structures. This is further overlaid by informal systems that arise where people are not provided for by municipal services. WASH interventions can sometimes be done on a localised and community scale, but that does not factor in how a city can act as a total system of pathogen flows. Therefore, systems thinking must be the explicit foundation for this research in order that, while the task of formulating a PhD is to make a question small enough to be tackled within the time frame, the big picture of the context and systems surrounding the pathogen pathways continue to exist and be acknowledged.

3.4 Public Health Ethics and Justice

Public health ethics is about ensuring that public health interventions and policies are guided by principles and values that are ethical (Ortmann *et al.*, 2016). One approach would be to say that it is up to the individual to take care of their own health, such as by not smoking and eating healthily. However, many hazards are outside the individuals' control, meaning they cannot choose to avoid exposure, for example, to air pollution. This can also result in a sense of pessimism, powerlessness and fatalism, which weakens the impulses of the individual to take action to reduce their risk, even where that may be possible. This can be rightly or wrongly driven by the belief that their individual actions make little difference to the overall

risk they face. Inevitably, the risk we face as individuals is dependent on our own actions but also on the individual actions of those around us, the industries and the state that we live under: we place our lives in each other's hands. Blaming the victim offers those benefiting from structural injustices a ready-made justification, masking their complicity and obscuring the need for systemic change. This structural and systemic norm is known as market justice, where the benefits are available and 'on the market' for those who wish to adhere to the health advice or work hard enough to earn the money to purchase the benefits, such as living in a clean area or paying for medicine (Beauchamp, 1976). Market justice perpetuates inequities and is unethical.

There is a large body of work (Ostrom, 1990; Ostrom, 1996; Arnold *et al.*, 2015; De Angelis, 2017) promoting the power of the community collective action in being able to effect change. The idea of a 'commons' describes community assets that could benefit everyone if shared and cared for well. This often refers to shared spaces such as places to congregate or play, or rivers and oceans. A commons dilemma occurs when the collective benefit involves some cost, time or inconvenience for each person. For example, for individuals to avoid open defecation or littering and instead travel to the public toilets or municipal bins could be seen as an inconvenience. However, every member of the community adhering to these behaviours improves the environment and reduces hazards for all; those not doing so cause an unsanitary living environment for everyone (Ostrom, 1990; Kaplan, 2019; Sultana, 2020). This sharing of space and resources is more common in rural areas where community cohesion is more likely. Urban areas can be different, with higher transience of people and often lower agency over their surroundings. Work on the 'urban commons' has sought to understand where caring for the commons is still possible in urban areas and how it is different to the rural situation. It can involve more collective lobbying of municipalities, rather than direct action. This idea is sometimes promoted to engender community engagement to overcome problems, such as Solid Waste build-up, that the municipality is unable or unwilling to solve. Usually, solutions focus on the state or markets that have been shown as repeatedly failing to have the power to solve these 'wicked' problems (Arnold *et al.*, 2015; De Angelis, 2017). However, this standpoint assumes that the community effort, which might be substantial in terms of energy, time and even funds, has the power to afford the necessary changes and that it is something that the community members will want to engage in (Mosler, 2012). It is likely that often, these communal acts of local improvement are powered by one or a few charismatic and highly motivated members of the community who expend a lot of energy in persuading others to change their behaviour and join in the efforts

(Cleaver, 1999). There could be debate about the most appropriate line between state responsibilities and community action, but I would propose that community action should be for 'extras' like providing spaces for socialising, improved entrepreneurial activities, neighbourhood watch preventing petty crime, skills swaps, etc, and not for 'basics' like clean water, sanitation, Solid Waste management, health, social care, Transportation systems and safety from major crime (Evans, 1996; Willetts *et al.*, 2022). Asking members of the population to improve their own health through individual actions is a disservice to them because system-level changes are needed to affect real change. Kaplan terms this a 'betrayal' and suggests that public health researchers should be advocating for radical social and systemic changes (Kaplan, 2019).

Politicians advocate for policy reforms that reduce inequality for a variety of reasons; this can be to make a genuine difference, but it can also be to paint themselves in a favourable light. The advocacy for equitable policies can also be a distraction ploy to seem like the government is addressing a topic, while allowing the systemic failures to remain (Mosse, 2004). It strengthens the belief of the privileged that all that can be done is being done, and nothing more disruptive is necessary (Beauchamp, 1976).

As well as individual action, there is often a health promotion that relies on curative health services, such as hospitals and doctors. However, these cannot possibly make the major reductions in disease and death that would be needed to bring equality in health between populations. Real progress can only be made by wider alterations in the structures and systems around people, enabling changes in the environment and lifestyles lived (Beauchamp, 1976). The reality is that the causes of diseases are acutely political and, therefore, are outside of the scope of doctors to cure. Science is always ethical and political (Kaplan and Valles, 2021a). Minorities (even of very large numbers) can suffer social or health problems for a long time without public attention, but when attention increases, there may be some hope that this problem will be tackled and solved. The majority may hope for technological or local solutions that do not involve a major reordering of societal structures, but often, this is not possible. Solving the problem can threaten inconvenience, loss or cost for the majority who benefit significantly from their privileged position in the status quo. In this case, the problem may be considered unsolvable, and the deliberate or accidental disparities may be allowed to continue as an accepted norm (Downs, 1976). A key principle of public health is controlling health hazards, but when a small minority of people are exposed to the hazard, it is not always efficient or necessary to intervene. In these cases, it could be easier to identify why some people are exposed to the hazard by individual factors. In

attempting to change the behaviour of this minority, there can be a tendency to victim-blame and unfairly protect the majority from responsibility for allowing the hazard to remain (Beauchamp, 1976).

Instead, the public health approach is to control the hazards, not consider the affected individuals as having failed. It is the system that has failed to control the determinants of health sufficiently (Beauchamp, 1976). That is why looking at the factors leading to environmental contamination with faecal pathogens is so important for this work. The aim should be to protect all human life from hazards that cause illness, disability and death, where all persons have equal entitlement to good health and well-being (Beauchamp, 1976). Controlling hazards, as is the focus of this thesis, may be a technical task, but with profound social components. Removing the burdens of bad health from minorities and creating equal burdens and expectations in all walks of society means public health is a justice project.

If we do not have data, we cannot promote good public health. Understanding pathogen pathways, as is sought in this work, can lead to outcomes that are beneficial for equity by improving health.

The approach adopted in this research is grounded by a positivist orientation. It is explicitly evidence-based, drawing upon empirical data to support analysis and interpretation. This work is informed by systems thinking, recognising the non-linear and complex nature of sanitation challenges and situating the investigation within the wider dynamics of the urban system. Finally, the approach is underpinned by a concern for public health justice, emphasising that effective responses must address structural inequities rather than place the burden of risk reduction on affected communities.

3.5 Research Formulation

Before working on this PhD, I had been working as a Researcher on the Bill and Melinda Gates Foundation funded SFD Phase 3 project. The aim of that project was to assess the impact of the SFDs and to identify improvements or updates that could enable the tool to be institutionalised without further investment phases. As part of that project, we organised expert forums with prominent sanitation professionals worldwide. A common reported theme was the challenge of prioritising interventions to gain the best health improvements, given that using the SFD revealed many concurrent and overlapping sanitation failures. This indicated that the sanitation professionals wanted to use evidence-based public health approaches but were unsure where to begin. This, in turn, indicates that data and models on

sanitation failure health impacts would be helpful for sanitation practitioners. This experience was seminal for me, revealing the need for furthering the understanding of health impacts related to the variety of sanitation chain failures found in typical cities.

At this time, I also carried out a search for other tools currently available for understanding risks from sanitation failures. The SaniPath tool is an excellent complementary tool for SFDs (Raj *et al.*, 2020). While SFDs describe the source of the faeces being emitted into the environment as in the Delhi example (Figure 21), SaniPath rates the relative significance of community exposure points. There was, however, no existing tool or model that could link SFD and SaniPath analyses to characterise the pathways linking sources and exposures. This led to the literature review outlined in Chapter 2 and the conceptual diagram described and displayed in Chapter 4. The method of the diagram’s formulation is described in detail in that chapter.

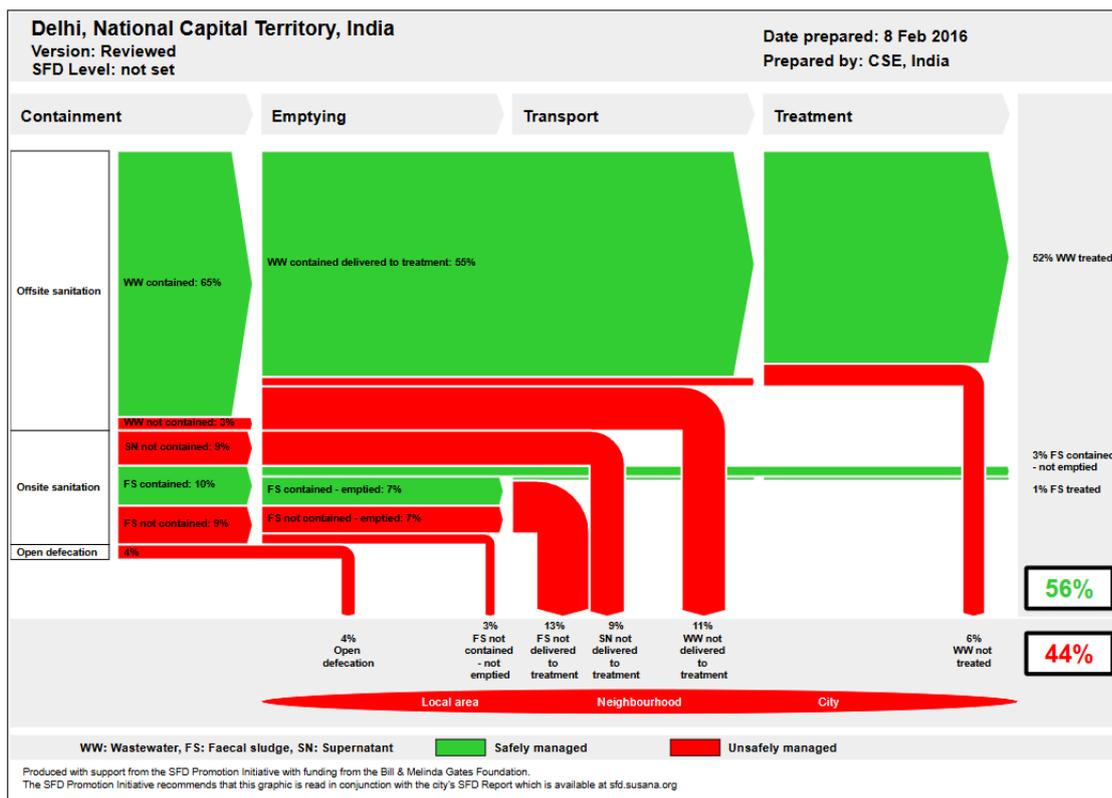


Figure 21 - Shit Flow Diagram of Delhi, 2016, made by CSE, India.

The SFD tells us that the sources of faeces in the environment come from all three stages of the sanitation chain. The three largest, red downwards arrows come from the Transport segment of the chain with faecal sludge (FS) not delivered to Treatment, supernatant (SN) not delivered to Treatment and wastewater (WW) not delivered to Treatment. The literature tells

us that these failings are likely to reach communities through surface water and Open Drains (Chambers *et al.*, 2008; Lara *et al.*, 2011; Xagorarakis *et al.*, 2014; Schoen *et al.*, 2014; Mills *et al.*, 2018; Islam *et al.*, 2018; Crank *et al.*, 2019; Peal *et al.*, 2020a; Amin *et al.*, 2020; Manga *et al.*, 2022; Salubi *et al.*, 2025), consumption of contaminated foods (Lara *et al.*, 2011; Xagorarakis *et al.*, 2014; Schoen *et al.*, 2014; Lam *et al.*, 2015; Mills *et al.*, 2018; Manga *et al.*, 2022) and fomite contact with the contaminated environment (Chambers *et al.*, 2008; Lara *et al.*, 2011; Graham and Polizzotto, 2013; Amin *et al.*, 2020; Manga *et al.*, 2022; Salubi *et al.*, 2025).

Evidence is needed to establish the actual hazards faced in Delhi, so a SaniPath analysis was carried out in the selected communities. The results of the SaniPath study carried out in the selected Delhi communities are described in Chapter 5 (page 75). These results informed the focus of the pathway investigations that are described in Chapters 6 and 7.

3.6 Nomenclature

In any thesis, language is used in a precise way to communicate a set of ideas.

The sanitation chain is sometimes referred to as the sanitation value chain. Here, the word value is omitted intentionally as the concept of the value of the faecal materials for use falls outside the scope of this work. In this context, the importance of the sanitation chain functioning as an unbroken chain is paramount.

While this work draws from a range of disciplines, often water and sanitation work is carried out by practitioners with a hydrology background. This leads to the incorporation of ideas such as point source for contamination, and then the impacts on downstream areas or communities. These flows are hydraulic (with water) and follow gravity. In low- and middle-income countries where there is not complete sanitation coverage, the situation is much more complex and erratic. There are hydraulic and gravity-mediated flows, and there are also flows that are not hydraulic and therefore do not follow gravity. These non-hydraulic flows could be considered neglected due to the paucity of evidence of their being considered in research or intervention planning.

Source-pathway-exposure linkages are a way to describe how pathogenic material travels from the origin to the new host. In this context, the source is the failures in the sanitation chain. These failures allow faecal matter to escape from where it is safely contained, transported and treated, and means that it is in the environment. Pathways are the ways in

which the faeces move around the environment and can be as short as a few centimetres or as long as thousands of kilometres. Flow is a simple word meaning the movement of something from one place to another, and is another word used for the pathways.

Faecal pathogens include a wide range of organisms that are transmitted through contact with faeces. Among them are bacteria (*Escherichia coli*, *Salmonella* spp., *Shigella* spp.), viruses (norovirus, rotavirus, hepatitis A virus), protozoa (*Giardia lamblia*, *Cryptosporidium* spp., *Entamoeba histolytica*), and helminths (*Ascaris lumbricoides*, *Trichuris trichiura*, hookworms) (Board, 2015). These organisms are responsible for the majority of diarrhoeal and enteric infections worldwide, with particular impacts on child health in low-income urban settings (WHO, 2017). In this thesis, exposure was measured rather than specific organisms, so when faecal pathogens or contamination is referred to it includes any and all of the above categories. Some studies extend the analysis of faecal contamination to include animal faeces as a source of community and household exposure. This thesis does not address that dimension, as the interventions required to reduce exposure to animal faeces are fundamentally different from those needed to address systemic weaknesses in sanitation infrastructure and management.

Exposure to potentially pathogenic materials is here used as a proxy for health impacts. Only if a high enough dose of pathogens is received by a susceptible host does exposure become disease (Board, 2015). In areas of profuse faecal pathogen exposure, the disease response may not be obvious (such as a case of diarrhoea), but may be chronic, impacting gut function and healthy growth (Bank *et al.*, 2006). Therefore, this thesis employs concepts such as exposure and contamination to describe an unacceptable state that is subject to conditions that may result in health impacts from faeces.

In this thesis, the idea of “solving” sanitation chain failures is employed as a shorthand for interventions that are both contextually appropriate and effective in preventing faecal pathogens from entering the environment. The term is not intended to imply a single universal solution or to advocate for one particular technological or behavioural approach. Rather, “solving” functions as a catch-all phrase to signal the necessity of targeted actions that address specific failures within their social, infrastructural and ecological context. Put simply, the focus is on the outcome of breaking the link between faeces and human exposure rather than on prescribing a fixed method of achieving it.

In this thesis, the use of capitalisation draws the readers’ eye to the important themes and concepts across the work. Examples of this are the stages of the sanitation chain

(Containment, Transport, Treatment), nodes of the Amplified F-diagram (e.g. Open Drain, Fomites, Fresh Produce) and Solid Waste.

Solid Waste is the term for municipal trash and litter that is generally generated in residential and commercial areas. This is usually managed separately from medical and industrial waste. In this case, the Solid Waste found in the communities is usually a mixture of snack packaging, raw foods, cooked foods and other items such as paper, foil and rags.

3.7 Selection of the data collection locations

Exploring the links between SFDs and SaniPath presents a considerable methodological challenge. Reliance on desk-based analysis could generate a complex model, but with a high degree of uncertainty. To address this, a single exemplar city was chosen as a case study through which these connections could be investigated in depth. The process of city selection required the identification of a context with certain characteristics, including the availability of an SFD (Figure 21) and existing projects that collected a range of relevant supplementary data. Delhi was selected, not only because it met the practical requirements but also due to its strategic significance as one of the world's largest and fastest-growing megacities (Mallick *et al.*, 2024). Therefore, it offers a critical setting in which to examine the interplay between sanitation chain failures and environmental exposure risks.

Three urban low-income communities were selected, along a drainage line where there was good hydraulic information to support the interpretation of the results. This hydraulic information, and extensive social, infrastructural and economic data, was being gathered by teams associated with The Water Security and Sustainable Development Hub (Water Security Hub, 2022). This group will be referred to as The Hub subsequently. The project partners in the India branch of this Collaboratory were the Institute of Technology Delhi, Jayna Collective, and the School of Planning and Architecture New Delhi. This doctoral research was affiliated with their work.

Three study locations were selected in cooperation with the Jayna Collective team, who had been working along the Barapullah drain and had built a relationship with the communities there. Jayna Collective also provided experienced enumerators and translation services for this doctoral project.

Communities with good access to clean piped water were chosen due to the research focus, which aims to focus on faeco-oral disease transmission from failed sanitation (see Table 2).

Due to the interest in the upstream and downstream effects of living adjacent to the Open Drain, the final choice of the three communities was made to span the drain. These were also chosen as they were relatively homogenous for social background, income status and quality of living. All the communities selected are JJBs (Jhuggi-Jhompri Basti), which is the municipality designation of a registered slum community, but these were relatively formalised and longstanding.

Table 2 - Relevant data about the three study communities (data provided by Jayna Collective and The Hub).

	Year Established	Households	HH Toilet coverage	Water Coverage
Jagdamba Camp	1975	1099	29%	95%
Andrewz Ganj	1978	904	13%	80%
Madrasa Camp	1982	483	11%	100%

Their locations and other key locations are shown in Figure 22.

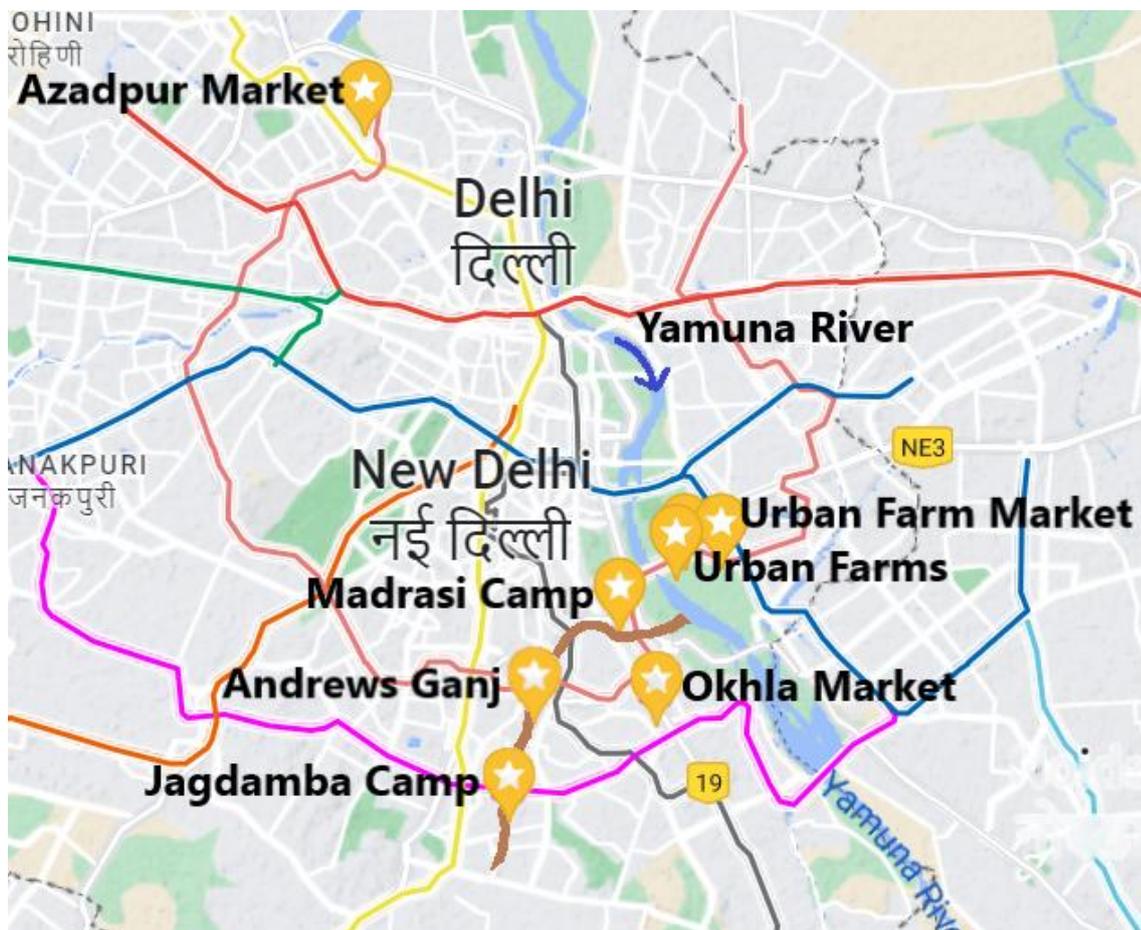


Figure 22 – Delhi and surrounding area, showing the locations of the study communities (Madrasi Camp, Andrewz Ganj and Jagdamba Camp) shown along the Barapullah Open Drain (brown) and their relationship to the Yamuna River (blue, arrow showing flow direction). (Google, 2025).

The Barapullah Open Drain was originally an irrigation channel to bring the waters of the Yamuna River onto farming lands. Since the population has expanded to the surrounding areas, the drain has served the population for drainage and as an open sewer. Dilution from all other water runoff can keep the contamination levels lower than closed drains.

Additionally, in this instance, due to the way that the drain was originally built, it is possible that there is some dilution added from backflow from the river near the mouth of the drain. This would affect the contamination of the drain at the location of our most downstream community of study.

Cultivation along the Barapullah corridor is not governed by the same blanket prohibition that applies to the Yamuna floodplain (Zone O), where farming edible crops has been banned by the National Green Tribunal since 2015 (National Green Tribunal, 2015). Authorities have taken action against farming in these areas due to repeated findings of contamination in produce irrigated with wastewater (Singhal, 2023). By contrast, kitchen gardens on private plots or rooftops, away from the drain, are generally permissible, although larger farming activities must align with the land-use designations in the Delhi Master Plan (Delhi Development Authority, 2020).

Site 1 is Jagdamba Camp, which is upstream from the other two sites. It is situated at the point where the urban density is high and the point where tributaries of the drain converge. From this point until the river, the drain is consistently more than five meters wide. This site is 225m above sea level. Site 2 is Andrewz Camp, which is around halfway and is at an elevation of 215m. Site 3 is Madrasi Camp, which is near the outflow of the drain to the Yamuna River and is at an elevation of 210m. The floodplains where the crops are grown have an elevation of 203m above sea level (Topographic-Map.com, n.d.).

3.8 Microbial Methods

Environmental sampling was necessary to establish the extent of faecal contamination on different pathways and exposures. Following the SaniPath approach, indicator bacteria were selected as a proxy measure of contamination. It is not feasible to test for every pathogen, but the presence of the indicator provides evidence of faecal contamination and therefore

suggests that pathogens are likely to be present. SaniPath suggests the use of *Escherichia coli* as the indicator bacteria because simple, low infrastructure testing methods are available. *E. coli* has many subtypes, which means that it is not specific in distinguishing between contamination of human or animal origin. For this study, human faecal coliforms were selected as the indicator bacteria in order to demonstrate contamination of human origin. For each target pathway and exposure, sampling protocols were adapted from the SaniPath portal (Emory University, 2020).

3.8.1 Microbiological Sampling

At the seven sampling sites across Delhi, samples were collected using sterile equipment. More details about these methods can be found in Appendix E (page 234). Piped Water was collected directly into a sterile container after running the tap for 30 seconds. The Open Drain water was collected using a bucket on a string. In each location, it was possible to access the flow away from the banks via a bridge or other infrastructure. A representative grab sample of the Fresh Produce was collected using a sterile plastic bag, inverted for collection. A representative grab sample of the Solid Waste was collected the same way.

Samples were immediately placed on ice in a cool box and transported to the cold storage in the laboratory within two hours of collection. In the laboratory, the solid samples were prepared for plating by adding 150ml of sterile water to each bag, shaking for 60 seconds and draining into a clean bottle. The liquid samples and the solid sample rinses were plated raw and at serial dilutions, in duplicate. Aliquots (0.5ml) were plated on faecal coliform media containing rosolic acid and NaOH, using three serial dilutions in phosphate-buffered saline, and processed in duplicate. Plates were incubated at 44°C for 24 hours. After this time, the samples were refrigerated, and colonies were manually counted and recorded.

Plates containing between 20 and 200 colonies were considered most accurate; therefore, where possible, that range was selected for data analysis. Colony counts were multiplied by the dilution factor and plating volume to calculate colony-forming units per millilitre (CFU/ml), with the mean of the least diluted duplicate plates taken as the result for each sample (Cappuccino and Sherman, 2014).

Testing was carried out in the Wastewater Testing Laboratory at IIT Delhi. Eight plates were necessary for processing each sample due to dilutions and duplication. Therefore, due to limitations of space in the laboratory, it was necessary to be selective about the number of samples processed.

3.8.2 Data Analysis

Quantitative data analysis was carried out using Excel (Microsoft® Excel® for Microsoft 365 MSO (Version 2508 Build 16.0.19127.20192) 64-bit) for collating and cleaning the data, and MiniTab (version 22.1) software to allow a thorough examination of the data, building figures and investigation for significance. The observational and microbiological data were assessed, making a comparison between categorical data types. The observation tally sheet data was transformed into deposit-event level rows.

For two-category comparisons, two-sided binomial tests against a null probability of 0.5 were used, with p-values reported. For comparisons across more than two categories, Pearson's chi-square tests were applied to contingency tables, with Cramer's V used as an effect size measure. Continuous datasets were tested for normality using the Shapiro-Wilk and Anderson-Darling tests, both before and after log transformation. All the data remained non-normally distributed, so non-parametric approaches were adopted. Kruskal-Wallis rank-sum tests were used to assess differences between groups. Where significant differences were observed, Mann-Whitney pairwise tests (adjusted for ties) with Bonferroni correction for multiple comparisons were applied (Campbell and Machin, 2003). These tests were to determine if there was a random split between the finding categories, or if there was something driving a meaningful difference.

3.9 Ethics and Risk Assessment

Ethical approval was sought and gained from the University of Leeds (see Appendix C - page 173). Collaboration was sought from partners in India to ensure that the correct permissions and protocols were adhered to.

Participants involved in the household surveys, focus group discussions, and key informant interviews gave fully informed consent to their participation. All these participants were adults and were not recruited from vulnerable groups. There was no coercion nor reward for participation. Participants could leave at any point during the surveys, discussions or interviews if they wanted to. There was no element of deception in the research; the purpose was explained fully to the participants, and they could ask questions if they wanted further clarification or information.

None of the data recorded included any personally identifiable data and was saved onto a University of Leeds laptop that was password-protected. It was also stored on the University of Leeds OneDrive storage cloud. There are no conflicts of interest for the researcher or funding bodies and the research outcomes.

Due to the sensitive nature of the topics, regarding cleanliness and private behaviours, it was important to respect the dignity of the participants and move on from any topic if they expressed any discomfort at all. Indian people who were Hindi speakers were employed for all activities to ensure that they were carried out in a culturally sensitive way.

Participants in the observation were not given the opportunity to consent to their involvement; however, they were being observed in public spaces with no personally identifiable information being recorded. The only information that was being recorded was a tally of different behaviour types according to male/female and adult/child, so it was very general.

Participants were recruited for the household survey by random sampling, going from household to household, focus group discussion participants by convenience, and key informant interview participants by snowballing. Access to the communities was mediated by the in-country partners, particularly Jayna Collective LLP, who have worked extensively in those communities.

Mapping the faecal contamination in New Delhi could have unintended consequences for homes and businesses in the affected areas. This issue has been considered and managed before the publication of any data in order to produce visualisations that are meaningful but not harmful, particularly for the urban farming communities who are at risk of eviction by the authorities.

Although participants did not receive immediate benefits from this study, this research is intended to contribute to the broader public health knowledge base, which has the potential to improve interventions in water, sanitation and hygiene. By sharing the findings with relevant stakeholders, policymakers, and the academic community, I aim to contribute insights that could help inform future interventions, health policies, or research studies that address similar issues in public health. This knowledge, while not immediately impactful, holds potential for shaping improvements in the health and well-being of communities over time.

Before beginning data collection, a thorough risk assessment was carried out to identify any potential physical, psychological, or social risks to the researcher or to others. That was

assessed and granted by the University of Leeds before each data collection activity and is included in Appendix D (page 173). Hazards that were recognised and mitigated include risks from the high temperatures and sunburn, poor air quality, access to clean drinking water and food, safety of accommodation and Transportation, contamination from microbial samples and safety in the laboratory. All necessary and precautionary vaccines and prophylaxis were taken before travel. COVID-19 guidance was adhered to, including vaccination.

3.10 Positionality statement

In interdisciplinary fields like civil engineering and public health, human and environmental systems intersect, which means that recognising positionality supports more ethical, inclusive, and context-sensitive research. As a white English woman, my positionality is shaped by the intersection of my identity, background, and the contexts in which I work. My upbringing in Leeds, a big multicultural city, has allowed me an understanding of social inequities, informing my approach to designing my research to benefit those of low-income and socio-economic positions. My family are originally from Scotland, a nation that has experienced its own complex history of colonisation and systematic cultural oppression. This has given me the ability to step outside the usual lens of English perspectives.

Despite my history, I acknowledge that I am working within a broader global structure of inequality, where my race and educational opportunities afford me privileges that are not equally distributed. In India, a country with British colonial history and a complex sociopolitical landscape, I strive to be sensitive to local knowledge, cultural dynamics, and the ongoing impacts of historical injustices. I am acutely aware of my status as an outsider, both as a foreigner and as someone whose appearance carries historical connotations of colonialism. One person I spoke to in India told me, “I don’t usually make friends with white people or give them space to be involved in my work, as they are usually here with their own agenda and to interfere”. I did not take for granted any person who collaborated with me or allowed me into their spaces.

My gender also influences my research approach, particularly in the field of engineering, a discipline that has historically been male-dominated. In many contexts, including both the UK and India, gender expectations can influence perceptions of competence within academic and professional spaces. While collecting data in India, I was especially mindful of the local gender norms and expectations, which may differ significantly from those in my home country.

Navigating these intersecting post-colonial and gendered landscapes requires a balance between adapting to local contexts and advocating for equity and inclusion in my work environment. I aimed to approach my work with humility, recognising the need to constantly interrogate how my presence, privilege, and cultural background may influence both my process and the conclusions that I reach.

4 Chapter 4 - Formulation of the Amplified F-Diagram

The review in Chapter 2 located a need for a diagram that does not oversimplify the sources, pathways, or exposures but remains focused on human faeces. This led to the development of the Amplified F-diagram by this author; this is shown in Figure 23. The coding to recreate and adjust this diagram using the SankeyMATIC tool (SankeyMATIC, 2025) is available in Appendix B (page 172). This is a generalised or conceptual model, and therefore, all of the plausible types of failure that could plausibly occur are included. In that way, this is similar to the Master SFD diagram Figure 15.

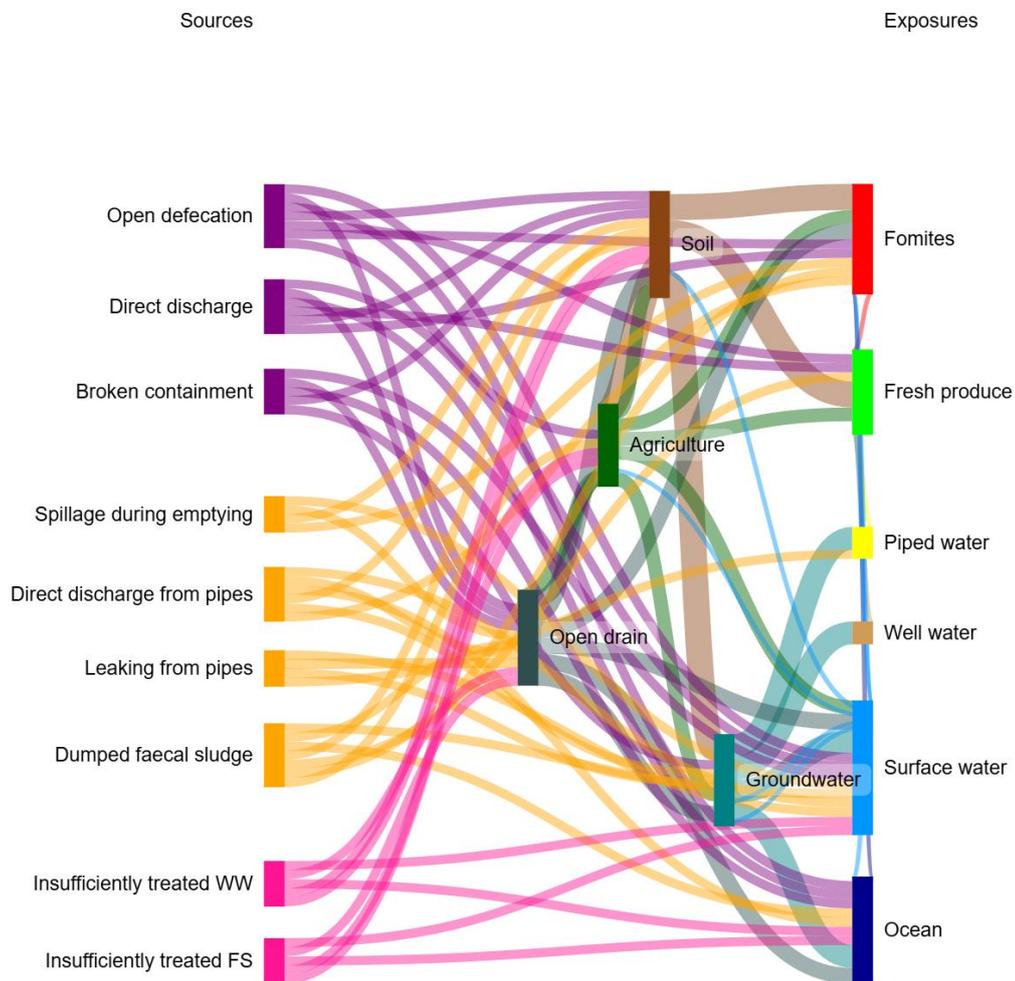


Figure 23 - Amplified F-diagram: a model for understanding the flows of faecal pathogens (source, pathway, and exposure). Colour-coded flows: Containment failures (purple), Transport failures (orange). Treatment failures (pink), flowing through Open Drains (navy), Soil (brown), Agriculture (dark green), Groundwater (Teal).

It is important to explain the evolution of the original F-diagram aspects and how they are represented in the Amplified F-diagram. The singular node of 'faeces' is now included in the

nine sanitation chain failure nodes as the sources on the left-hand side. The true source of faecal matter is so much more than just the image of a person practising open defecation on the F-diagram; in fact, faeces is reaching the environment in many ways concurrently. For the Amplified F-Diagram, the failures from the SFDs are utilised (Peal *et al.*, 2020a); the categories are Containment, Transport and Treatment which are separated by colours (purple, orange and pink).

‘Fluids’ are now shown as Piped water, Well water, Surface water, Ocean and Groundwater. This separation is important as the different water sources have different sources of contamination, people interact with them in different ways and for different reasons and different interventions are needed to prevent faecal contamination and exposure. ‘Fields’ and ‘floors’ are included in fomites, which are anything that can be touched and cause exposure to faecal pathogens. ‘Fingers’ are considered part of the person being exposed but are connected to fomites. ‘Foods’ is included as Fresh Produce. Food in general is not included, as often the contamination related to food is a hygiene issue, and this thesis is focused on sanitation failures leading to environmental exposure. The ‘new host’ of the F-diagram is not shown but is implied here in interaction with the exposures. The exposures are the hazard; this diagram does not define whether those hazards become a risk, as that is determined by the behaviour of the communities in interacting with the exposures. One challenge in making this diagram is that many of the nodes and pathways are concurrently sources, pathways, exposures and sinks. This is particularly the case for the nodes that are located in the middle of the diagram, which do not fit neatly on the left or the right side of the diagram.

In this conceptual diagram, each flow begins as the same width. Some of these flows go directly to the exposures, but others flow to the central nodes first. Therefore, the width represents how many flows are arriving at that node. In order to retain the weight of the multiple sources, each mid node outflows are split equally between the outflows. There are also flows from some of the exposure nodes to other exposure nodes.

This means that the size does not necessarily signify contamination or health risk but signifies the number of different sources leading to the potential faecal contamination on the central node or exposure. Hence, the size suggests how difficult it may be to protect that exposure from contamination due to how many different potential pathways would need to be interrupted. This suggests the number of different types of interventions that would be needed to render it free of contamination.

This model does not include consideration of the die-off or sinks that could occur in the environment, nor the multiplication of pathogens. This is because this model is showing potential pathways. Confirmation of the pathways and the contamination level would need to be determined on a case-by-case basis with context-specific data. Epidemiology is concerned with quantifying risk numerically, but in contexts with high and pervasive contamination of faecal pathogens, the only numbers that really count are 'none', 'few' or 'many' (MacLennan, 1983). All the flows represented in this diagram have the potential to bring 'many' faecal pathogens to human exposure and therefore have been included in this diagram. Work to quantify this further can be done on a context-by-context basis as required.

As described, the size represents the complexity of solving the sources and pathways leading to the exposure point. Those larger nodes may be the ones that retain some contamination even while the city is making progress towards safely managed sanitation. In this conceptual diagram, Surface Water is the largest node, closely followed by Fomites, Ocean and Fresh produce. This suggests which exposure points might be the hardest to solve and which may have lingered faecal contamination even as the sanitation chain is nearly failure-free.

In the diagram, the nodes and flows are colour-coded in order to enable the reader to more easily see the origins of each pathway. The Containment, Transport and Treatment failures (purple, orange and pink), and the mid flows of soil, Open Drains, groundwater and agriculture (brown, navy, teal and forest green), could each be modelled as 'solved' to show more easily how different intervention activities may impact on the resultant exposure hazards. If an 'intervention' dealt with all of the flows to an exposure, then that node would disappear from the diagram.

Figure 24 reapplies the idea of barriers as used in the original F-diagram to the Amplified F-diagram. This time, the barriers have been split into 18 different potential points where interventions are commonly made. This visual is useful for showing how few of the sources, pathways or exposures are interrupted by any one intervention, and how many remain uninterrupted.

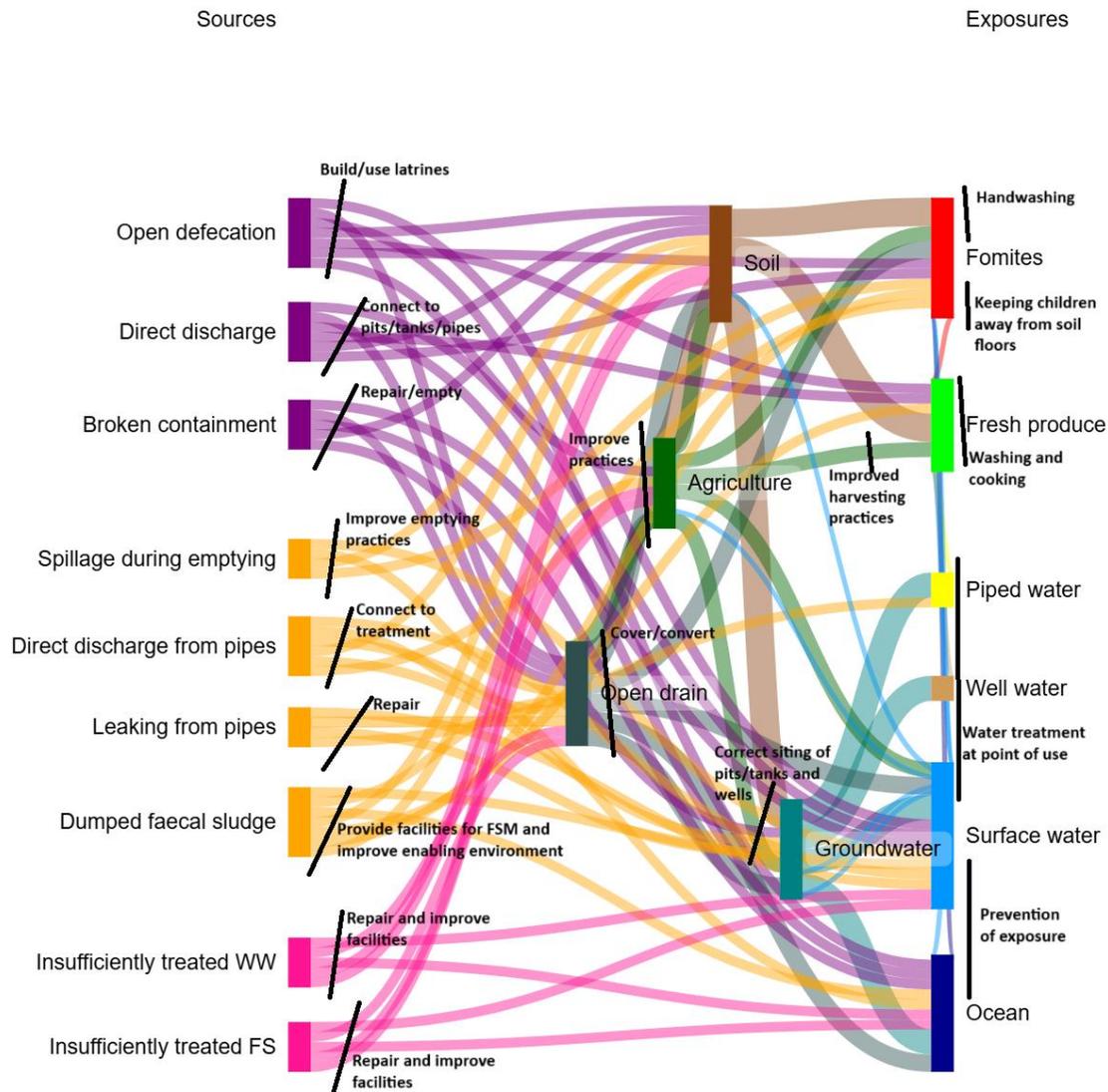


Figure 24 - Amplified F-diagram with potential barriers as in the original F-diagram.

This chapter has set out the development of the Amplified F-diagram, explaining in detail how it was constructed and how it extends the original model to better reflect the complexity of urban sanitation systems. By mapping the multiple and overlapping sources, pathways and exposures of faecal contamination, the diagram provides a framework that can accommodate both localised and city-scale processes. It is intended not only as a conceptual tool but also as a practical guide for identifying where interventions are most likely to deliver meaningful public health benefits. This meets Objective 1 as outlined in Chapter 1 (page 19).

5 Chapter 5 - Exposure Risk Analysis

This chapter describes the faecal exposure risk assessment in the study communities. The purpose of the assessment is to identify the most significant hazards. This will inform more detailed investigations, which are described in subsequent chapters.

The assessment of risk to the communities from exposure to faecal pathogens was based on the SaniPath project approach, which uses microbial sampling and behavioural questionnaires. This combination of data was used to estimate the relative risk based on the size of the hazard and the frequency and severity of exposure.

5.1 Methods

5.1.1 Before Data Collection

The researcher carried out transect walks in the three communities to identify the possible exposure points. This was done with the team of local enumerators. The targets for sampling were identified as Open Drains, municipal piped water, raw produce and Solid Waste. The sampling method for Solid Waste was adapted from the SaniPath method for raw produce sampling.

The SaniPath household survey was downloaded and amended to establish how often the community members interact with the identified environmental exposures. This was then translated into Hindi by the project partners, for use by the enumerators. Back translation was not necessary as the results were numerical. Training was conducted with the experienced local enumerators who were part of the Water Security Hub partnership, and they had opportunities to ask questions before beginning and throughout data collection. After each day of sampling, this researcher checked the survey responses, and an opportunity for any further enumerator queries was provided for clarification. The survey and other data collection forms can be found in Appendix F (page 239). The Kobo app was downloaded for this researcher to enter the data into the SaniPath portal for further analysis.

5.1.2 Data Collection

A total of 87 environmental samples were collected during the dry season in the study communities. A household survey was carried out within two weeks of the samples being taken, likewise in the dry season. The details of this are shown in Table 3.

Table 3 – Sample type and process information.

Sample type	Sampling method	Method	Where	Number of samples and reasoning
Open Drain	Scoop water from the drain using a bucket on a rope, as near to the middle as possible utilising existing infrastructure like bridges.	Plating raw and at serial dilutions, in duplicate.	Jagdamba Camp Andrewz Ganj Madrasi Camp	21 Samples from each site were taken to gain a clear understanding of the contamination levels in the Open Drains adjacent to the communities.
Piped water	Water was collected directly from the tap after the tap had been running for 30 seconds.	Plating raw and at serial dilutions, in duplicate.	Jagdamba Camp Andrewz Ganj Madrasi Camp	8 Previous tests done by the project partners on piped water showed it to be low in faecal coliforms, so a small number of samples were taken to confirm this was still the case.
Raw produce	Collected directly from vendors within the community and placed into sealable plastic bags.	150ml of sterile water was added to the bag, shaken for 60 seconds and drained into a clean bottle. The rinse liquid was plated raw and at serial	Jagdamba Camp Andrewz Ganj Madrasi Camp	46 From the published SaniPath datasets, it was clear that produce eaten raw was likely to be an important exposure route, so a large number of samples were taken to gain accurate understanding of this.

		dilutions, in duplicate.		
Solid Waste	Collected directly from the municipal bins within the community and placed into sealable plastic bags.	150ml of sterile water was added to the bag, shaken for 60 seconds and drained into a clean bottle. The rinse liquid was plated raw and at serial dilutions, in duplicate.	Jagdamba Camp Andrewz Ganj Madrasa Camp	6 There is no published data about the testing of faecal contamination of Solid Waste while still within the communities. These samples were taken to confirm if this will be an exposure route that will merit further investigation.
Household Survey	House-to-house surveys	Closed questions asking about the frequencies of interactions with the selected exposure points.	Jagdamba Camp Andrewz Ganj Madrasa Camp	259 Every 8 th residence, as recommended in the SaniPath methodology to result in 12% coverage.

5.1.3 Data processing and Analysis

This was carried out as described in section 3.7 on Microbial Methods.

5.1.4 Further analysis

The goal of this stage of data analysis was to compare the hazards faced by the community from various exposures. Therefore, the level of contamination was multiplied by the frequency of exposure to assess the overall risk. Analysis was done using the MiniTab platform to make comparisons between sample type, sample location, and spatial location along the drain.

As a secondary analysis, the SaniPath online tool was used. This uses dose predictions, quantitative microbial risk assessment and Bayesian analysis to combine microbial and behavioural data to produce an estimated monthly dose of faecal pathogens (Raj, 2020). This allows for a comparison of the health significance of each exposure for the communities. Due to the higher sample number requirements, comparison between the communities was not possible, but the tool could still be used by combining all the locations in order for it to provide analysis between the sample types.

To use the SaniPath tool, the data had to be converted from faecal coliforms (as measured) to *Escherichia coli* count using a ratio. The literature recommends ratios varying from 0.59 to 0.77. Two recent documents suggested 0.77; therefore, this researcher chose this ratio, which was also beneficial in preventing underestimation of the risk (Garcia-Armisen *et al.*, 2007; Leydecker, 2008; World Health Organization, 2017).

When inputting the data into the SaniPath data collection tool, it was somewhat challenging to know how to amend it for the inclusion of the Solid Waste. This is because, although some of the calculations are published in the supplementary material, some of the underlying assumptions are not specified (Raj *et al.*, 2020). After some consideration, it was decided that Solid Waste was interacted with as a fomite, which has the most similarity to the interaction with public latrines in the assumptions that the SaniPath model is likely to make. Therefore, the Solid Waste data was coded using the public latrine assumptions within SaniPath.

5.2 Results

5.2.1 Faecal contamination exposure in the communities

Faecal coliforms were detected in all three communities: in the Open Drains, raw produce and Solid Waste. Only minimal or trace faecal coliforms were detected in the drinking water in all three communities.

Figure 25 shows the visual comparison of the level of FC in samples relating to the four exposure types for the three communities. The Open Drain in Andrewz Ganj has the highest mean value. The raw produce, by far, has the largest range and the highest absolute values.

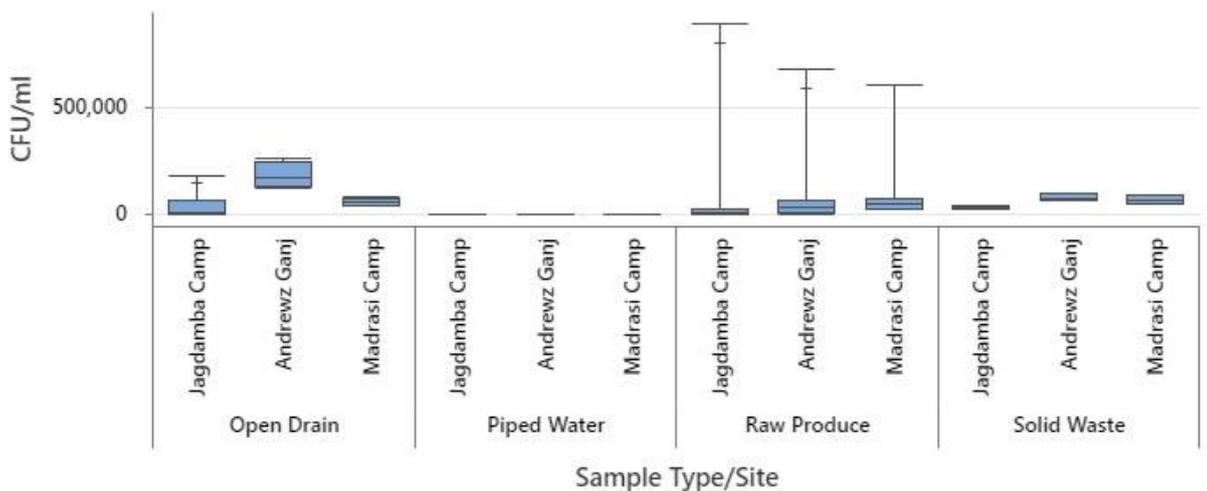


Figure 25 - Prevalence of faecal coliforms in Open Drain, Piped Water, and rinse water from Raw Produce and Solid Waste in samples taken from study sites in New Delhi in November 2022. The bar shows range, and the box shows the 25th and 75th percentiles.

Another way to represent this is shown in Figure 26. If the Open Drain was gathering contamination as it flowed downstream, the expected results would be increasing contamination levels. However, this is not found to be the case. If the Open Drain was the driver for the contamination in the communities, the expected findings would be that the other contamination levels would follow the same pattern of the contamination rise and fall as the Open Drain. However, it is only Solid Waste that even appears to somewhat follow a similar pattern of being highest at Andrewz Ganj and lower at the other two sites. This means it is likely that other confounding factors are also influencing faecal coliform concentration in the communities.

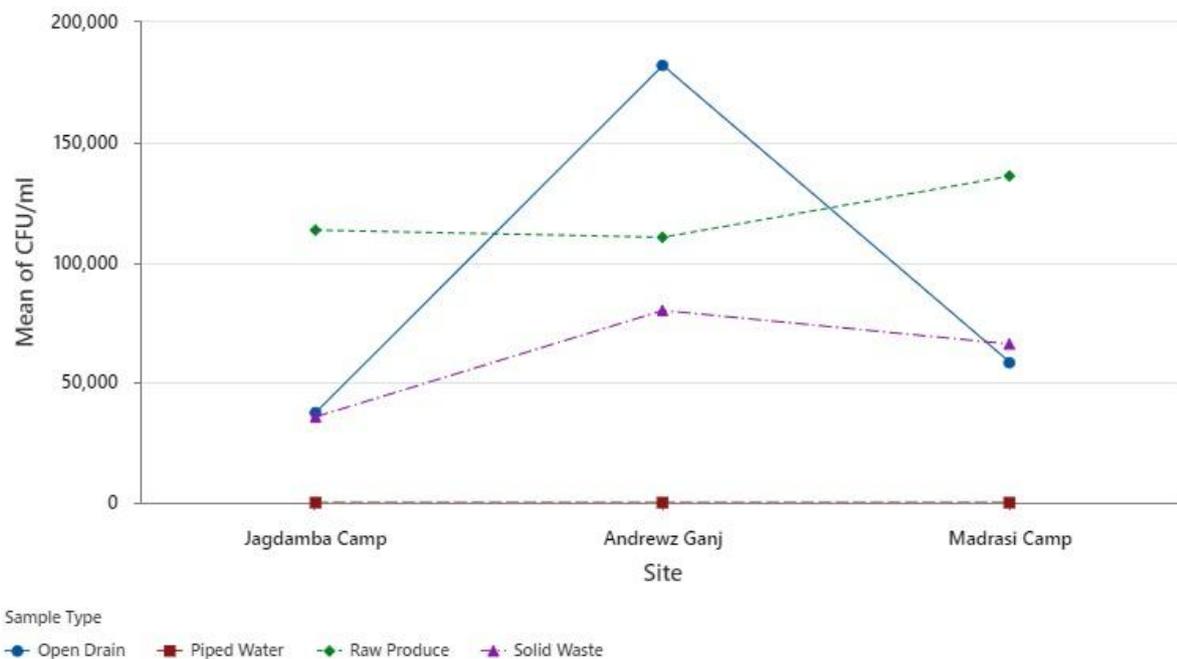


Figure 26 - Relationship between the total mean faecal coliform count in samples relevant to four exposure pathways, along the Barapullah drain from upstream to downstream. Data collected in Delhi, November 2022.

5.2.2 Differences between samples

All the sample categories were compared for significance, and the data are shown in Table 4.

Table 4 - Results of statistical significance tests run on CFU data collected in Delhi, November 2022. Orange cells represent where significant differences are indicated.

Section	Comparison	Variable 1	Variable 2	p-value (orange means significance is indicated)
Sample types				
	Raw produce vs Open drain	Raw produce	Open drain	0.322
	Raw produce vs Solid Waste	Raw produce	Solid Waste	0.080
	Open drain vs Solid Waste	Open drain	Solid Waste	0.620
	Piped water vs Solid Waste	Piped water	Solid Waste	0.001
	Piped water vs Open drain	Piped water	Open drain	0.000

	Piped water vs Raw produce	Piped water	Raw produce	0.000
Sites:				
Open drain	Jagdamba Camp vs Madras	Jagdamba Camp	Madrasi Camp	0.081
	Jagdamba Camp vs Andrewz Ganj	Jagdamba Camp	Andrewz Ganj	0.001
	Andrewz Ganj vs Madras	Andrewz Ganj	Madrasi Camp	0.004
Raw produce	Jagdamba Camp vs Madras	Jagdamba Camp	Madrasi Camp	0.010
	Jagdamba Camp vs Andrewz Ganj	Jagdamba Camp	Andrewz Ganj	0.174
	Andrewz Ganj vs Madras	Andrewz Ganj	Madrasi Camp	0.291
Solid Waste	Jagdamba Camp vs Andrewz Ganj	Jagdamba Camp	Andrewz Ganj	0.245
	Jagdamba Camp vs Madras	Jagdamba Camp	Madrasi Camp	0.245
	Andrewz Ganj vs Madras	Andrewz Ganj	Madrasi Camp	0.699
Sites: Overall				
	Jagdamba Camp vs Andrewz Ganj	Jagdamba Camp	Andrewz Ganj	0.025
	Jagdamba Camp vs Madras	Jagdamba Camp	Madrasi Camp	0.003
	Andrewz Ganj vs Madras	Andrewz Ganj	Madrasi Camp	0.961

Piped water forms a distinct (and plausibly much cleaner) exposure category than environmental and food pathways. Raw produce contamination is of a similar order of magnitude to environmental surfaces and flows; the borderline comparison to Solid Waste suggests a trend, but not a reliable difference at $\alpha=0.05$. Non-hydraulic (Raw produce, Solid Waste) and hydraulic (Open drain) pathways are statistically indistinguishable from one another in these pairwise tests, consistent with the thesis argument that “shit also flows uphill” via non-hydraulic routes.

While all three sites had substantial faecal contamination, there were differences between the concentrations in the three communities. The difference is driven by the lower contamination levels in Jagdamba Camp, with no significant difference between Andrewz Ganj and Madrasi Camp.

5.2.3 Community behaviours impacting exposure

Figure 27 shows the exposure rates. This was calculated by the frequency of exposure assessed from the household survey. In the survey, respondents were asked to report activities on a (daily, number of times a week, or less) basis. This was then converted to how many times in a year that exposure would occur, and then standardised to a population of 1000 people to mitigate for the communities being of different sizes. As shown in the figure, the respondents revealed rarely interacting with the Open Drain. Municipal water use varied between the communities, as did interactions with the Solid Waste. All respondents to the household survey ate raw Fresh Produce daily, which is 365 exposure days a year.

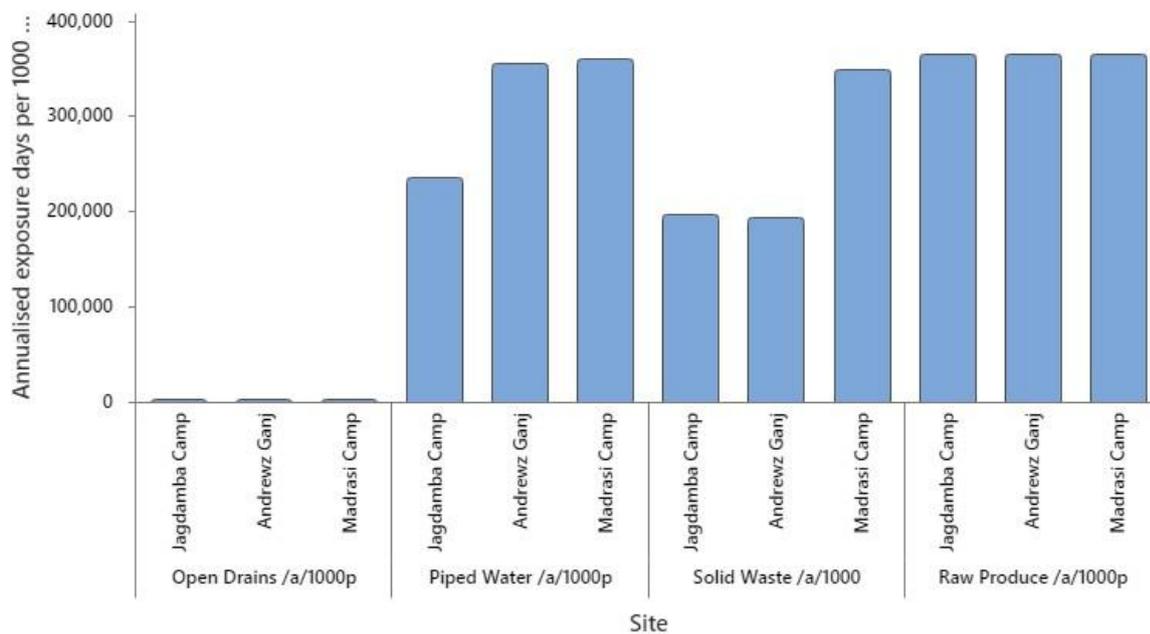


Figure 27 - Comparison of frequency of interaction with different faecal contamination exposure points, in sites along the Barapullah drain, Delhi. Data collected in November 2022.

Exposure days per year per 1000 people. This data was extracted from the household survey where participants were asked about their frequency of contact with the Open Drains, Piped Water, Solid Waste and Raw Produce.

5.2.4 Risk Analysis

Combining the microbial contamination data with the behaviour data gives a crude measure of risk of exposure to faecal contamination. The results of this calculation are shown in Figure 28.

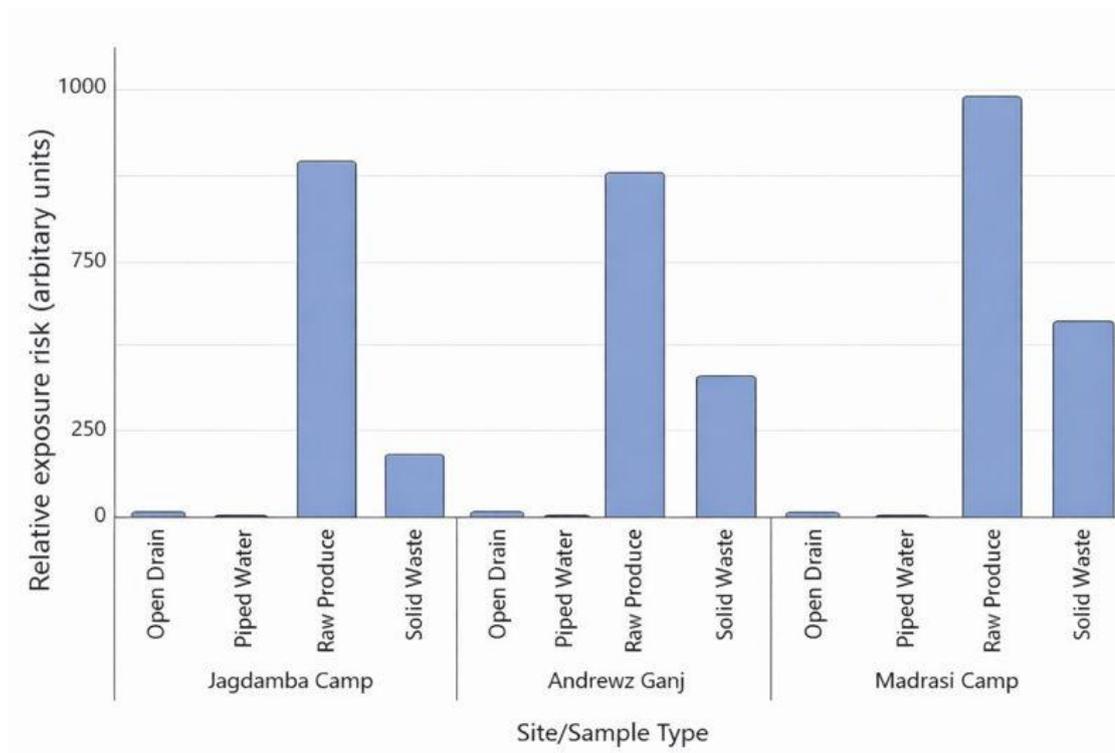


Figure 28 – Relative Exposure Risk: calculated by hazard (CFU/ml on the samples) multiplied by exposure (exposure days per year per 1000 population). Data collected October 2022, Delhi.

The risk calculation was also calculated using the online SaniPath tool (Emory University, 2020) which is shown in Plate 1. Risk from drinking water is negligible due to the low levels of CFU detected, and therefore, a SaniPath graphic was not available.



Plate 1 – SaniPath People Plots. Online tool output, microbial and behavioural data collected in Delhi, 2022. Results (a) Raw Produce, (b) Solid Waste, and (c) Open Drains.

Both Figure 28 and Plate 1 show that Fresh Produce eaten raw brings the highest risk for the three communities. The second-highest risk interaction is with Solid Waste; Open Drain is third. Drinking water generates the least risk due to low contamination levels despite high intake.

5.3 Discussion

Gathering contamination and behavioural data enables the hazard and exposure to be examined and analysed for resultant risk.

5.3.1 Raw Produce

The findings here of Raw produce as a high-risk exposure are unsurprising due to the previous SaniPath dataset findings and other published research that also find similar results (Emory University, 2020). The only Indian data point on the SaniPath dataset is from Vellore (2018), where high levels of contamination were also found in Raw Produce.

An inconsistency was observed in participants' responses regarding the frequency of Raw Produce consumption. While many respondents reported never or only seldom consuming raw produce when asked in general terms, the same participants reported daily consumption when asked about specific items such as chillies or mint. The use of item-specific questions allowed cross-verification, ensuring a more accurate understanding of actual dietary practices and preventing underestimation of raw produce exposure.

5.3.2 Solid Waste

Despite clear correlational support in the literature of the multidimensional hazard caused by Solid Waste build-up within communities, little empirical evidence exists in the literature to understand the level or nature of faecal contamination on Solid Waste or the precise resulting health risks. The results presented here suggest that the role of Solid Waste may play an important role in the transmission route for faecal pathogens. However, there were only two samples taken in each community, and these were from a central location; there is definitely scope for a wider analysis of the faecal contamination on the Solid Waste and an investigation into the cause of this. The behavioural data collected in the household survey was gathered by the question “How often do you interact with the Solid Waste in the community?”. Respondents may have understood this to mean “how often do you take your Solid Waste to the bins?” rather than the intended question relating to how often people are at risk of exposure to faecal pathogens from dumped Solid Waste. Preliminary results from the survey and sampling suggest that the question of faecal hazard exposure due to contaminated Solid Waste merits further investigation and a better understanding of the nature of contamination and related behaviours, and to understand the sources of the faecal contamination of the Solid Waste in the communities.

5.3.3 Open Drains

The Open Drains seemed likely to contribute a lot of risk to the study communities due to being directly adjacent to the houses and looking and smelling unsanitary. However, it seems that while the appearance and odour cause disgust (Curtis, 2013) this has the effect of preventing direct interaction with the large Open Drains. It is also possible that people interact with the drains more than they admitted to in the household survey. This is particularly likely for the smaller drain tributaries that run through the communities. During the transect walks, it was observed that people hopped across these small streams of less than a meter wide, and animals were kept around them. It was also observed at one location that pigs were being kept on the bank of the large Open Drain, and the pig pen was partially submerged in water. This means it is likely that people involved in animal husbandry in the drain localities may have been more exposed to the contamination from the Open Drain than the general population, and this may not have been captured in the survey.

Aside from direct interaction with the Open Drains, it is possible that the Open Drain is a contributing factor to the faecal contamination in the community at other exposure points. The Open Drain faecal contamination was significantly higher at Andrewz Ganj, but none of the other exposure points, or the collective community contamination levels, had significantly higher contamination at Andrewz Ganj. This suggests that, in this case, there is no evidence of higher community faecal contamination being driven by higher Open Drain contamination. It could be that the Open Drain does not contribute to the environmental contamination at all or very minimally. It could be that the Open Drain contributes significantly, but that other contributing factors overwhelm the correlation. It could be that the Open Drain has a significant contribution at certain times of the year, such as during flooding, and this was not picked up by this data collection carried out during the dry season (Yadav *et al.*, 2019).

5.3.4 Piped Water

Water supply was not a major source of risk, contradicting other studies in Delhi (Yadav *et al.*, 2019). A plausible explanation is that the water supply in these three locations suffers less intermittency and therefore less contamination, although this could not be confirmed. Importantly, where community members use alternative water sources such as bore wells and sachets, these could be associated with higher or lower levels of contamination (Chauhan *et al.*, 2017).

5.3.5 Methodological Limitations

The liquid samples (Open Drain and Piped Water) were compared directly with the solid samples (Raw Produce and Solid Waste). The washing process for measuring contamination on Solid Waste samples is not a standard method, and the relationship between the raw condition of the waste samples and the test results is unknown. The results for Raw Produce and Solid Waste are likely to underestimate the true level of faecal contamination compared with the liquid samples. Despite this potential underestimation, the contamination detected in these solid samples was sufficient to indicate that they pose a more significant risk to the community than the liquid exposures. Thus, even under conservative estimates, these exposure routes represent a serious risk that warrants further investigation and intervention.

This data was collected at limited sites within the city of Delhi; the results are not representative across the whole drainage system. Nonetheless, the sites selected were of a typical drain catchment passing through a typical low-income housing area. While behaviour and contamination data may be highly context-specific particularly due to differences in behavioural, cultural, religious and social practices, the results confirm general trends in the literature, including previous SaniPath studies, which suggest that contamination of Fresh Produce eaten raw and poor Solid Waste management are common sources of contamination globally. The study in Barapullah could be a useful prompt for further contextual studies in different locations (Drechsel, 2010a; Wilson *et al.*, 2012; Robb *et al.*, 2017).

This data was collected during the dry season, and there was only one round of data collection. This means that the results must be treated with some caution as they do not capture the variation across the year, particularly in relation to the rainy seasons.

There are some risks of lost nuance due to the data collection tools being translated from English to Hindi. However, the researcher and enumerator team worked in close collaboration with the researcher on site for real-time clarification of any queries.

5.4 Conclusion

This chapter presents the data collection that has shaped the direction of the next two chapters. The analysis of community exposure has been central in determining how to allocate research effort in ways that are most beneficial for both the study and for public health priorities. While the methodological limitations outlined above must be acknowledged, the findings point clearly to the importance of investigating specific transmission routes. Accordingly, the following chapters focus on the sources and pathways of faecal contamination that lead to exposure through raw produce (Chapter 5) and through solid waste (Chapter 6).

6 Chapter 6 - Faecal Contamination Pathways through Fresh Produce

In Chapter 4, Raw Produce was revealed as the most significant potential pathway for exposure to faecal pathogens for people in the three study communities. This finding aligns with other literature (Drechsel, 2010a; Alegbeleye *et al.*, 2018; Emory University, 2020; Raj *et al.*, 2020). Previous studies have asserted or shown that faecal contamination on Fresh Produce may occur at many points along the journey from farm to fork: on the farm, after harvest, at the market and by consumers. Studies have also suggested that the main drivers towards this exposure are the use of unclean water in irrigation and post-harvest washing (Badosa, Trias, Pares, *et al.*, 2008; Faour-Klingbeil *et al.*, 2016a).

Faecal contamination leads to exposure to pathogens including bacteria (*Escherichia coli*, *Salmonella enterica*, *Vibrio cholerae*), viruses (Norovirus, Hepatitis A virus) and protozoa (*Cryptosporidium hominis*, *Giardia intestinalis*). It is likely to be a larger problem where coverage of safely managed sanitation is low, the prevalence of endemic diseases high (Seymour and Appleton, 2001; Drechsel, 2010a), and safe storage practices such as refrigeration are not practiced consistently due to unreliable or expensive energy supplies and infrastructure constraints (Harris *et al.*, 2003; Todd *et al.*, 2007; Badosa, Trias, Parés, *et al.*, 2008; Faour-Klingbeil *et al.*, 2016b). Consuming faecally contaminated raw Fresh Produce has been shown to be strongly associated with increased risk of diarrhoeal diseases (Beuchat, 1998; Harris *et al.*, 2003; Drechsel, 2010a) and *Ascaris* infections (Shuval *et al.*, 1984b; Cifuentes, 1998; Bosch *et al.*, 2006). India has experienced rapid economic growth in recent decades, as evidenced by its GDP, but it still grapples with significant nutrition, food security and infrastructure challenges, particularly among the poorest populations (World Food Programme, 2025). This chapter aims to build on the community-level data described in Chapter 4 to identify, quantify and model the pathways and sources leading to the contamination of the food eaten raw in the study communities in Delhi.

The approach in this chapter is exploratory and uses mixed methods. The data collection was carried out in the dry season. In Delhi, Fresh Produce is sold daily at wholesale markets, from where it is distributed by carts across the city and sold to local vendors within the communities. Therefore, in order to locate the sources of faecal pathogens in the study communities, the food network must be considered more widely than at the point of exposure. The tracing began in the communities and followed the food supply 'upstream'

with a view to identifying likely points of contamination. Data were collected through surveys, environmental sampling, focus group discussions, observations and key informant interviews.

6.1 Methods

6.1.1 Pre data collection

Discussions were held with The Hub team to identify the types of Fresh Produce to prioritise; however, their limited familiarity with the dietary habits of households in the study communities made it difficult for them to provide informed guidance. Examples of this were whether the study communities eat raw herbs, greens, and radish on a daily basis. They were also unsure if community members bought only from their local vendors or would travel further afield. Therefore, exploring these questions became a starting point for the food network investigations.

It was not clear from the literature what form the food network would take in the study communities. Figure 29 outlines several possible models that were considered prior to data collection. These included (a) a linear network in which each of the three study communities relied on separate food source pathways, (b) a collective network in which all three communities shared the same food source pathways, and (c) a more chaotic network in which multiple sources and pathways intersect to contribute to the food consumed.

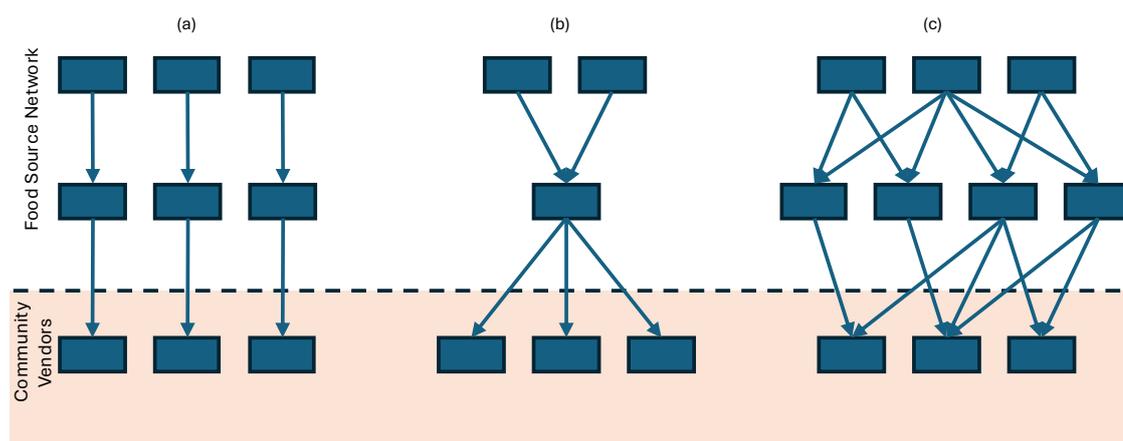


Figure 29 - Food network model possibilities to consider before data collection began. (a) a linear network where each of the three study communities has separate food source pathways, (b) a collective network where all three communities have the same food source pathways and (c) a chaotic network where there is a range of food network sources and pathways contribute to the communities' Fresh Produce.

Preliminary discussions with the Hub team indicated that the food supply network was likely to resemble option (c), characterised by overlapping and shifting routes rather than neat separations. This expectation required the investigations to be designed with multiple starting points, in order to capture the range of possible flows and to avoid assuming a single dominant pathway.

6.1.2 Household Survey

A survey was carried out with 259 participants from the study communities to identify what foods they commonly ate raw. The list of produce was taken from what was seen as available in the communities and a wider range, as suggested by the project partners, to ensure nothing was missed. Survey tool available in Appendix G (page 246).

6.1.3 Focus Group discussion

Focus group discussions were held in each of the three communities. The objective was to get the community's perspective on their Fresh Produce shopping behaviours, to discuss why they chose their vendor, and to see if they view the produce as dirty or contaminated. Printed maps were used for the participants to place sticky dots on to represent where they buy their Fresh Produce locally.

6.1.4 Key Informant Interviews and Observations

At each stage of the food network that was studied, interviews were carried out with key stakeholders, and observations were made of relevant conditions and practices. These twelve stakeholders were located through convenience and snowball sampling while following the chain of the food network from the study communities. The objective of the questions asked was to find out where they purchased the Fresh Produce that they were selling, if they believed it was contaminated in any way, and if they washed it. This includes the urban farms where observations were conducted to establish farming practices.

Following this pathway of information, data collection was carried out at the market identified by most vendors, on the urban farm in the Yamuna flood plains and at the market where Fresh Produce arrives from outside the city boundary.

6.1.5 Microbial sampling

Samples of Fresh Produce were taken from each of the nodes of the food network that were discovered in the network explorations. These samples were transported, plated and analysed in the same way as described in section 3.7 (page 57), resulting in CFU/ml values.

Microbial samples had already been taken in the study communities as described in Chapter 4. Table 5 describes the additional data collection necessary to build an accurate model of the food network and contamination factors.

Table 5 - New Data Collection for investigating the Sources and Pathways leading to the Community's exposure to faecal pathogens on Raw Produce.

Site	Microbial Sample	Behavioural Sample Types
Jagdamba Camp		Produce Survey Focus Group Discussions Key Informant Interviews
Andrews Ganj		Produce Survey Focus Group Discussions Key Informant Interviews
Madras Camp		Produce Survey Focus Group Discussions Key Informant Interviews
Okhla Market	Fresh Produce	Key Informant Interviews
Wholesale Market	Fresh Produce	
Urban Farm Market	Fresh Produce	
Urban Farm	Fresh Produce Ground Water Wash Water Soil	Key Informant Interviews Observations

6.1.6 Statistical Analysis

Data from this sampling group were combined with the results from the data collected as described in Chapter 4. Data analysis was done using Excel and MiniTab software to allow a thorough examination of the data, production of descriptive and analytical figures and investigation for significant differences. Comparisons between the sampling locations and food sample types were carried out as described in section 3.7 (page 57).

6.1.7 Flow and Dose Modelling

The food network pathways were modelled using the SankeyMATIC diagram builder tool. This was done using the collected data and estimated likely contamination and flow data to balance the model.

The potential CFU exposure doses that the community members could encounter were modelled using a script written by the author, included in Appendix H (page 248). This allowed multiple scenarios to be run, taking advantage of the range of data collected to plot out the wide range of outcomes. Probabilistic exposure modelling was used to estimate the distribution of hand contamination arising from interactions with Fresh Produce. Rather than relying on point estimates, a Monte Carlo simulation was implemented to propagate empirical variability and parameter uncertainty. The model resamples measured produce contamination and combines these draws with parameterised contact behaviours to generate ensembles of plausible exposure scenarios.

6.2 Results

6.2.1 Community findings

The household survey shows that coriander, cucumber, chilli, radish, tomato, carrot and mint are eaten raw daily by more than 80% of the community members. (Figure 30)

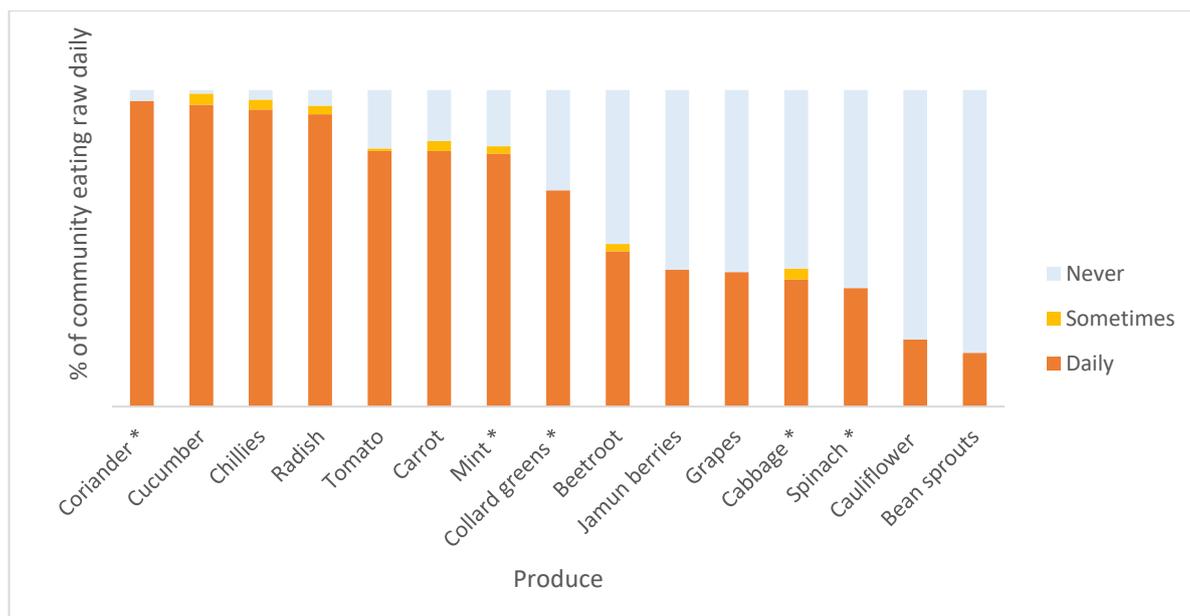


Figure 30 - Proportion of respondents reporting daily consumption of produce eaten raw. Pooled results for Madrasi Camp, Andrewz Ganj and Jagdamba Camp. Delhi, November 2022.

FGD participants reported that most produce is purchased from vendors within and around the communities, although not all participants buy locally. Unsurprisingly, purchase locations are clustered along roadsides (Plate 2).

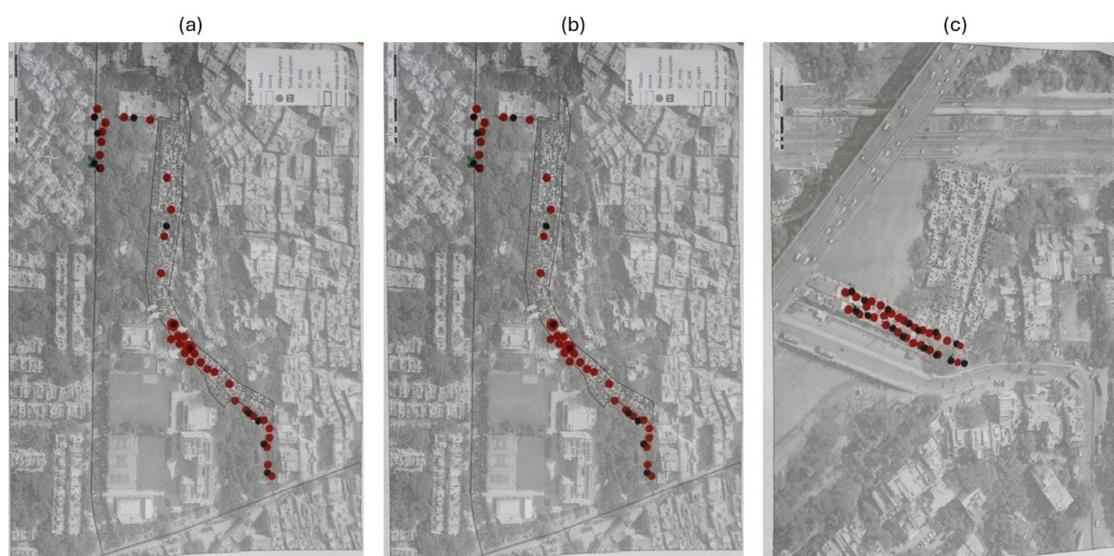


Plate 2 - Location of purchase of raw produce as reported by Focus Group Discussion participants in (a) Jagdamba Camp, (b) Andrewz Ganj and (c) Madrasi Camp (c). Data collected October 2022, in Delhi.

6.2.1.1 Jagdamba Camp

In Jagdamba Camp, most residents buy from vendors within 100m of their homes. There is one vegetable vendor who sells from their home within the camp, but the rest are mobile

vendors who arrive on carts and bicycles daily. Twenty-five percent of residents go to an evening market that is situated 1.2km away.

The participants stated that they do not believe the produce to be contaminated with anything, or they would not purchase it, but they wash it before eating as a good practice and to remove any soil.

6.2.1.2 Andrews Ganj

Andrews Ganj has two main roads running through it. On one road vendors are present all day and evening, while on the other vendors are only present in the morning. Ninety percent of residents go to these local vendors, but 10% go to Shadiq Nagar, a market about 3km away, as they find the prices cheaper.

Participants reported knowing it is generally good practice to wash Fresh Produce, and some people said they wash their Fresh Produce. Some people said tomato, chilli and cucumber can be eaten immediately without washing. They reported knowing that sometimes vegetables can be contaminated, so they like to stick to the vendors they trust who sell clean produce.

6.2.1.3 Madrasi Camp

All the residents of Madrasi Camp get Fresh Produce from the market that runs along the road outside the camp. This road runs over the bridge that crosses the Open Drain.

These residents believe the produce can be contaminated, and that is why they wash it.

6.2.2 Community Vendors

Vendors from all three locations reported getting the majority of their produce from Okhla Mandi, which is a wholesale market in the southern area of central Delhi. A small number from Andrewz Ganj also purchased from a market in Old Faridabad, about 20 km away, because they appreciated the fresh quality they could get there. Some vendors working in Madrasi Camp also reported buying from Ghazipur Mandi and some directly from urban farms in the Yamuna floodplain. The vendors believed that the Yamuna River water was used to irrigate vegetables grown in that area. They also stated that there was agriculture along the Barapullah Open Drain, and some vendors reported that they grow some produce themselves using Barapullah drain water for irrigation. However, when pressed further for information about the agriculture along the Barapullah drain, they were not willing to speak further.

The vendors only reported washing produce if it was if visibly dirty to increase the sale price. They believed some vegetables were impossible to wash, but did not state which ones. Typical operating conditions for vendors are shown in Plate 3.

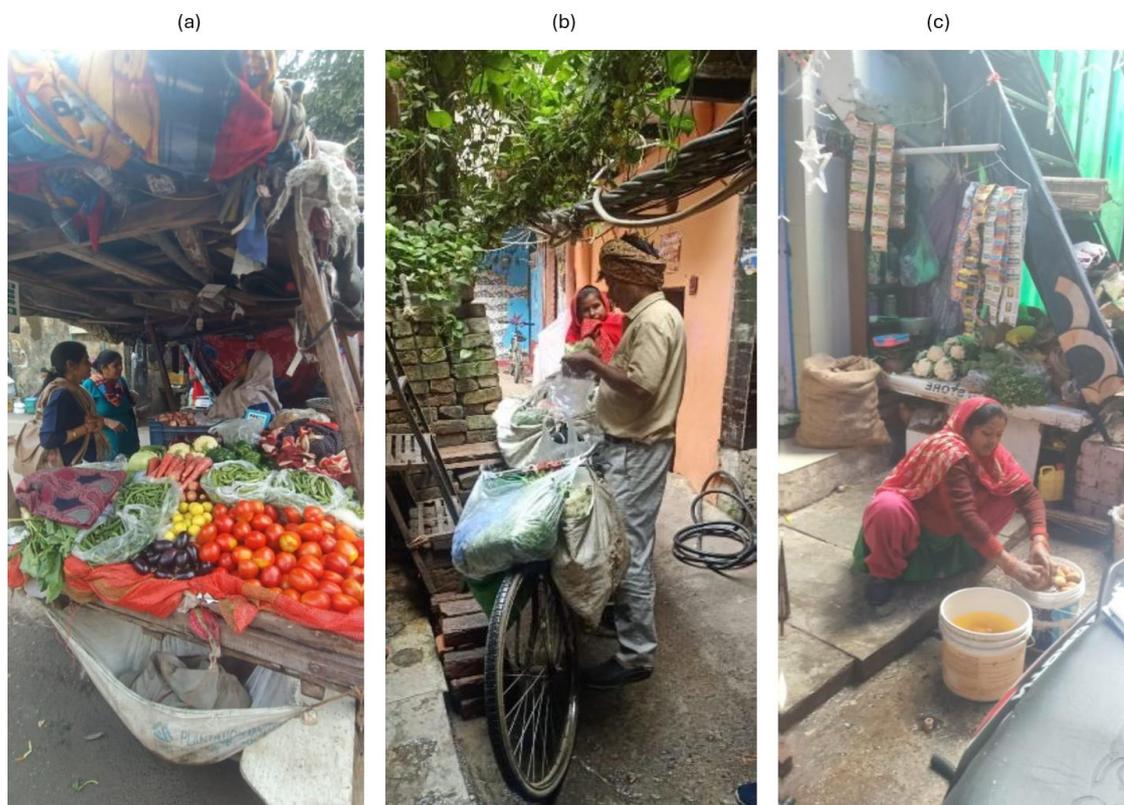


Plate 3 - Food vending in New Delhi (a) Food vendor in Jagdamba Camp (b) Food vendor operating from a bicycle in Andrewz Ganj, (c) Food vendor washing produce in Madrasi Camp. All photos taken by Jayna Collective, November 2022.

6.2.3 Findings at the Markets

As directed by the reports of the community-based vendors the next point for investigation was Okhla Mandi. Food samples were collected and a selection of vendors who had delivered vegetables or sold vegetables there were interviewed.

The vendors at Okhla Mandi reported buying produce from the Yamuna Floodplain urban farms and Azudpur Mandi, so this directed the investigations to both locations.

In Delhi, all of the fresh food that is sourced from outside the city must be processed at the Azudpur Market. This is the bureaucratic centre for measuring and logging all Fresh Produce arriving in Delhi from outside the city boundaries. Records are kept in the offices there on the tonnage, quality and sale price for each produce type (such as tomatoes, apples etc) for each

day. This market plays a pivotal role in the aggregation, registration, and resale of Fresh Produce.

A distinction can be made between the 'internal' markets, whose bulk supplies and sales both take place within the city, and 'Extracity' markets, whose bulk supplies come from outside the city but whose sales take place inside the city. Azudpur is an example of an 'Extracity' market and will be referred to as such from this point.

6.2.4 Findings at the Farm

Leafy greens and radish were seen to dominate the cropping at the urban farms on the Yamuna flood plain, in the dry season, during the field visits.

Five farmers were interviewed about their farming practices. They explained they select crops so that they can have several growing cycles throughout the year and maximise their income. They dig cattle manure through the soil before the crops are sown to fertilise and improve the soil. After germination, petrol-driven pumps with tubewells are used to extract groundwater, and they irrigate with this water. They reported that they never use the Yamuna River to irrigate their crops, but that they have heard some farmers directly adjacent to the water might do so. They reported no use of animal or human faecal materials once the crops were planted. They also reported no open defecation around the crops despite the communities living there having no access to suitable sanitation services. There was visible evidence of open defecation around the crops. They said they buy and use chemical fertilisers.

The farmers were seen to wash the crops they had harvested. Water from tubewells was poured into a shallow ditch dug into the soil (see Figure 31) or in one instance, a concrete trough. Several kilos of radishes and leafy greens tied in small bundles were put into the water. The farmers got into the water with their bare feet and proceeded to use their hands to rub and wash the produce. They eventually laid it on the soil, or on a cloth, beside the washing pool to dry in the sun. At this point, the produce looks visibly clean.



Figure 31 - Farmers washing their Fresh Produce on the Yamuna flood plains in Delhi. Photo taken by Jemma Felicity Phillips, November 2022.

6.2.5 Faecal contamination

6.2.5.1 Sampling locations

During the process of exploring and tracing the sources and pathways of the food eaten in the study communities, samples were collected at four locations. Results from these samples can be combined with data from the samples taken at the three community sampling sites as described in Chapter 4, resulting in a total of seven sampling sites discussed here. These are: Jagdamba Camp, Andrewz Ganj, Madrasi Camp, Wholesale Market (Okhla), Extracity Market (Azudpur), Urban Farm Market and Urban Farm.

High contamination levels were found in the sample rinse from all three community sites. High levels were found at the Wholesale market and on the urban farm. Low contamination levels were detected at the Extracitry market: this market sold produce that was grown outside Delhi city boundaries (Figure 32).

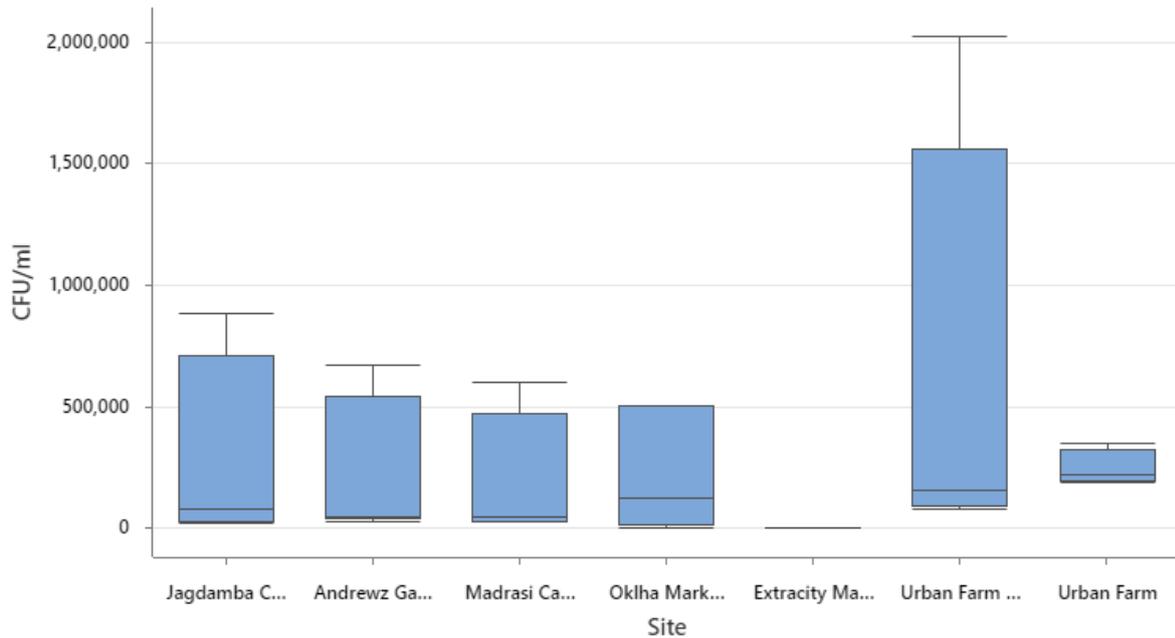


Figure 32 - Colony-forming units per millilitre of rinse water from vegetables sampled at selected sites in New Delhi, India, November 2022. Mean represented by the central line, box representing the 25th and 75th centiles and whiskers representing the range.

The Kruskal-Wallis test suggested that there were significant differences between the sites (p-value: 0.044), and the pairwise Mann-Whitney test (with Bonferroni correction) confirmed the only significant difference to be between the Urban Farm Market and the Extracitry Market.

6.2.5.2 Food types

At the sampling sites, a mixture of different food types was available for testing for faecal coliforms. These were carrots, chilli, cucumber, herbs (mint and coriander), pea pods, radish, tomatoes and other (such as grapes and apples) (Figure 33).

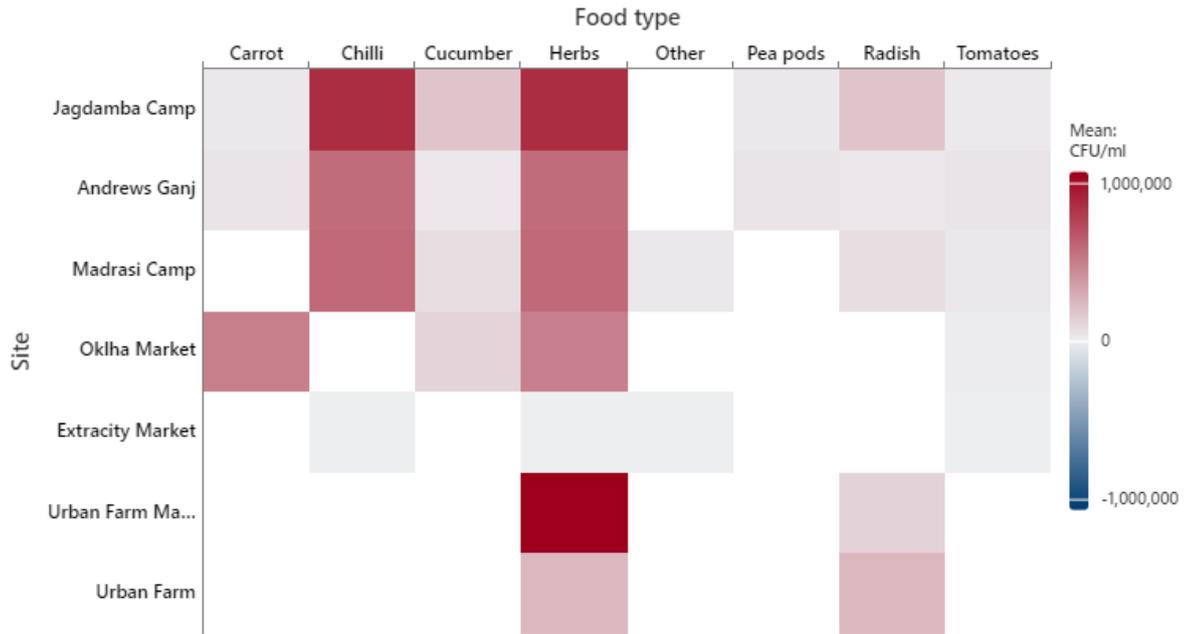


Figure 33 - Colony-forming units per millilitre of rinse water from vegetables sampled at selected sites in Delhi, India, November 2022. Arranged by produce type and site to see patterns of contamination.

Kruskal-Wallis test was carried out and found some significant differences, which were located by Mann-Whitney tests. Herbs had a significantly different CFU/ml than all the other types except Chilli. Tomatoes had a significantly different CFU/ml than all the other types. However, none of these differences held up against the Bonferroni correction. The samples were then divided into three categories: Herbs and Chilli, Other and Tomatoes. These were tested in the same way and found to be significantly different from each other, even against the Bonferroni correction (the p-values were all below 0.0167), as shown in Table 6.

Table 6 - Significance testing results of the grouped food types from the CFU/ml testing on the food network in Delhi, November 2022.

	<u>Herbs and Chilli</u>	<u>Tomatoes</u>
<u>Herbs and Chilli</u>		0.001
<u>Other</u>	0.003	0.000

This categorisation made it possible to see the trends across the different sites, as shown in Figure 34.

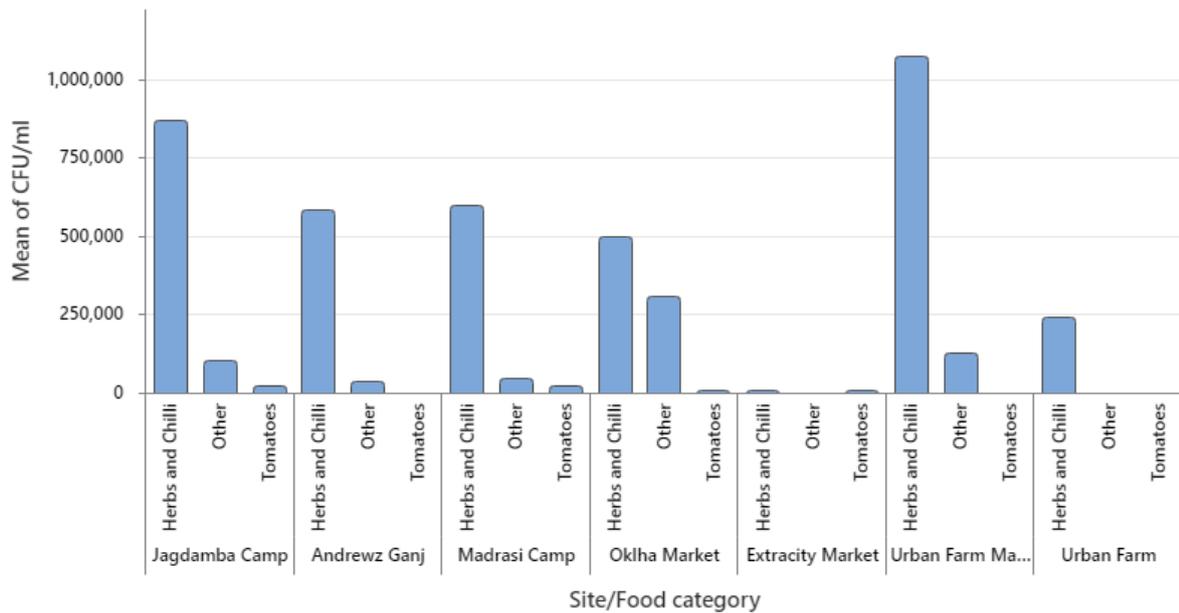


Figure 34 - Faecal contamination levels on samples taken across Delhi, India, in November 2022. Divided by site and food type group.

The highest contamination was found on samples of the herbs, and these were extensively grown on the Delhi urban farms. The Herbs and Chilli tested from the Extracity market, grown outside Delhi, were found to be low in contamination.

6.2.6 Combining behaviour and contamination data

Data from the initial survey about the frequency of eating different types of raw food was combined with the contamination data from the produce sampled within the communities. These results are shown in Figure 35. An indicative red gradient visual was added to show that the greatest exposure risk is from the data points in the top right of the figure. These represent highly contaminated produce types that are eaten raw the most regularly.

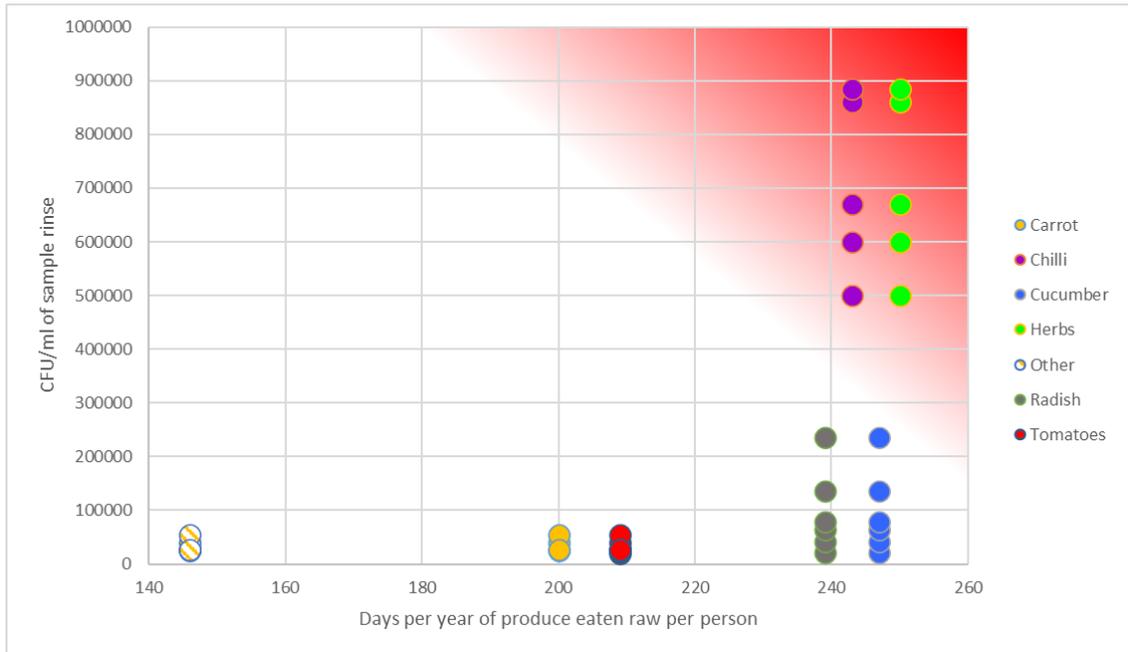


Figure 35 - Colony-forming units per millilitre of rinse water from vegetables sampled within Madrasi Camp, Andrewz Ganj and Jagdamba Camp. Combined with the number of days that survey respondents reported eating each Fresh Produce type raw, in Delhi, November 2022.

6.2.7 Dose calculations

Having established a picture of relative risk and identified important routes for both hazard and exposure, it is possible to convert the available data to estimate the ingested dose of the indicator faecal pathogens in a typical consumer. This can be used to estimate the absolute severity of the risk using Monte Carlo modelling.

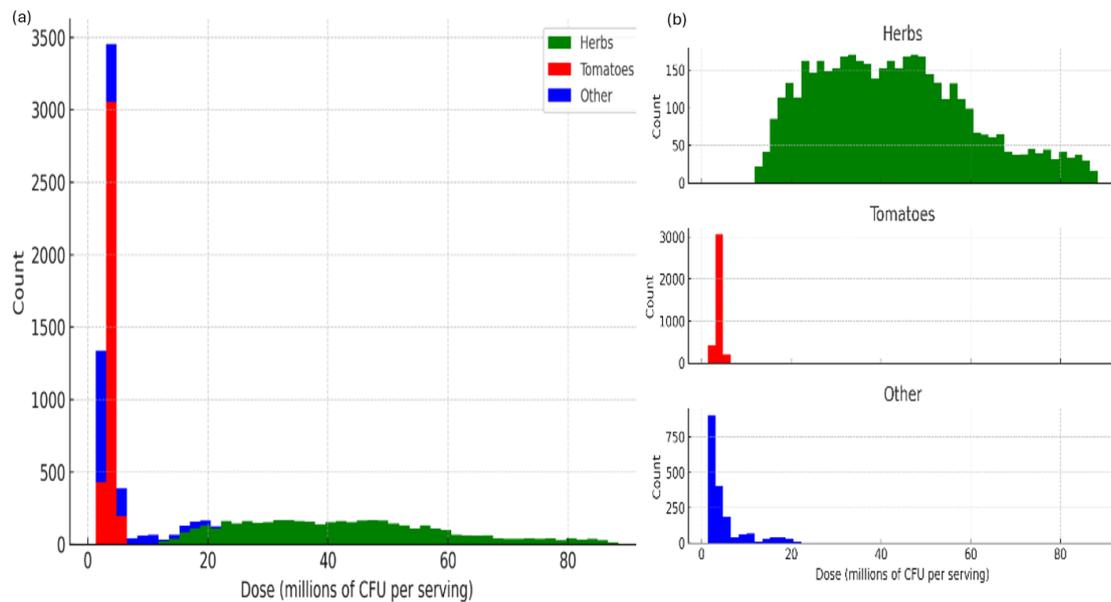


Plate 4 - Frequency of modelled doses received by community members from consuming contaminated Fresh Produce raw. (a) showing total modelling results and (b) the results split by produce type.

The results are shown in Plate 4. This shows that of the 10,000 iterations in the model, there was a large peak of incidence around zero exposure dose. This demonstrates that a large majority of the time (~60%), the community members receive a zero or low dose of faecal coliforms from the Fresh Produce eaten raw. However, 40% of the time, the doses are higher. On the histogram, this is shown by the dose incidences that do occur between 20 and 90 million CFU per portion. Around 10% of these higher doses are extremely elevated CFU numbers, which are likely to represent an extremely high risk of a high dose exposure to faeco-oral pathogens. To give some context, in the UK, ready-to-eat salad is considered unsatisfactory with CFU levels over 100/gram (UK Health Security Agency, 2024).

On panel (a), it is possible to see the colours representing the food categories disaggregated and further split out for clarity in panel (b). This makes it clear that the majority of zero or near-zero exposure doses are from the tomatoes and other Fresh Produce types. The higher dose exposures almost exclusively come from the herbs.

6.2.8 Modelling Fresh Produce Networks within Delhi

As suggested by The Hub partners and prior reading, the data collected supports interpreting the Delhi food network as following a chaotic model (Figure 29 (c)).

While the city as a whole is likely to involve further complexities, this analysis begins to clarify the food sources and distribution routes leading to Fresh Produce consumed in the three

study communities. Two principal origins were identified: produce arriving in Delhi via the Extracity market, and crops grown on the Floodplain Farms. Additional sources were mentioned but could not be fully verified. These may ultimately trace back to one of the two main origins, but others may represent pathways not captured in this dataset. There was also a suggestion that some Fresh Produce may derive from crops cultivated further upstream along the Barapullah Open Drain.

From the data collected and some reasonable assumptions, it was possible to make a notional flow diagram, building on the chaotic model with what we know. Data on the volume of Fresh Produce was not collected, so we had to make some plausible estimates. Then, using the known levels of faecal contamination tested at the communities, the markets and the farm, it was possible to propose a level of contamination coming from the other, untested sources of Fresh Produce. This model is shown in Figure 36.

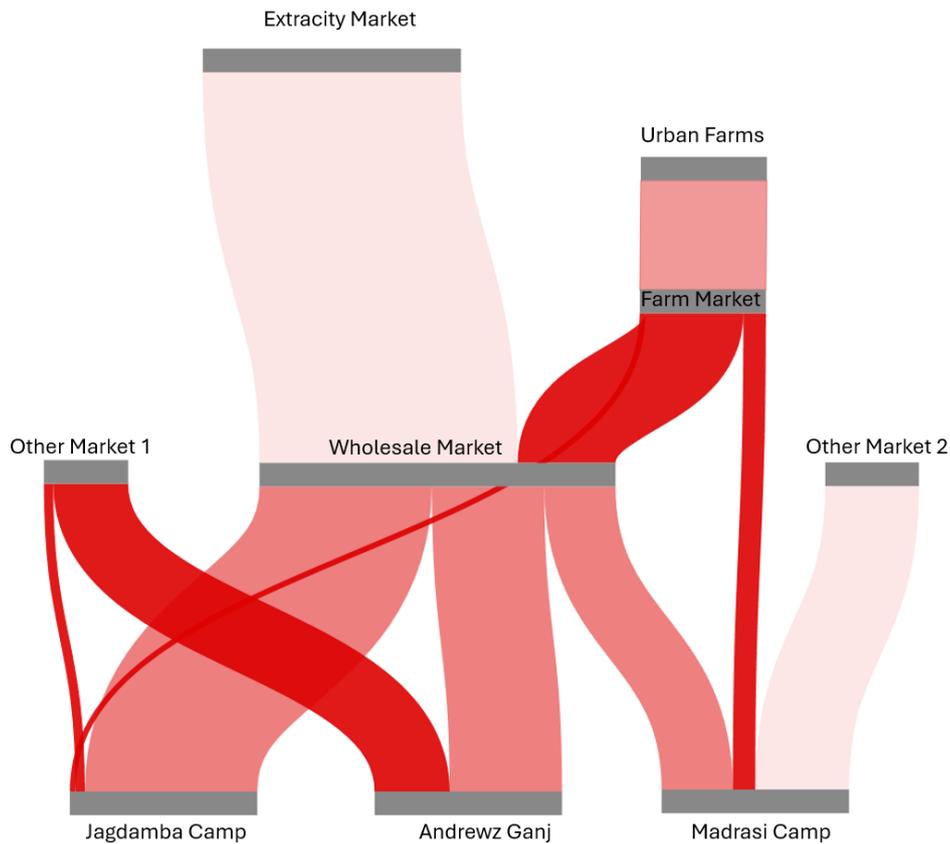


Figure 36 - Modelled Fresh Produce flows across Delhi that end in the three communities selected for sampling along the Barapullah Drain. Data collected in November 2022. The thickness of each line is an approximation of the relative volume of raw produce items flowing from one location to another in the flow, and the darkness of the red colour represents the level of faecal coliforms per ml.

The Floodplain farm was observed to produce mostly Herbs, which were also found to be one of the most contaminated and most regularly eaten raw food types in the communities. Chilli was not observed being grown on the Floodplain Farms. Focusing just on herbs reinforces the importance of the flood plain farm (Figure 37).

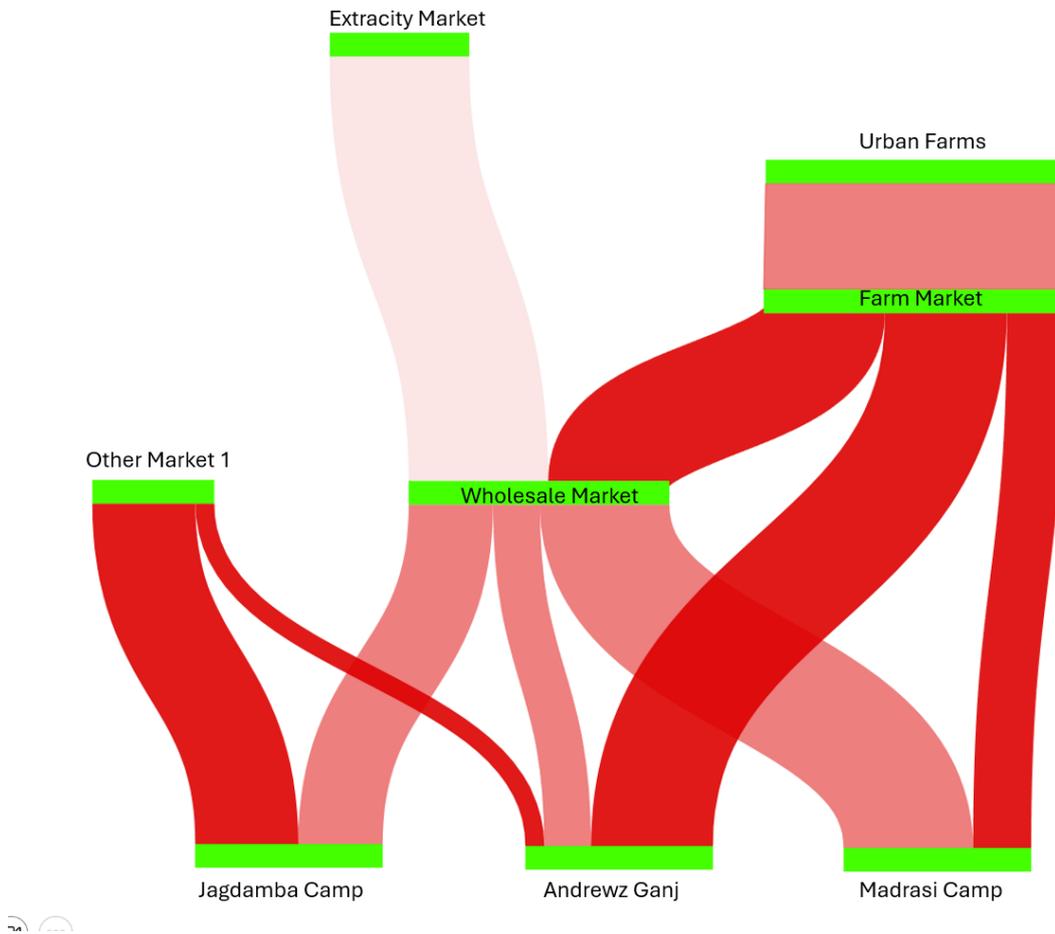


Figure 37 - Modelled herb flows across Delhi that end in the three communities selected for sampling along the Barapullah Drain. Data collected in November 2022. The thickness of each line is an approximation of the relative volume of Herbs items flowing from one location to another in the flow, and the darkness of the red colour represents the level of faecal coliforms per ml.

These notional models should not be read as exact representations of the Delhi food network but rather as heuristic devices. By combining empirical data with informed assumptions, they allow patterns, gaps, and possible linkages to be visualised in ways that purely descriptive accounts cannot achieve. In doing so, they provide a means of thinking through the likely routes by which Fresh Produce reaches the study communities, while also highlighting uncertainties and areas that warrant further investigation. Even if necessarily simplified, such models create space for reflection on how food systems function in practice and offer a starting point for more detailed analysis. Herbs play an important role as a pathway for

moving faecal coliforms across Delhi, leading to high exposure in the study communities of the Barapullah drain.

6.3 Discussion

6.3.1 Communities

Food is an important reflection of not only nutrition but also cultural identity, family and home (Priyadarshini *et al.*, 2024). Accurate, locally grounded data are essential for understanding exposure pathways in low-income urban communities. In this study, it is clear that raw produce consumption is a frequent behaviour in the study areas and therefore constitutes a relevant pathway for exploration.

Members of the communities had some understanding that washing was important before eating Fresh Produce, but the discussion centred around visible dirt (Curtis *et al.*, 2000b; Drechsel, 2010a). There were mixed ideas about whether the produce could be contaminated by something they could not see. Trust in vendor reputation and customer relationship functioned as a substitute for risk assessment, as communities lacked access to relevant information. They stated that trustworthy vendors would not sell contaminated products.

This accords with other studies (Dreibelbis *et al.*, 2013) that there is a mismatch between risk perception and actual risk, and that better public health messaging may enable community members to understand the nature of microbial risk. Currently, communities do not have access to information about how to avoid invisible contamination better and to reduce their own risk of ingesting faecal pathogens.

Household buying behaviours situate their immediate decisions of where and who to buy from as a localised issue. This is useful for understanding how the produce pathway flows into the communities and the importance of the local vendors.

6.3.2 Vendors

Vendor practices accorded with the community practices: prioritising visible cleanliness rather than considering microbial safety.

Despite the produce being visibly clean and recently washed, high faecal contamination was still found on the produce at this point. It is unlikely this was caused directly by the water used for washing, as the piped water was found to have low faecal contamination (see

Chapter 4). However, it is possible that the water was used for multiple batches of produce, which means that vendor washing practices may have been a point of spreading and increasing, rather than decreasing, contamination. Therefore, encouraging vendors to consider contamination and wash their produce is likely to be counterproductive.

Discussions with vendors revealed a discrepancy between their initial 'official' answers given and their actual Fresh Produce sourcing practices. This gives the impression that they knew that the wholesale markets were the better places to buy from, particularly considering the line of questioning being about safety and contamination. This suggests that there are other drivers leading to them sourcing produce from sources that they know are not to be professed. These drivers could be price and locality, meaning less time spent on travelling to the wholesale market. Any policy changes or health promotion activities must not ignore the realities of the priorities for the vendors of making a daily living and survival for themselves and their families. Customers in these low-income communities will also appreciate the ability of vendors to keep costs down.

6.3.3 Markets

There is only one Extracity market in Delhi for the bureaucratic management of importing Fresh Produce within the city boundaries. The purpose of this administrative process is unclear, with some data published on the government website, but no other obvious outputs. Microbial quality is not part of the records collected. The state or country that the produce originated from is recorded, but immediately, the produce's origins lose traceability as it is mixed and sorted by quality and price, ready for distribution across the city. The many wholesale markets across Delhi are critical to the infrastructure and system of food distribution. At this stage, the produce from the Extracity market is mixed with the produce from the urban farms, and traceability is further eroded. The complex market system directly results in loss of traceability, and also probably results in mixing between produce with different levels of contamination.

It is plausible that the low faecal contamination found in the samples from the Extracity market could be due to safer farming and washing practices in rural farms. It could also be due to bacterial die-off on large trucks throughout the journey before arriving in Delhi.

Observation revealed that at both the Extracity market and inner-city wholesale markets, there were several risk factors. Contamination may happen in these markets due to vendor handling and other unhygienic practices. No evidence of facilities for washing hands or

produce was observed at any markets visited during the data collection. Many cows at the markets were observed eating the vegetation waste and consuming plastic and paper items, which adds to the risk of microbial contamination before reaching community customers. This means that markets may act as hazard multipliers and require multipronged implementation to improve.

6.3.4 Urban Farming

Urban agriculture contributes to food security, household income, and environmental sustainability in many contexts (Kaur and Rani, 2006; Drechsel, 2010a; Diehl, 2015). More than half of India's working population is employed in agriculture (Diehl, 2015). In urban areas, many people turn to agriculture to supplement their main income. However, urban space for growing crops is being squeezed by ever-increasing housing needs and is increasingly happening on land that is unsafe for growing food crops (Kaur and Rani, 2006). Delhi's agriculture is concentrated on the east bank of the Yamuna River across the flood plains.

Despite these challenges, urban agriculture holds significant potential in reducing Transport emissions, decreasing costs and increasing food security (Chandra and Diehl, 2019). The quantity of food that urban agriculture farms contribute to Delhi is unknown, but previous estimates have placed it at around 20 – 30% of the total consumed Fresh Produce (Cook *et al.*, 2015). In African cities, urban production supplies 50–90% of Fresh Produce (Drechsel, 2010b). However, urban farming in Delhi will need considerable augmentation to contribute meaningfully to sustainability (Maheshwari and Singh, 2017).

Much of the global literature identifies irrigation water as the leading cause of Fresh Produce contamination (Mcheik *et al.*, 2018). Outbreak investigations typically attribute contamination to water sources, but in practice, evidence is often circumstantial: farms or distributors are identified and routes such as irrigation water, poor hygiene during handling, or pests in storage are suggested, but rarely confirmed (Todd *et al.*, 2007; Kozak *et al.*, 2013; Drechsel *et al.*, 2022) Similarly, it treats contamination as common but not worth tracing in routine investigations, instead focusing on interventions at the point of exposure, such as removing contaminated produce or closing restaurants. Contrary to expectations, farmers reported irrigation using groundwater rather than Yamuna River water, aligning with national policy promoting groundwater irrigation (Mukherji and Shah, 2005; Aldy and Stavins, 2012). This concurs with findings by (Cook *et al.*, 2015), who found that farmers reported that even

cows would not eat crops irrigated by Yamuna flood waters, so they considered them too dirty or contaminated to use. The use of clean groundwater means that irrigation practices may not be the main source of faecal contamination on the crops grown in the Yamuna flood plains.

Farmers interviewed did not demonstrate appreciation of the risks associated with the use of faecal waste as a soil amendment due to their denial of its use. When asked about anything that helped their plants grow, they spoke of their use of chemical fertilisers as an agricultural necessity for growth, which suggested they did not view the open defecation as fulfilling this purpose. It was not possible to know if the farmers perceived any benefits from open defecating around the crops, as this practice was denied completely. Whether intentional or not, this is still a plausible source of the faecal contamination. Providing sanitation infrastructure and behaviour change interventions could be an effective way of reducing faecal pathogens on Fresh Produce, affecting many urban communities in Delhi. However, with the tenure and political situation, this may be challenging to implement.

Post-harvest washing practices are critical, as repeated immersion of produce in contaminated water can elevate microbial loads (Gagliardi *et al.*, 2003; Faour-Klingbeil *et al.*, 2016b). This was reflected in the findings of this study: samples taken directly from the field looked dirty and were found to have faecal contamination, but contamination increased fivefold after washing, despite then looking clean. Implementation to improve washing practices on the farm could reduce the hazards associated with eating Fresh Produce raw in the study communities. However, it was observed that one farmer had a concrete produce washing station that he used instead of the pits dug into the ground used by the other farmers. It is possible that this was an intervention done to improve washing practices, but this farmer used the concrete trough in the same way, washing repeated batches and standing in the water with his bare feet. The water was still highly contaminated after use, showing that changing from a soil pit to a concrete trough was not enough to change the outcome. Other ways of improving the farmers' washing practices would need to be explored. Herbs, with their large crenulated surface areas, are particularly vulnerable, and even where chlorinated water is used, they are commonly recontaminated during washing and handling (Gagliardi *et al.*, 2003).

6.3.5 Risk

This study demonstrates a range of risks and the joint drivers of frequency of consumption and level of faecal contamination. Herbs, chilli and cucumber represented the highest risks for these reasons. Herbs, as a key concern, are observed to be among the main crops grown on Delhi's urban farms, suggesting that the contamination risk is not randomly distributed, but caused by urban farming practices.

The pattern of risk observed in this study reflects the way that the microbiological results were understood in relation to public health. The dose-exposure plots highlight relative risk and how risk thresholds could be conceptualised (such as using the diagonal gradient in Figure 33). This study does not attempt to define an acceptable threshold, however, because in the context of the Delhi study communities, levels of faecal exposure were orders of magnitude beyond what would ever be considered tolerable in a high-income context. In such circumstances, effective risk reduction is a better focus than excessive data collection and modelling in order to produce an arbitrary threshold. In this way, the indicator bacteria serve as a pragmatic signpost that unacceptable faecal contamination has occurred. From the indicator bacteria, it can be inferred generally that faecal pathogens will be present. More precise risk estimates can be carried out using modelling such as QMRA. Yet without direct pathogen sampling, such models still rely on published literature to assume ratios between indicators and pathogens in this setting. While this could be carried out in future work, it is unlikely to change the conclusions made here that current farming and washing practices expose communities to high levels of faecal pathogens, which are carried on herbs and other foods eaten raw.

Although this analysis is specific to the low-income study communities in Delhi, there is no evidence that high-income communities and expensive restaurants in Delhi have a different source of herbs, and, therefore, all consumers are exposed to the same risks. Such findings challenge the assumption that risks from poor quality food are a blight on those in poverty and reframe Fresh Produce safety as a city-wide issue. Further supply chain tracking could confirm that urban farm herbs reach high-cost outlets, with important implications for public interest and governance oversight.

6.4 Limitations

This research was exploratory in scope, and therefore, there is much more data that could be collected to confirm and extend the conclusions reached. Nevertheless, the evidence

presented consistently indicates a substantial risk from exposure to faecal pathogens through the consumption of Fresh Produce in Delhi.

The data collected did not encompass every potential node in the food network, nor did it empirically quantify the volumes of produce flowing through the network. These flows can only be inferred through vendor testimony and relative faecal coliform concentrations. As such, the conclusions of the modelling remain indicative.

Reliance on self-reported data and key informant interviews introduced constraints.

Community members, vendors and farmers may have withheld or curated information according to locally understood norms and their perception of illegitimacy. This could have led to an underestimation of the significance of the role of urban-grown produce entering Delhi's food supply. Omission of purposeful use of human faecal soil amendments and irrigation practices could have mischaracterised the risk sources. However, the findings here were consistent with previous work in the same context (Cook *et al.*, 2015), lending confidence to the conclusions.

The microbial data were constrained by the use of indicator organisms, which signal the presence of faecal contamination but do not confirm the presence or infectivity of specific pathogens. In addition, the microbial data collected were analysed by millilitres of wash water, yet consumers ingest food by portion. Estimated doses were derived through portion-based calculations; these inevitably represent approximations of actual exposure loads. Despite the careful documentation of the raw foods eaten by the target communities, the portion quantities were not documented. Even if the need for portion data had been anticipated, community members may have found it difficult to quantify the amounts consumed in any meaningful way.

Despite these limitations, the evidence from using multiple triangulated data sources converges on the same conclusion: that Fresh Produce in Delhi represents a significant exposure pathway for faecal pathogens, and that farming, marketplace, and consumption practices collectively contribute to this risk.

6.5 Conclusion

This chapter aimed to meet Objective 3: to identify and explore the sources and pathways leading to critical exposures from Fresh Produce eaten raw in the study communities. The findings show that Fresh Produce is a pathway for the Transportation of faecal coliforms

across Delhi's food supply. A critical source of the contamination has been traced to herbs grown on the urban farms, and this is due to a lack of sanitation facilities for the farming communities and amplification through unsafe washing practices. The risks are compounded by community consumption practices, where herbs are eaten raw and are not washed effectively, or at all.

These findings highlight the need for systemic public health interventions addressing agricultural, market and household practices through a multibarrier approach (Drechsel, 2010a; Galibourg et al., 2024). This study contributes evidence to the importance of viewing public health at the scale of the urban system, demonstrating that community-based interventions alone will not achieve their intended effects, given the distances that faecal pathogens travel through the food chain.

7 Chapter 7 - Qualifying Solid Waste as a Source of Exposure

In Chapter 4, community contact with Solid Waste was found to be a critical risk for exposure to faecal pathogens. Previous studies show a correlation between Solid Waste build-up and infectious disease (Maciel *et al.*, 2008; Curtis, 2011; Krystosik *et al.*, 2020), particularly where the Solid Waste is contaminated with human faeces (Hanks, 1967). While it is acknowledged that poor Solid Waste collection is often seen in the same communities that also live with unsafe sanitation, the mechanisms of the pathways between source and exposure are not known (Krystosik *et al.*, 2020).

There are some plausible pathway suggestions, such as depositing behaviour (including flying toilets, diapers, pet faeces), insects, birds, animals, flooding and Open Drains; but none of these are supported by evidence (Fedorak and Rogers, 1991; Gerba *et al.*, 2011; Haas *et al.*, 2014; Qian and Barlaz, n.d.). Understanding the most substantial contributors is a prerequisite for devising effective interventions (Gerba *et al.*, 2011).

In Chapter 4, community members were asked about the frequency of interaction with Solid Waste, but the question was found to lack specificity, and in that initial phase of the research, results were not triangulated with observations, leaving uncertainty about how such interactions would translate into exposure risk. This chapter, therefore, expands on those findings by gathering more microbial data and examining observed interactions with Solid Waste and their potential to act as faecal pathogen exposure pathways.

7.1 Methods

The detailed data collection plan is included in Appendix I (page 249).

7.1.1 Transect walks

The transect walks described in Chapter 4 identified a large quantity of Solid Waste around the communities. The aim in this follow-up study was to characterise the locations of the Solid Waste spatially and identify points for sampling. These accumulation sites are crucial nodes where contamination can occur, and people can be exposed. Therefore, new transect walks were carried out, and six sites were chosen for sampling in each community. The choice to capture multiple types of locations (municipal bins, edges of paths, near Open Drains, and

neglected areas) allows for cross-comparison in contamination levels between the communities. The locations were mapped and photographed.

7.1.2 Focus Group Discussions

Focus group discussions were carried out in each community with a total of 53 participants. Each FGD included men and women, and older and younger people. Discussions with community members explored household Solid Waste management practices, including the contents of bin deposits, methods of disposal, and whether waste was deposited elsewhere. Participants were also asked about handwashing practices following contact with Solid Waste. In addition, the discussions addressed perceptions of the dirtiness of waste and its associated health risks, as well as the guidance given to children regarding behaviours around Solid Waste.

7.1.3 Observational categories

Pilot observations were carried out in the communities to establish two things: firstly, to identify where interactions with the Solid Waste could be observed. Based on this exercise, the main observations were carried out at the municipal bins in each community (sampling sites: M1, J1, A4 on the maps in Plate 6), as community members were not observed regularly touching the Solid Waste anywhere else.

Secondly, the pilot observations were carried out to determine what kind of behaviours were observed from a long list of possibilities to design the finalised data collection sheet. For example, there were no observations of any community member removing anything from the bins and no observed examples of children playing in or on the Solid Waste. The resultant categories used in the data collection are explained in Table 7.

Observations were carried out from 7am until 4pm for three days. The observation data was divided by hour. The tally sheet recorded the type of deposit behaviour and whether it was made by a man, woman, boy or girl. Pilot and finalised blank tally sheets in Appendix J (page 250). There were workers and rag pickers present around the bins, but they were not included in the observational tallies, as the focus was on community contamination routes.

Table 7 - Solid Waste Depositing behaviour categories and descriptions

Deposit behaviour type	Description	Notes
No touch	Depositing the Solid Waste into the bin without touching anything.	This includes their own Solid Waste, the bin sides, the Solid Waste in the bin, and the Solid Waste on the floor. This could be because the Solid Waste being deposited is in a polybag or being tipped from a bin or bucket without touching the contents.
Touch own	Depositing the Solid Waste without touching anything other than their own Solid Waste.	They do touch the Solid Waste that they are depositing in order to extract or scoop it out of the bucket or bin container. They do not touch the bin sides or the Solid Waste in the bin.
Touch existing	Depositing the Solid Waste and touching what is there with their hands	While depositing their Solid Waste, they touch the bin sides or the Solid Waste in the bin.

7.1.3.1 Microbiological Sampling and Analysis

At the 18 locations identified, a representative grab sample of the Solid Waste that was found there was collected using a sterile plastic bag, inverted for collection. The sample handling was carried out according to the description in 3.7 (page 57).

7.1.4 Exposure Modelling

The potential CFU exposure doses that the community members could encounter were modelled using a script written by the author. This allowed multiple scenarios to be run, taking advantage of the range of data collected to plot out the wide range of outcomes. This programme was run with 10,000 Monte-Carlo iterations.

Probabilistic exposure modelling was used to estimate the distribution of hand contamination arising from interactions with Solid Waste. Rather than relying on point estimates, a Monte Carlo simulation was implemented to propagate empirical variability and parameter uncertainty. The model re-samples measured Solid Waste contamination (e.g., concentration distributions) and combines these draws with parameterised contact behaviours to generate ensembles of plausible exposure scenarios. Observations were not made of the hand-to-mouth behaviours in this context, but hand contamination is a proxy for the likelihood of receiving an ingested dose of faecal pathogens.

As community members do not interact with Solid Waste in terms of millilitres of rinse solution, it was important to consider alternative ways of expressing the CFU data. The colony count obtained from each plate was multiplied by 150ml to estimate the CFU present in the total corresponding sample rinse. To account for potential differences in exposed surface area, the fill percentage and number of layers within each bag were estimated, allowing the surface area of each sample to be approximated. As the potential for Solid Waste to act as a fomite is directly related to the surface available for contact, this approximation was subsequently used to calculate CFU per square centimetre (CFU/cm²).

7.2 Results

7.2.1 Transect walks

During the transect walks in all three communities, there was such a diffuse spread of Solid Waste that it was difficult to choose sampling locations. Almost all pathways had Solid Waste along the entire edges, and Solid Waste was gathered in any drainage channels, gaps between walls, buildings, around trees and by any other structures. Abandoned areas were full of Solid Waste, and the edge of the Open Drain was a continuous bank of Solid Waste piled up Plate 5.



Plate 5 - Photos from the transect walk taken by the author, Oct 2023. (a) Jagdamba Camp path, (b) Andrewz Ganj municipal bins, (c) Madrasi Camp municipal bins, (d) Jagdamba Camp rooftop, (e) Andrewz Ganj side of a residence, pig styes and Open Drain, (f) Madrasi Camp Open Drain.

The municipal bin sites were located at points accessible to the large trucks that come to empty them each day. Six sampling sites in each community were selected with the aim of having a spread across the community and representing a range of place types such as the side of the path, beside the drain and abandoned places. The locations were mapped on a Google satellite image, as shown below in Plate 6.



Plate 6 - Locations for Solid Waste sampling. Each sampling location is shown in red for (a) Jagdamba Camp, (b) Andrewz Ganj, and (c) Madrasi Camp. Basemaps derived from Google Images (Google, 2025).

7.2.2 Focus Group Discussions

The participants in the focus groups described four different methods used to transport the Solid Waste to the bins: plastic bags, bins with lids, containers without handles or lids, and buckets with handles but without lids. A low proportion (around 5%) reported using containers with lids. They described depositing Solid Waste that is not sorted; wet, dry, recyclable, hazardous and sharps are generally mixed and deposited together. The participants see people sorting the waste, who they believe are informally engaged municipal workers, assisting with the waste collection and segregation process at the municipal bins.

They report that the municipal bins are usually emptied daily, before 9am, by trucks. This influences the positioning of the bins so that the trucks can gain access. Some participants felt that it would be better if the bins were emptied twice daily to reduce overflows, smells and mess.

Some people living near the Open Drains reported depositing all their Solid Waste directly into the drain. Very few people admitted to depositing Solid Waste in other open spaces around the community. Younger participants in the FGD expressed concern about the environment and keeping the drains clear of Solid Waste, and suggested fines for littering

offenders. The Open Drains are reportedly dredged periodically for the Solid Waste, and this is dumped along the banks near their community. There were varying descriptions about the frequency of the drain dredging, with two to 20 days reported between cleaning events.

None of the participants in the FGD had any idea about what they, or their neighbours, are depositing that makes Solid Waste 'dirty' or contaminated with faecal pathogens. All the participants denied any depositing of 'flying toilets', nappies or animal faeces in the bins. Some of the participants mentioned that they put things that they consider dirty directly into the Open Drain, such as nappies and sanitary pads, while depositing the rest of their Solid Waste in the bins. The participants reported that elderly and disabled people would be supported to access toilets or sit over the drain, and that there were no adult members of the community who were housebound and needed any kind of temporary storage or pad for their sanitation needs. Therefore, this was dismissed by the community members as not being the cause of contamination of the Solid Waste.

Some participants from each community mentioned that they felt that dealing with Solid Waste was mainly a woman's responsibility in the home, but some said it was a shared job.

Participants of the focus group discussions were asked if they washed their hands after visiting the bins. Around 40% of the participants said they did not wash their hands; the rest said that they did, mostly just with water, around 10% mentioning soap.

The FDG participants did demonstrate awareness of the Solid Waste being dirty and expressed reluctance to retrieve their belongings if they fell into the Solid Waste bins. However, most said they would retrieve dropped items, if necessary, that had come from their own home. Less than a quarter of participants said they would pick up something valuable from the Solid Waste bins or piles that were not from their home, but they said if they did, then they might wash it.

Participants reported concerns about the health and hygiene of their environment and the Solid Waste. They complained of breathing difficulties, migraines, headaches and skin allergies without specifying how they believe that the Solid Waste can cause these problems. They also mentioned issues with mosquito breeding in the environment, which brings malaria, dengue, and body pain. Parents reported not wanting their children to play on or near the Solid Waste and instructed them on this, but were not always able to supervise this due to work commitments and children having the freedom to play in the community. They expressed concern about things like balls going into the Solid Waste and drains, and being

regularly retrieved by children. There are no designated play areas seen in any of the communities.

7.2.3 Observations

There were 2274 Solid Waste deposits observed over three sites and three days. These observations were at the main municipal bin site for each community, as mapped in Plate 6 (Jagdamba Camp – location 1, Andrewz Ganj – location 4, Madrasi Camp – location 1).

The vast majority of observed Solid Waste deposits in all three communities were categorised as “no touch” (81.53%), with only a very small percentage of “touch existing” (2.51%). The behaviour of “touch own” varied between the communities (total figure 18.47%) (Figure 38).

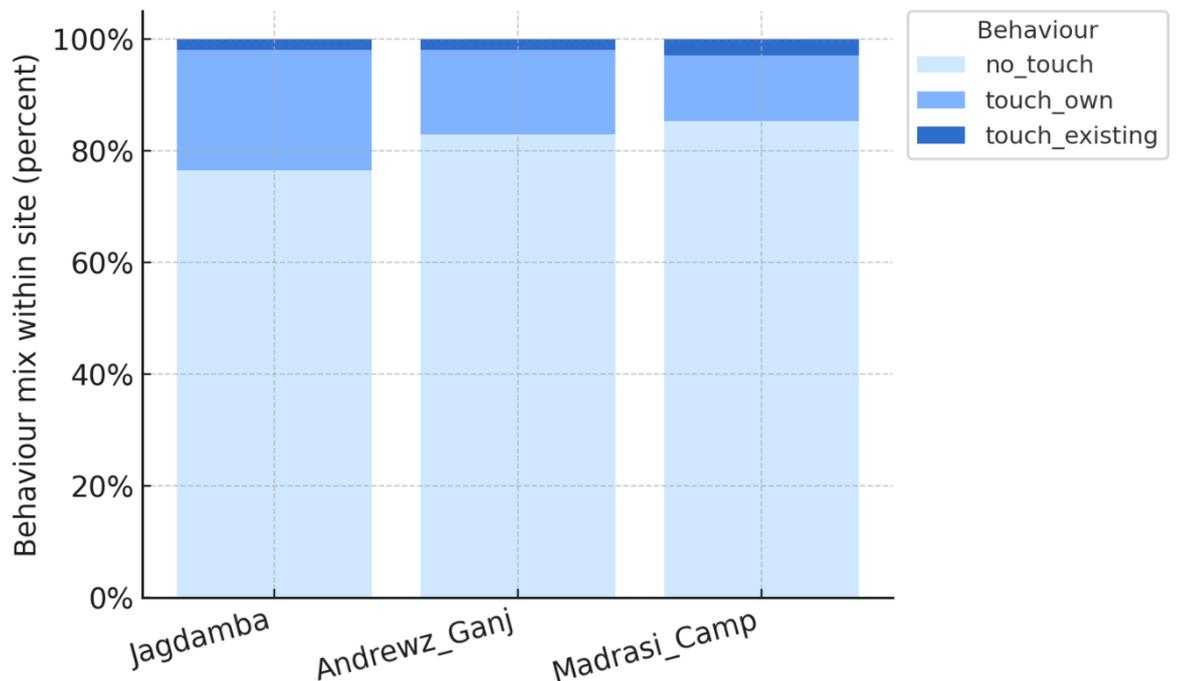


Figure 38 - Percentage of observed Solid Waste deposit behaviour for each study site. Data collected in Delhi, October 2023.

The overall chi-square for site and behaviour was found to have significant differences ($\chi^2(4) = 37.0, p \approx 1.8 \times 10^{-7}$), with a mild effect (Cramer’s V of 0.09). The pattern is driven by the differences in “touch own” behaviour between Jagdamba Camp ($z = +4.13$) and Madrasi Camp ($z = -3.57$).

7.2.4 Gender and Age distribution

The type of person who was making the deposits was observed and recorded.

In the observed deposits, there were slightly more deposits by women than men, and this difference, though small, was statistically significant ($p = 0.0062$, 95% CI 44.4%-49.1%). Boys and girls made a similar number of deposits ($p = 0.714$, 95% CI 44.5%-53.6%). Children (boys and girls) made 21% of the deposits observed (Figure 39).

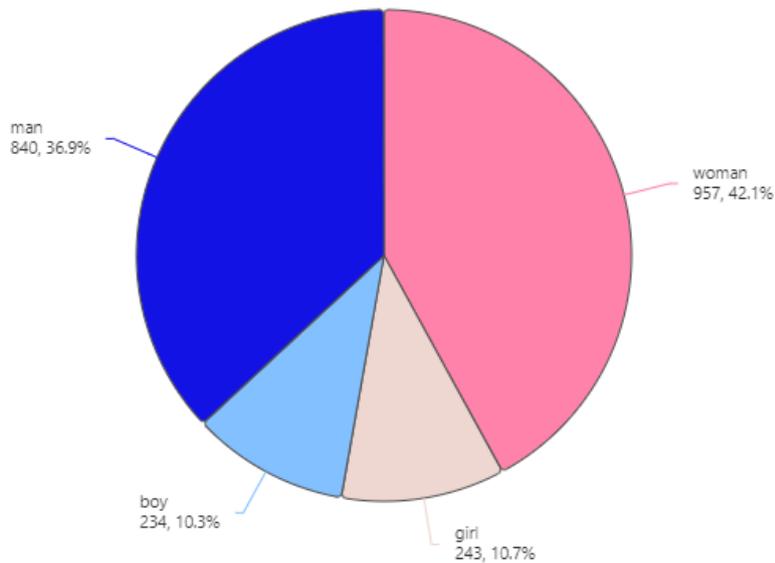


Figure 39 - Proportion of Solid Waste deposits made in the observations in the study communities in Delhi, October 2023.

For all age/gender categories, the most common deposit behaviour is “Deposit no touch” at 89%. This can be seen Figure 40.

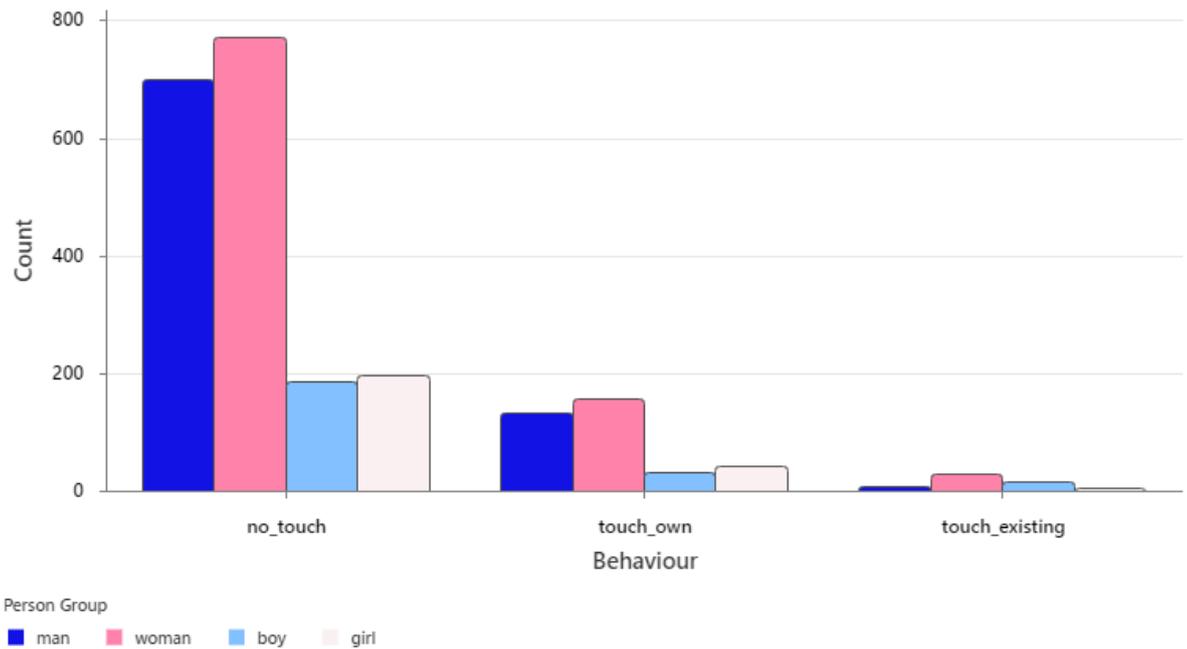


Figure 40 - Solid Waste deposit count from observations in study communities in Delhi, October 2023. Disaggregated by deposit behaviour and man, woman, boy, and girl.

Analysing the significance of these behaviours was carried out using a 4x3 chi-square test. It was found that the Person Group types did not affect the behaviour frequency, and any differences were not significant. The exception to this was that boys touch the existing Solid Waste slightly more than expected ($z = +3.77$), and men slightly less than expected ($z = -2.63$).

7.2.5 Gender And Temporal Patterns

The data was examined to see if there were different temporal patterns for the age and gender groups in Figure 41.

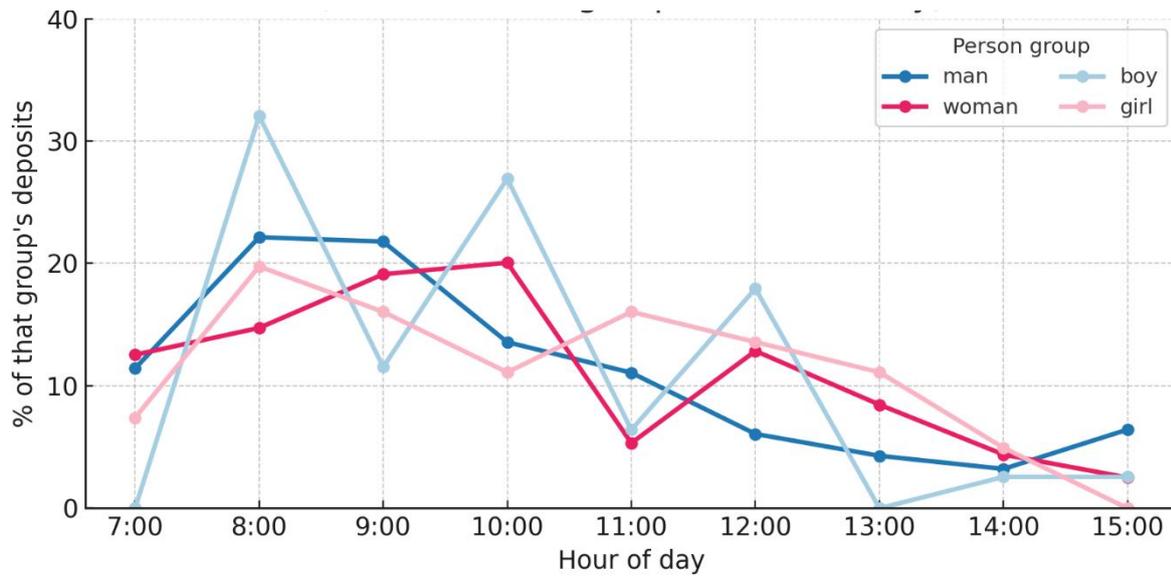


Figure 41 - Temporal patterns of Solid Waste deposits, disaggregated by men, women, boys and girls. Data collected in Delhi, October 2023.

Across the time slots starting from 7am to 3pm, all the groups followed a similar pattern of decreasing throughout the day. The statistical differences between men, women and girls were statistically significant but small (Cramer’s V = 0.21 to 0.23). Boys, compared to the other groups, were different with a larger effect size (Cramer’s V = 0.28 to 0.43).

7.2.5.1 Microbiological Data

Photographs of some of the bagged samples can be seen in Plate 7. The microbiological data show that the rinse of the Solid Waste samples from all 18 selected samples was contaminated by faecal pathogens, but the levels of colony-forming units varied.



Plate 7 - Bagged Solid Waste samples. (a) from Jagdamba Camp, (b) from Andrewz Ganj, (c) from Madrasi Camp. Collected in Delhi, October 2023. Photographs taken by Jemma Felicity Phillips.

The average sample contamination varied between the three communities but within the same order of magnitude. Jagdamba Camp had the highest mean and median CFU/ml values, and Madrasi Camp had the lowest. Kruskal-Wallis testing showed that the differences were not significant ($H(2) = 5.33, p = 0.070$). Therefore, the dataset can be treated as a pooled dataset.

The data was used to calculate and estimate the CFU per whole sample, per ml of sample rinse, per gram of sample and per cm^2 of the sample's surface area. The surface area was determined based on the fill and layers of Solid Waste in each sample bag. However, this added an extra element of uncertainty due to the estimated nature of the calculations and did not materially alter the sample ordering; therefore, the CFU/ cm^2 data were only used for the dose modelling calculations.

7.2.6 Solid Waste sample location types

The Solid Waste samples were collected from six different places around each of the three communities. These were then categorised by location type; some were from the edges of paths, some from out-of-the-way places such as abandoned buildings and rooftops (this was categorised as “away”), some from the large municipal bins and some from the banks of the Open Drains. These results can be seen in Figure 42.

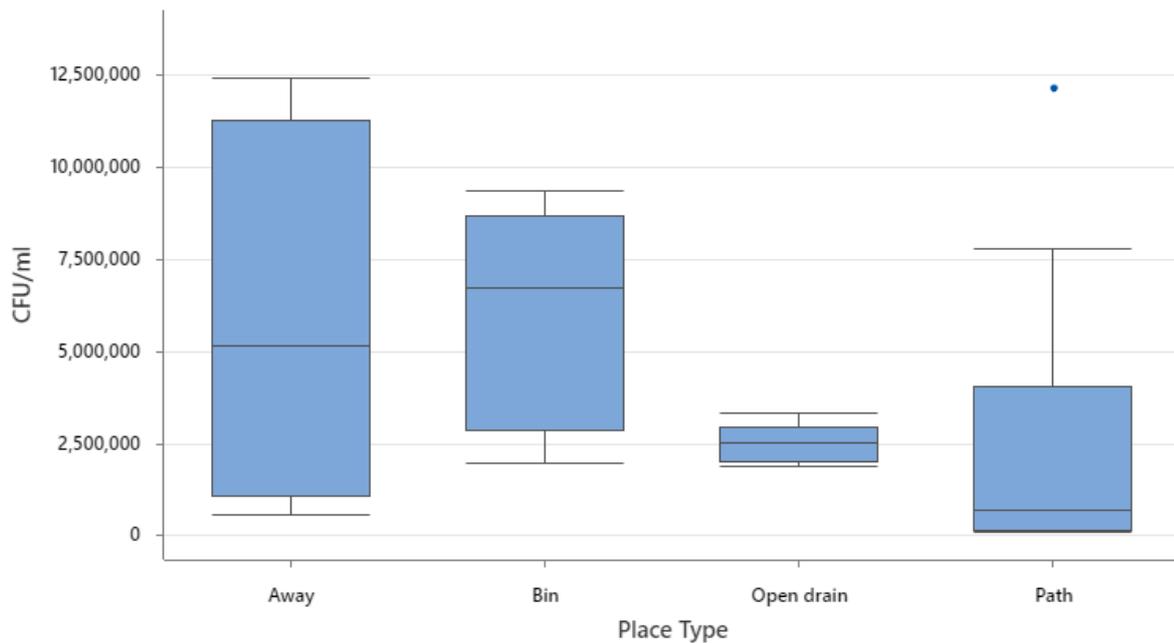


Figure 42 - CFU/ml on sample rinse from Solid Waste collected in the three study communities in Delhi in October 2023. Whiskers show range (excluding outliers), the box shows the 25th and 75th centiles, and the midline shows the mean.

Median contamination was highest on the bin samples and lowest on the paths. Pairwise Mann-Whitney tests (with Holm correction) did not identify any pair with adjusted $p < 0.05$, so the differences were not found to be significant.

7.2.6.1 Content of the samples

The contents present in each sample selected from the sample sites were recorded. Most samples contained some form of packaging (often snack wrappers). There was a mixture of other products across the samples, such as raw food, cooked food, leaves, foil and paper. Some of the samples also included some mud/soil gathered accidentally due to the samples being on the floor. There was no clear association of any of the content types being a leading contributor to the CFU/ml. There was a slightly lower average contamination in the samples containing mud/soil, but this difference did not survive multiple-comparison correction across all contents (See Appendix K – page 252).

7.2.7 Exposure modelling

Behavioural inputs capture determinants of hand contamination following contact with contaminated media, specifically contact frequency, duration, contacted surface area, and

surface-to-hand transfer efficiencies, which are established drivers of contamination dynamics (King *et al.*, 2015; King *et al.*, 2020). Observed contact-and-transfer processes were analysed to quantify their relative contributions to between-scenario variance in estimated hand contamination. The variables, distributions, and data sources used in the model are summarised in Table 8 and detailed in Appendix L (page 253), which informed final variable selection and parameterisation.

Table 8 - Deposit behaviour categories with analysis of resulting risk, number of contacts and percentage of deposits, from observational data collected in Delhi, October 2023.

Behaviour category	Analysis of risk	Observed number of hand touches with Solid Waste or bin	Distribution of observed deposits (%)
“Deposit no touch”	This is the safest practice as the Solid Waste is put into the bin without the person coming into direct contact with the main bin, its contents, or their own Solid Waste. It would be better if they had washed their hands after tying up their own Solid Waste bag.	0	81.53
“Deposit touch own”	This is where the person extensively touches their own Solid Waste to get it into the bin, usually by scooping it out of a container with their whole hand. Their hands are likely to be heavily contaminated from this activity. However, this is just the contamination from their own home, so it may not contribute to new pathogen exposure. Yet without handwashing, they are likely to spread that contamination around the community in anything else they touch.	Between 1 and 5	18.47

“Deposit touch hands”	is unsafe as happens when the person touches the side of the bin or the Solid Waste that is already in the bin. This is likely to cause exposure to faecal pathogens. Specifically, this will be exposure to faecal pathogens that originate outside the person's household.	1	2.51
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From these findings, the contact number was selected to be a range from zero to 5 contacts. The efficiency of transfer from the Solid Waste to the person’s hand is selected from a range of 0.0001 to 1 is a truncated normal with mean 0.255 and variance 0.155 (Lopez, 2018). Whole hand contact with uniformly contaminated objects was modelled based on the observed behaviour, and for simplicity, unidirectional transfer was assumed based on being far from saturation at five or fewer contacts (King *et al.*, 2020).

Around 95% of the modelled doses received were zero or almost zero. The median dose is also zero. However, due to some depositing events, including up to 5 touches, some of the samples were very highly contaminated with faecal pathogens, and some of the transfer efficiency data were up to 100%; there was a small frequency of very high dose figures. This led to a mean dose of 404,338 CFU/deposit. The highest value was 47,431,295 CFU/deposit. Despite being modelled as a rare occurrence, this dose presents a very real health hazard on those occasions. Across the three communities, it will take just over two weeks for 10,000 deposits to occur, as per the model. That could be up to 10 people per day in each community receiving a high faecal pathogen dose from interacting with the Solid Waste. See Figure 43 for the distribution of doses. For healthy adults, Enterotoxigenic *E. coli* infection typically occurs at a dose of between 1 million and 10,000 million CFU.

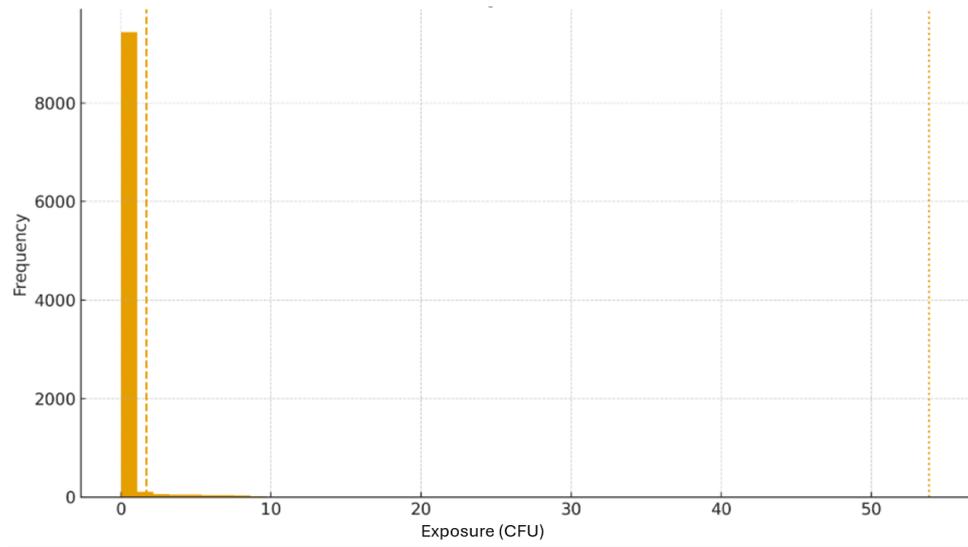


Figure 43 - Histogram of exposure per Solid Waste deposit event, expressed as CFU (millions). Modelled from data collected in Delhi, October 2023. The left yellow dashed vertical line marks the 95th percentile exposure level, indicating the threshold above which only a small fraction of events occurs. The right-hand yellow dashed vertical line represents the maximum modelled exposure.

As only 11% of deposits included any kind of contact with the Solid Waste, it is unsurprising that the vast majority of modelled interactions result in a zero or near-zero dose received. Another histogram was created, including only the top 5% of doses received, in order to more easily visualise the range of doses and the number of people potentially receiving those extremely high doses Figure 44. The top 5% of doses received account for 95% of the total modelled dose load. The 95th percentile dose is 1.62million CFU, the 99th percentile is 12.51million CFU/ml. The maximum dose modelled is 51.47million CFU.

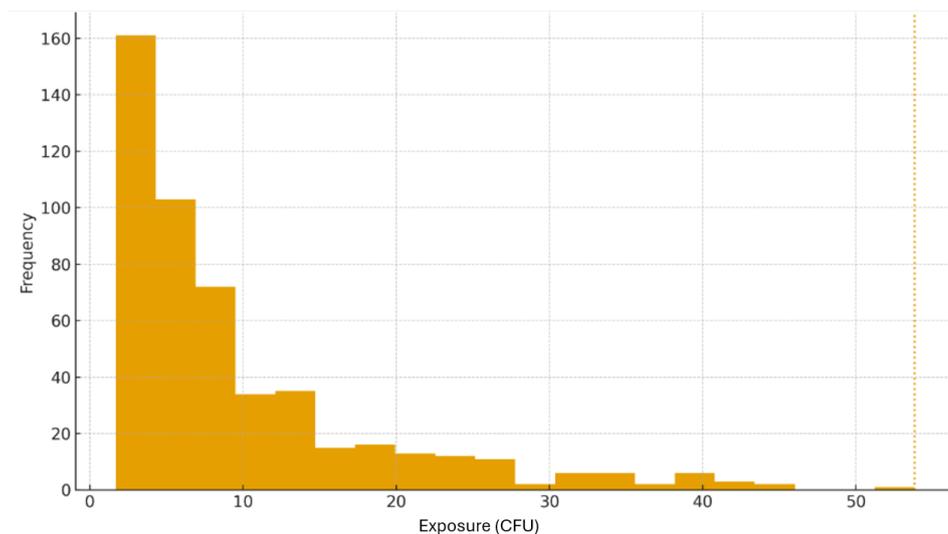


Figure 44 - Histogram of the top 5% of the modelled doses received from depositing Solid Waste in the municipal bins in Delhi. Exposure represented in millions of CFU. The dotted line represents the maximum modelled exposure amount, which was 51.47million CFU.

7.3 Discussion

Solid Waste is prevalent in every public area of all three study communities, and therefore, assessing the microbial hazard that this presents to the communities is worthwhile.

7.3.1 Community perceptions and behavioural mediators

FGDs showed that community members saw Solid Waste as unclean and a health hazard, with concerns mostly linked to bad smells. This disgust was also reflected in observed behaviours and may serve as a protective factor (Curtis, 2011). Yet participants were unwilling to admit contributing to the waste's dirtiness. Similar to findings on attitudes toward child faeces (Sclar *et al.*, 2016), people may discount the risks of their own contributions (Case *et al.*, 2006; Lenk *et al.*, 2019). More broadly, the community did not demonstrate a clear understanding of how Solid Waste could affect health. Many appeared desensitised to its presence in the environment. Disgust is an important emotional mechanism for keeping people safe and curbing unhealthy behaviours, but its protective role is uneven (Tybur *et al.*, 2018).

7.3.2 Microbiological evidence of hazard

All Solid Waste samples were heavily contaminated with faecal coliforms. Rinsing likely underestimated the true contamination (Jensen *et al.*, 2017) (Jensen *et al.*, 2017), and overgrowth on plates may also have led to undercounts (Haas *et al.*, 2014). Contamination was found at similar levels in samples from both bin sites and drain banks. This indicates that faecal material is diffuse and not driven solely by sewage in drains. Samples taken in 2023 showed higher contamination than the 2022 pilot. Flooding and drain overflows earlier in the year may have spread contamination more widely (FloodList, 2023). No clear pattern was found by type of waste content, despite literature suggesting food or organic matter would be the main drivers (Gerba *et al.*, 2011; Meyer-Dombard *et al.*, 2020). Contamination appears to distribute across items in mixed bins, although larger disaggregated sampling would be needed to confirm this.

7.3.3 Exposure pathways and risk implications

The dose modelling indicates that while most deposits involve minimal exposure, rare high contact events dominate risks. These include households that scoop waste from containers directly into the bin and children who handle Solid Waste while playing. Three consequences arise from such exposures. First, individuals may become unwell. Second, illness increases the circulation of pathogens in the environment. Third, people who interact with contaminated waste and fail to wash their hands may spread pathogens even without symptoms. The results suggest that interventions should be targeted at households and groups engaging in high-contact behaviours, rather than applied uniformly across the community.

7.3.4 Infrastructure and management failures

None of the municipal bins had lids, and few household containers used for deposits were covered. This creates opportunities for vectors such as flies, dogs, rats and goats to spread faecal pathogens. Although community members considered Solid Waste dirty, handwashing was not observed after deposits. The absence of nearby facilities, combined with the fact that many deposits were made en route to work, made this impractical. With facilities in place, uptake might be higher. Younger participants showed more awareness of the environmental impacts of littering and drain dumping, suggesting a potential entry point for future engagement to reduce indiscriminate disposal.

7.3.5 Social dimensions: gender and age

Cultural expectations placed responsibility for Solid Waste management on women, and government campaigns targeted them (Luthra, 2021). However, observations showed that both men and women deposited waste, often on their way to work. Gendered household responsibilities may not translate to public practices. Children were consistently more likely than adults to touch bins or step on waste, partly due to their smaller size and reach. One observed case involved children clearing waste with their hands to make space to play, without handwashing. Although women are often reported to have higher disgust sensitivity than men (Al-Shawaf *et al.*, 2018), men in this study engaged slightly less in touching waste. Physical differences such as height may explain this variation, as the bins were around 1.4 meters tall.

Observed temporal patterns also differed slightly between groups. All were deposited mainly in the early morning, though women showed a small midday increase, possibly linked to returning from work.

7.3.6 Implications for intervention and governance

Solid Waste is an under-recognised but important source of faecal pathogen exposure. While disgust and routine behaviours limit frequent contact, high-dose events create serious risks. Yet little research has examined the role of Solid Waste in pathogen transmission compared with water, food or drains (Han *et al.*, 2022). Generalised behaviour change activities are unlikely to succeed in changing exposures. More effective approaches would target households with high-risk practices, supply safe deposit materials such as plastic bags, and provide covered bins and handwashing facilities. Interventions that reduce Solid Waste accumulation would not only improve health but also support broader poverty reduction and improve quality of life in the communities (Milea, 2009). The findings reinforce the central argument of this thesis: that it is not only individual behaviour but infrastructural and systemic failures of waste management that drive exposure. Failures of transport and collection are key determinants of public health risk in these communities.

8 Chapter 8 - Discussion: Applications of the Amplified F-diagram.

8.1 Don't dismiss the real complexity

Urban sanitation systems are complex and dynamic, with overlapping systems and overlying and simultaneous failures. The F-diagram provided a helpful framework for many years but was not enough to support intervention decisions in the modern urban environment. This became the starting point for the Amplified F-Diagram described in Chapter 2.

8.2 Shit also flows uphill

There are many plausible pathogen pathways in the urban environment that could disrupt the conventionally held understanding about downstream communities. Paradoxically, the “downstream community” of Madrasi Camp was not found to have the highest overall contamination levels (Figure 25, Chapter 4). However, the upstream Jagdamba Camp did have a statistically significantly lower level of overall pooled contamination levels in the first set of data collection. Yet in Chapters 5 and 6, when more Fresh Produce and Solid Waste samples were analysed, the highest contamination levels were found at Jagdamba Camp, although these differences were not statistically significant. Therefore, the upstream and downstream nature of the communities did not correlate with the level of faecal contamination found; the principal exposures of Fresh Produce and Solid Waste were not found to be gravity-mediated.

This conclusion is reached because the concentrations are not higher at the community located at the lowest point of sampling in the catchment, which is Madrasi Camp. These results demonstrate the haphazard and intersecting nature of the reality of faecal contamination in Delhi. This is a reminder that urban sanitation risk cannot be reduced to a simple linear pattern but emerges from overlapping and shifting interplay across the sanitation chain.

Engineers and practitioners working in the water and sanitation sector may be influenced by hydrological approaches. In urban environments, there are conflicting layers of urban infrastructure and human behaviour that disrupt these organised assumptions. There is also a disjointed mix of formal and informal systems. This misunderstanding of the situation can

mean that contamination dynamics are ignored and allowed to remain, impacting public health. This work provides evidence to challenge the established thinking around upstream and downstream communities. Confronting urban sanitation requires an assessment style that integrates considerations of gravity-mediated and stochastic flows, with contamination risk that is not neatly contained by community, municipal or topographic boundaries. The cityscape disrupts traditional contamination mapping.

8.3 Modelling interventions on the Amplified F-Diagram

Chapter 2 describes the process and displays the resultant Amplified F-diagram. From this diagrammatic starting point, it is possible to model what would happen if different types of flows are removed from contributing to the resultant nodes as shown on Plate 8 (SankeyMATIC codes in Appendix M – page 255). This modelled approach deliberately does not specify any particular type of intervention at the different stages of the sanitation chain. Rather, the emphasis is on the underlying principle that the interventions must be effective in ensuring faeces and faecal pathogens are contained in the sanitation system. The intention here is to draw attention to outcomes rather than technologies (whether a system is onsite, offsite, container-based, urine-diverting, solar-powered, centralised, or decentralised), but only if it is successful in preventing transmission pathways that lead to human exposure. The right sanitation solutions are highly context-specific, and this work does not attempt to suggest appropriate technologies. There is much work published on how to make the correct selection according to the topographical, population density, social norms and institutional capacity context (GIZ, 2022). The Amplified F-diagram offers a framework for considering meaningful interventions accommodating diverse technologies and approaches, as shown in Plate 8. This method provides the benefit of anchoring the emphasis from infrastructure creation to the public health aims of preventing the escape of faeces into the environment.

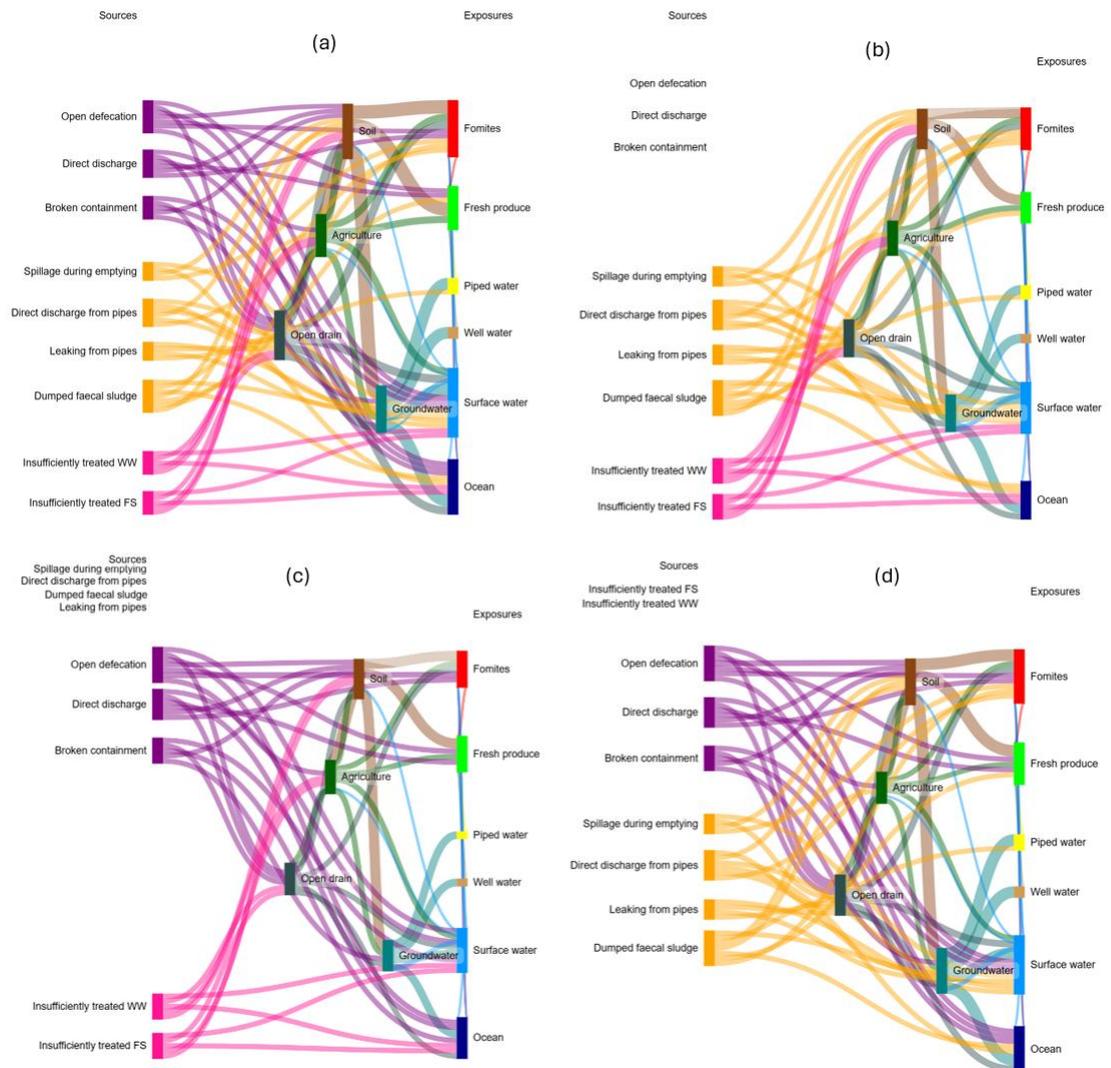


Plate 8 - Iterations of the Amplified F-diagram. (a) Amplified F-diagram, (b) Containment failures solved, (c) Transport failures solved, and (d) Treatment failures solved. The resultant change of node size represents decreased number of sources and pathways.

These overall improvement percentages were compared using a pairwise Wilcoxon signed-rank results test with Bonferroni corrections. The difference between Containment and Transport is not significant, but the Treatment improvements are significantly lower than the other two types (adjusted p-values 0.0176 and 0.0117).

In comparison, the modelled improvement percentage in the diagram midway and exposure nodes from the different intervention foci is shown in Figure 45.

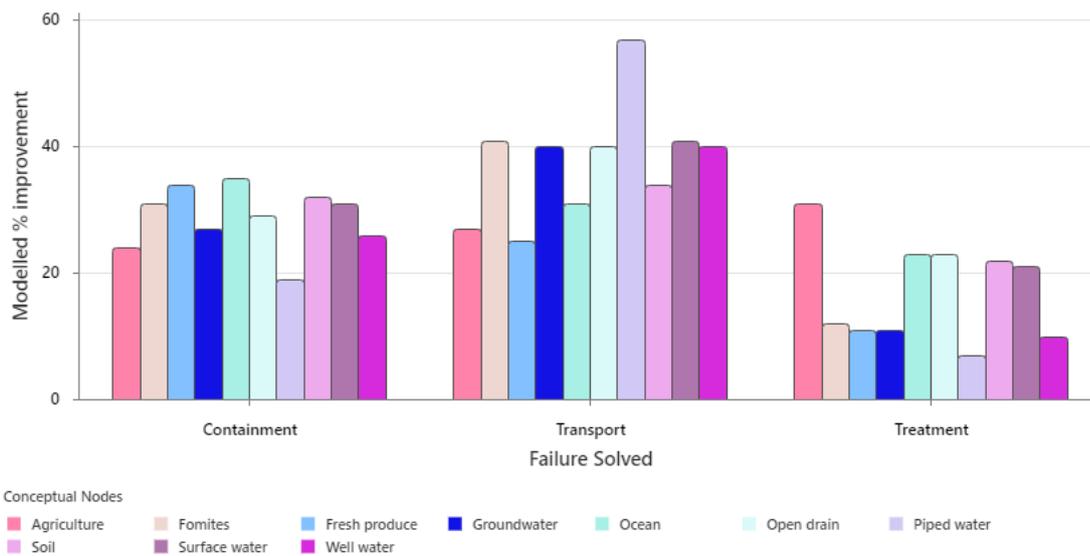


Figure 45 - Modelled percentage improvement of flows contributing to the contamination at each exposure node. Disaggregated by the sanitation chain stag.

None of the focal categories reduced any of the nodes to zero, and the mean improvements were between 25 and 40% leaving exposure hazards in existence. This means that simply solving Containment, Transport, or Treatment will not remove the hazards that communities face. While this would vary from situation to situation and would need to be assessed with a location-specific weighted diagram, the potential pathways remain important. This exploration in Chapter 2 shows that the current evidence for how faecal pathogens from failed Containment, Transport and Treatment reach the environment is not comprehensive enough to make a weighted Amplified F-diagram. In the literature, the most discussed failures cover all of the sanitation chain, as these are improper on-site sanitation siting, child faeces management, direct discharge, dumping of FS, and Treatment plants that release pathogens (either by design or in error). The most discussed exposures were through water contamination, fomites and Fresh Produce. The SFD data portal and the SaniPath data portal could contribute to this, but currently, they do not cover any overlapping locations. Therefore, further data collection was necessary. This was an interesting thought experiment, being able to demonstrate visually and numerically some of the things that sanitation experts have been advocating for many years about the importance of the Transport phase of the sanitation value chain (Peal et al., 2014; Peal et al., 2015; Mills et al., 2018; Peal et al., 2020).

This visualisation in Figure 45 is also helpful when there is an exposure point resulting in known health impacts. For example, if piped water was identified as a key exposure point, then using the model and resulting node changes, then this demonstrates that addressing failures in Transport, particularly leaking sewer pipes, can reduce groundwater contamination

and resultant risk to piped water (Mukherji and Shah, 2005). Conversely, if you want to reduce the faecal contamination exposure from Fresh Produce, it is unlikely to be helpful to build a wastewater Treatment facility.

8.4 Applying the Amplified F-diagram

Data collected in the study communities was used to edit the conceptual Amplified F-diagram, with the focus on demonstrating the evidenced flows. Data collected in this research, publicly available information, and the Shit Flow Diagram data were used to inform further decisions about the types of sanitation chain failures occurring across the city, both within and outside the study communities.

The ocean was removed as it was not relevant to the Delhi context, but all other nodes remained. The weighting was adjusted, and the positions of some items were repositioned to better represent the interactions between flows and to enhance the diagram's clarity. Evidence is that all the sanitation failure types described in the conceptual Amplified F-diagram are present in Delhi and have the potential to impact the study communities (susana.org, 2019; Emory University, 2020).

Surface water was a topic for much consideration because there is none in the study communities; however, the Yamuna River is located in Delhi. It was decided that surface water would be repositioned from being an exposure node to a central node. Insufficiently treated WW and FS had a similar deliberation process because there were no Treatment works serving the study communities. However, there are Treatment works around Delhi that have been shown to have low efficacy (Jamwal *et al.*, 2011), which discharge into other Open Drains and the Yamuna River. This could then be distantly influencing the contamination reaching the communities.

There is evidence that the community is exposed to faecal pathogens through Fresh Produce and fomites such as Solid Waste. Low levels of exposure were found to result from drinking water. However, due to known instability in the system (Yadav *et al.*, 2019), this could be fragile. Well-water usage was reported, but the water quality was not sampled. Open drain interactions were self-reported to be low; however, it is likely that interactions were higher with the smaller tributary drains that crisscross the community, due to their proximity to people's homes. Even without direct interaction, Open Drains remain an important feature of the study communities due to the likely contamination spread through other nodes, such as the Fresh Produce and Solid Waste. There is also evidence of the Open Drain being used for

pig farming, so it remains an important part of the diagram (Figure 46 – code available in Appendix N, page 258).

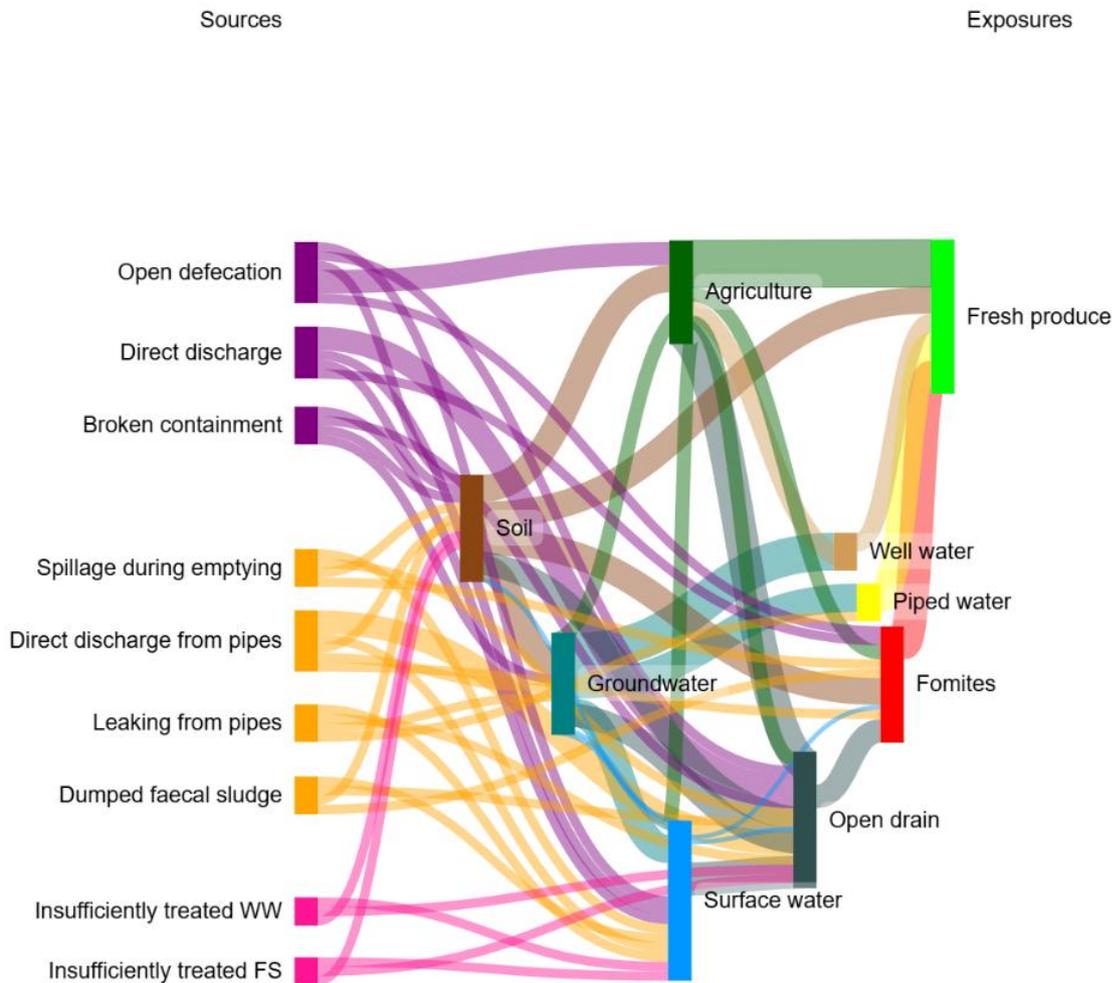


Figure 46 – The Applied Amplified F-diagram for the study communities in Delhi, based on data collected in October 2022 and November 2023.

As for the conceptual diagram, the applied diagram is reiterated by solving different facets of the sanitation chain to see how that affects the flows and the sizes of the exposure nodes Plate 9. SankeyMATIC codes available in Appendix O (page 259).

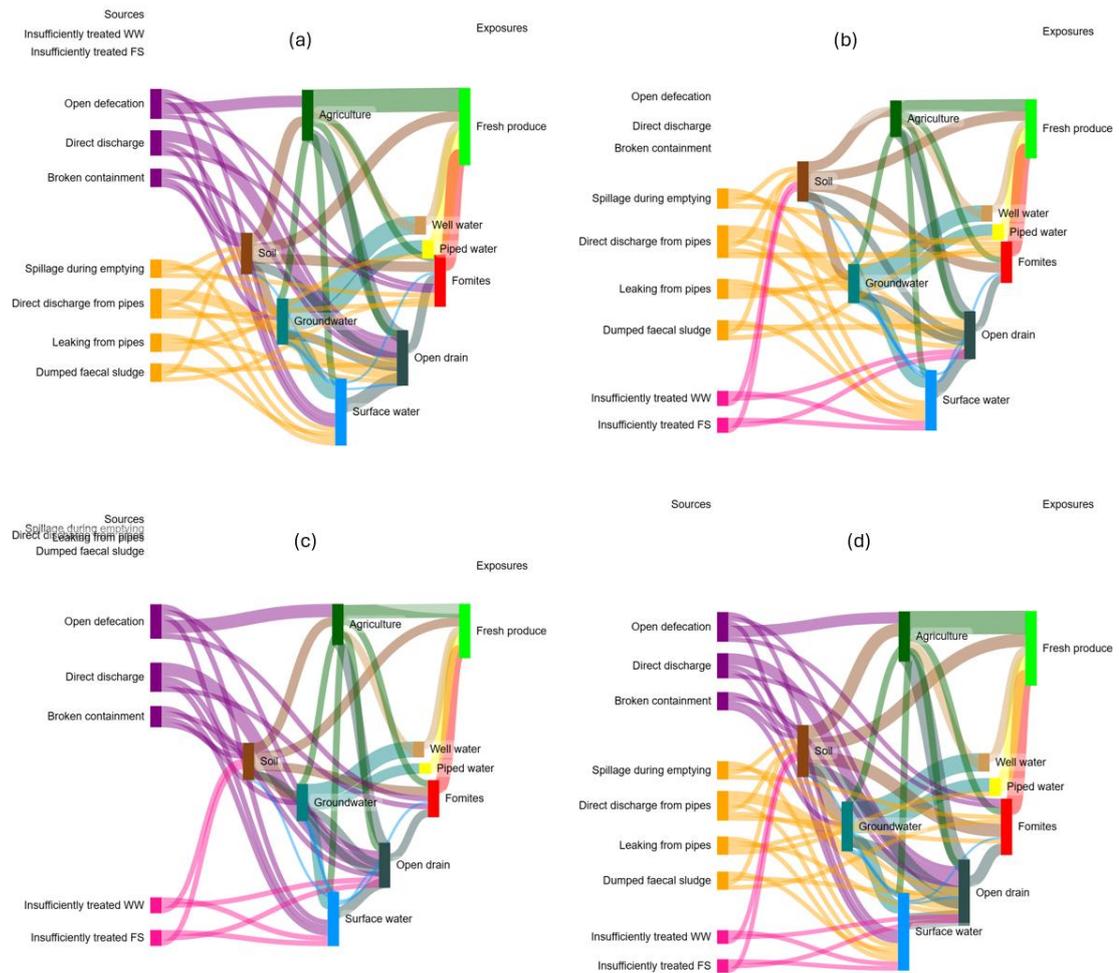


Plate 9 - Iterations of the applied Amplified F-diagram. (a) Applied Amplified F-diagram, (b) Containment failures solved, (c) Transport failures solved, and (d) Treatment failures solved.

All three diagrams in the plate show some reduction in the size of the nodes, but clearly, there are still many pathways and substantial exposure hazards remaining. Pairwise Wilcoxon signed-rank tests with Bonferroni corrections (Greenhalgh, 2019) find that there are significant differences between all three pairs of Treatment types.

As before, in comparing the effects of the intervention types on each of the subsequent nodes, it is possible to see the contributing factors to each point (Figure 47).

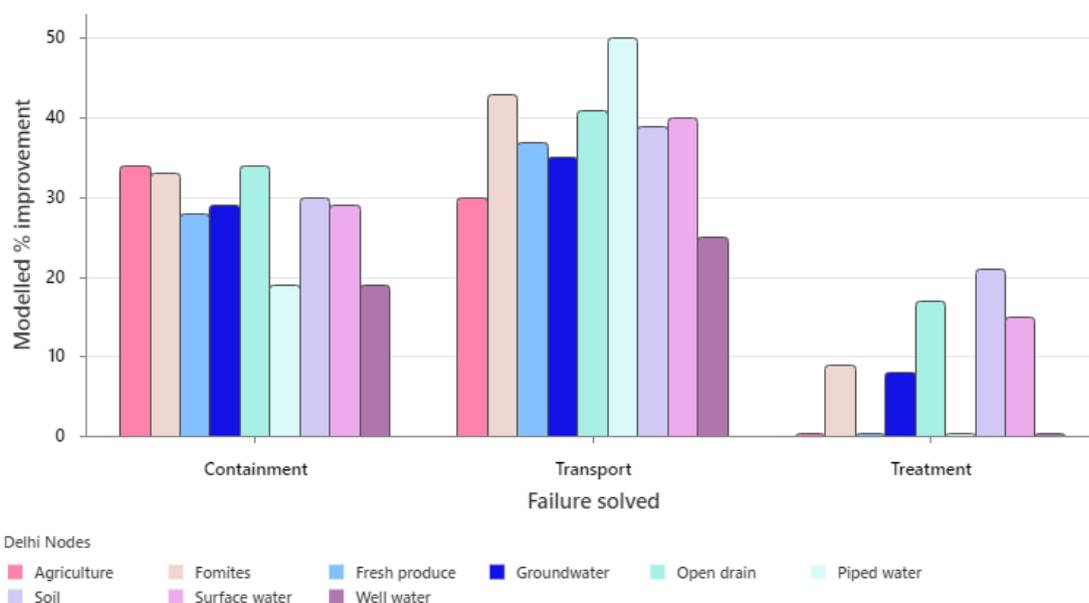


Figure 47 - Modelled percentage improvement of flows contributing to the contamination at each exposure node in Delhi. Disaggregated by the sanitation chain stage.

Solving the failure groups had an impact on the sizes of many of the subsequent nodes, but none of the intervention types completely resolved any of them, as all the nodes have contributions from more than one source group. In the conceptual diagram, all the nodes showed some improvement in each intervention group. However, in the applied diagram, some nodes (Agriculture, Fresh Produce, Piped water and Well water) had no improvement at all in the Treatment intervention diagram.

8.5 Findings from Applying the Amplified F-diagram

The conceptual and applied F-diagram both tell the same story: Transport is the most important segment of the sanitation chain for reducing environmental faecal contamination, and hence public health. As such, any interventions that only prioritise increasing coverage and access to toilets will have a limited impact on population health. Many toilet provision interventions are also limited by being localised and fail to see health improvements because faecal contamination moves widely around the city and does not always follow the hydrological principles of upstream and downstream.

The Amplified F-diagram offers a structured means of reframing responsibilities for faecal contamination control. The nodes positioned on the left side of the diagram represent systemic failures that fall squarely within the remit of the state, municipal and public health authorities. In contrast, the nodes in the central and right of the diagram illustrate more

complex intersections where responsibility may be shared, including some scope for community action and behaviourally mediated practices. Crucially, the diagram makes explicit that interventions focused only on exposure reduction at the individual or community level will yield, at best, marginal improvements. Without sustained and large-scale investment in the systemic failures of the sanitation chain, other interventions will remain ineffective and inappropriate. In this way, the Amplified F-diagram provides both a visualisation of the contamination network and a critique, demonstrating the necessity of systemic solutions over fragmented local and behavioural approaches.

8.6 Intervention Response Focus

Public health approaches to preventing infectious disease transmission work in four ways (Friis, 2018; Webber, 2020): reducing the vulnerability, reducing the exposure, interrupting the pathways and reducing the source of the hazard. Each of these will be considered here, but while reducing vulnerability is important to note, it is outside the scope of this study.

For faecal-oral diseases, reducing the vulnerability would include nutrition programmes and oral rehydration salts therapies to prevent life-threatening dehydration from diarrhoea.

There is a plethora of options for reducing exposure, and these are often first-line interventions for community health projects. Regular handwashing at key points such as after defecating, before eating and before feeding children is the subject of many behaviour-change programmes. This can include providing helpful items such as handwashing stations and soap (Curtis and Cairncross, 2003). In the study communities, handwashing opportunities around the municipal bins could reduce exposure to faecal contamination. There could also be behaviour change activities such as sensitisation, signs to remind people not to touch the bins or Solid Waste, and provision of waste bags for safer depositing.

Behaviour change interventions could target food-related contamination by encouraging thorough cooking and washing of produce before eating, as recommended in other research (Ehiri and Morris, 1996). These can be initiated through community action projects, schools and health providers. Although community members, when asked, state that they already wash their produce, the reality is that washing may not appreciably reduce the contamination, particularly of herbs with their high surface area (Drechsel *et al.*, 2022). Vendors and farmers could be educated about safer produce washing practices, such as changing the water regularly and using chlorine to provide disinfectant. These changes could be supported by policy approaches and enforcement due to their importance.

It is implausible that people will stop eating raw produce when it is part of the daily normal diet, and therefore, preventing exposure to any pathogens on raw produce will be impossible. Many of these exposure reduction actions are focused on community behaviours, which are notoriously hard to embed. Even expensive, high-intensity projects have been shown to have limited success and little longevity (Curtis and Cairncross, 2003; Null *et al.*, 2019). Worse, these interventions effectively make individual community members responsible for protecting themselves from pathogens that are ubiquitous and concentrated in their environment as a result of failing infrastructure and systemic neglect. This not only places the burden on those with the least resources, but it also obscures the accountability of institutions that should be responsible for safeguarding public health.

By contrast, removing the sources of the hazard of faecal contamination by building and repairing the sanitation chain offers the only viable and just option. High-income countries have achieved this to a satisfactory level due to sustained investment into infrastructure and political commitment, enabling the entire population to reach a threshold standard of living. Although this comes with a financial outlay, India has economic capacity and a large and growing GDP (World Bank, 2025). Indian investment into other types of infrastructure, such as Transportation networks, has been major (KPMG, 2020). A similar prioritisation and investment into sanitation, particularly in solving failures in the Transport segment of the chain, would directly reduce pathogen contamination in the environment and protect communities in a way that exposure reduction strategies cannot.

It is necessary to examine how hazards can be removed through strengthening each stage of the sanitation chain.

8.6.1 Potential impacts of solving Containment

For the many communities without any sanitation facilities, building toilets would be an obvious and merited first step to provide secure Containment of faecal waste at the household and community level. Without this, any interventions towards Transport and Treatment would not be possible, as the faecal waste would not be able to enter the sanitation chain.

In many low- and middle-income urban settings, Containment infrastructure is likely to be on-site systems such as pits or tanks. Rarely are these types of communities connected to sewer networks (Hasan, 1998; Hasan, 2006). Solving Containment means providing services where there are none, and also mending, maintaining and upgrading facilities that are not functioning effectively. This includes considering the impact on the groundwater and safe and

effective emptying methods. Installing sewage infrastructure in informal settlements can be disruptive due to the high household density.

As found in the WASH Benefits and Shine trials (Pickering et al., 2019) improved household-level WASH (which was only tackling Containment) did not reduce the likelihood of diarrhoea and stunting in children. The Amplified F-diagram provides a clear model to understand potential rationale for these findings; even completely solving all contamination sources from failed Containment (which is unlikely to have been achieved in reality) and assuming perfectly clean drinking water, there are still a myriad of ways that faecal pathogens could have reached the studied children. Consequently, it is likely that those other pathways resulted in an exposure level that did not drop below the threshold level for health impacts. Additionally, faecal pathogens from failed Containment in other localities could have also contributed to their environmental exposure.

The authors who question the merits of sanitation investment (Bartram *et al.*, 2018) have a valid point that there is little public health reason to make investments into only Containment services. However, rather than this conclusion leading to reduced investment, the investment should be extended to the whole sanitation chain and ensure that there are barriers preventing faecal pathogens from escaping into the environment from all parts of the system.

The Swachh Bharat Mission has been an enormous effort to ensure all people in India have access to a toilet facility and no longer practice open defecation (Ministry of Jal Shakti, Government of India, 2020; Ministry of Jal Shakti, Government of India, 2025). However, going above just access to a toilet would be necessary in order to solve the problem of contamination originating from unsafe Containment.

Solving Containment across the entire Delhi would be a challenging task due to the numerous informal settlements and the currently low coverage of piped sanitation services. The percentage coverage of piped services is declining due to urbanisation and population growth (Office of the Registrar General & Census Commissioner, India, 2011). Estimates of the coverage of safely managed sanitation vary, and official coverage rates may not account for informal and unregistered populations (Harvard Law School International Human Rights Clinic and Centre). Even where appropriate infrastructure exists, it may be unused or in disrepair. The study communities had incomplete access to toilet facilities, but even where facilities existed, most of these were not safely managed, and some were shared. Therefore, increasing the household toilet provision is still valuable as part of the picture. However, the

reductions in exposure contamination modelled in the diagram do not just refer to Containment solutions within the communities, but also in the wider city.

It has been clear to see the substantial city-wide contamination impact from the open defecation in the farming communities, and therefore targeted interventions there could bring an important decrease in faecal contamination across the city, across the raw food pathway. In addition to the infrastructure needed, behaviour change work would be needed, but there may be resistance as losing the human faecal addition to the crops could reduce productivity. However, it was unclear if this was something the farmers recognised.

In Delhi, urban farming is legally and environmentally contested. Cultivation of food crops on the Yamuna floodplain (Zone O) is officially prohibited due to heavy metal pollution (IWMI, 2010; Singhal, 2023). Farmers nevertheless continue to grow food crops. Farming communities experience recurrent evictions without warning and insecure tenure, and have little quality of life infrastructure (Awasthi, 2013; Cook *et al.*, 2015). Despite this, many of the farming families have lived and worked on that land for many decades (Main Bhi Dilli, 2020). Some non-profit organisations work with the farmers to support them with their legal status, well-being and fund the provision of a school (Singhal, 2023). There has been a study checking the level of heavy metal contamination on the crops from the floodplain farms and found it to be within guideline levels (Central Pollution Control Board, 2019). However, this outcome is contested by local environmental experts who state that there is lead and other contaminants and blame the farmers for their use of the Yamuna River and unsafe fertilisers (Singhal, 2023).

Various methods could be considered to reduce the study community's exposure to Solid Waste: Community litter picking could reduce the dispersal of Solid Waste, and the municipality could be lobbied to change its Open Drain dredging method to prevent Solid Waste from piling up along the banks. Increased coverage of safely managed local toilet facilities may be effective in reducing some of the contamination sources on the Solid Waste. This would be the case if there is the unadmitted use of 'flying toilets', diapers and disposal of faeces for elderly and disabled people, and instead people used their household toilet provision. If this is the case, then improving access to household sanitation, combined with some behaviour change sensitisation if needed, could substantially reduce the short-circuit loop of contamination within the community. However, as the sources and pathways to Solid Waste contamination were not adequately identified in this or previous work, reducing unnecessary exposure to Solid Waste remains a practical and appropriate barrier.

In the Barapullah basin, many households along the Open Drains have sanitation systems that directly discharge into the drain. This means that contamination in the Open Drains would be reduced by communities having safely managed Containment. However, according to the self-declared data, community interaction with the Open Drain was minimal, so any interventions to reduce this contamination may not make a big difference to public health.

Some of the contamination of the groundwater comes from the on-site sanitation that is not safely managed, such as pits and tanks, which leach into the ground. In the study communities, there was low contamination detected in the microbial sampling of the Piped Water. This suggests that the piped water is being run with adequate system pressure and chlorination, preventing the ingress and multiplication of faecal pathogens in the water. If the water pumping system were to fail, there is a high potential for the contaminated groundwater to ingress and create a hazard for the communities. Currently, they are not in the habit of needing to boil or treat their water at the point of use, so there are no barriers in place at the point of exposure if the pathway becomes an active hazard.

The findings of this research and modelling demonstrate that localised, piecemeal and Containment focussed interventions cannot overcome the systemic sanitation chain failures. Containment failures in other parts of the city have a direct impact on the study communities, demonstrating that pathways can originate at varying distances away. Contamination pathways cross community and socio-economic boundaries, and therefore, only city-level approaches can meaningfully reduce public health risks.

8.6.2 Potential impacts of solving Transport

In Plate 8 (c) and Plate 9 (c), the Transport failures were removed. This shows a situation without sanitation chain failures of spillage during emptying, direct discharge from pipes, dumped faecal sludge, and leaking from pipes. There was no example to be found in the peer-reviewed or grey literature where anything comparable to this modelled intervention had ever been attempted or achieved as an intervention focus to understand any real-world before and after benefits this could have, particularly in settings where Containment and Treatment are not adequately functional. In the original SFD studies (Peal *et al.*, 2014), none of the cities controlled FSM effectively. However, now there are some high-income country SFDs in the data set that demonstrate sanitation chains functioning at a high efficacy, and public health improvements are seen (susana.org, 2019). In the diagram model, solving the Transport did make a big difference to the sizes of the subsequent nodes, with the biggest

impact on Piped water, which decreased by more than half. Fomites, Well water and Surface water nodes each decreased by around 40% and Ocean and Fresh Produce decreased by 32% and 25% respectively. This is a greater overall decrease than the Containment failures and suggests that it might be a more effective intervention focus. However, solving informal pit and tank emptying and Open Drainage would be a very technically challenging and expensive venture. This is why some authors are revising previously held ideas about on-site sanitation being cheaper and easier, because the necessary FSM is, in fact, not. Traditional sewerage and condominal sewers are increasingly being recommended as a practical and cost-effective way of reaching safely managed sanitation, even in low-income communities (Mara, 1996).

In the sanitation chain, the Transport segment is where the faecal pathogens have the most potential opportunity to move far from their source. Sewer pipes can run long distances and can also be fitted with pumps to allow the flow to run at low gradients or against gravity. In failures of the sewer network, the pipes can be cracked or leak, causing groundwater contamination. The leaks can be some distance from the source, and then groundwater can move long distances (Jamwal et al., 2011; Peal et al.,) Sewage pipes can be built without connection to Treatment works, but instead discharge into Open Drains, Surface Water, Oceans or onto the ground. On-site sanitation emptying systems can be utilised to take the faeces to Treatment services or even to a sanitary landfill. However, there can be many barriers to this process occurring effectively, such as cost, distance and the effort involved. This means that, often, faecal matter is dumped into Open Drains, Surface Water, Oceans or onto the ground. It can also be dumped directly onto Agricultural land. This can be 'uphill' from the source of the faecal matter and can also be several miles away if transported by trucks, although sometimes it will be dumped locally if being transported on carts or other non-mechanical options (Grisaffi *et al.*, 2022; Wilcox *et al.*, 2023).

These failures in the Transport phase of the sanitation chain can all happen at once, meaning that the city can act as one big leaky, connected system. Any attempt to improve public health with interventions only at the community level is inevitably going to be unsuccessful because faecal pathways are flowing into every community from so many pathways with sources located at varying distances away. The way that the pathways cross large distances also means that in higher-income communities with excellent water and safely managed sanitation can also be affected by the failing sanitation in the city around them. This knowledge should be able to galvanise the popular and political will to tackle these challenges, but so far it does not seem to have been persuasive enough (Lerebours *et al.*, 2021; Lerebours *et al.*, 2022). Solving the failures in the Transport part of the sanitation chain

would mean that there would be less potential for faeces to be moving around the city, potentially reducing contamination over large areas.

The failures in the Transport systems, both of the limited piped network and onsite emptying practices, are widespread in Delhi (Jamwal *et al.*, 2011; susana.org, 2019; Yadav *et al.*, 2019).

As can be seen in the modelled improvements in Plate 8 (c) and Plate 9 (c), solving the Transport phase of the sanitation chain would have a substantial effect on the exposure contamination in the study communities, with node reductions between 25 and 50%. Fresh produce contamination is influenced by many pathways, and many of those are contributed to by Transport sources.

Solving Transport would improve the contamination levels in the Open Drains. This would decrease exposure directly and indirectly. Some of the Solid Waste contamination would be improved by the reduction of contamination in the Open Drains due to being dredged out of the drain and dumped beside the houses on the banks.

In reality, finding appropriate ways of solving Transport in urban areas is one of the wicked problems of the 21st century (Carvalho and Van Tulder, 2022). This is particularly the case in densely populated urban areas with high levels of informality and slums. The problematic nature of this topic cannot take away from its importance for public health. Faeces in the Transport section of the sanitation chain can move long distances, can move against gravity and uphill, and therefore is a contributing factor to the wide reach and unpredictability of the resultant contamination from sanitation chain failures.

8.6.3 Potential impacts of solving Treatment

In Plate 8 (d) and Plate 9 (d), the Amplified F-diagram has been iterated with all the Treatment failures solved. This would be a situation where there is safe and effective Treatment of all liquid and solid faecal matter that reaches Treatment, meaning that pathogens are sufficiently reduced before being released into the environment to not pose a hazard. Building new wastewater Treatment works is an investment and can cost large sums of money. Rarely are Treatment works built to accommodate faecal sludge. There were no examples in the literature found where the effectiveness of a Treatment intervention was verified by testing exposure to faecal pathogens or direct health outcomes. The modelling here in the Amplified F-diagram suggests that these interventions would have very little impact on the exposure nodes. Even though Treatment works provide a large piece of visible infrastructure, and even where they are working 100% effectively to remove pathogens from

all effluent, they are only likely to contribute in a small way to the reduction of pathways leading to faecal pathogen exposure.

Treatment plants are often designed to remove some turbidity and nutrients from the wastewater in order to protect the ecology in the river or sea where the outflow is (United States Environmental Protection Agency, 2010) Some Treatment plants may have secondary or tertiary levels of Treatment, and they can be more effective in removing pathogens. Treatment plants take a lot of maintenance and can fail. Consequently, whether working but not removing pathogens, or failing and therefore not removing pathogens, Treatment plants can be a source of faecal pathogens in the environment. In contexts where Open Drains, Surface Water and Oceans are used more extensively for drinking, bathing and urban agriculture, the failed Treatment could be causing a negative health impact. However, for the study communities in Delhi, this was not the case in the most part, and therefore, when these sources were modelled as solved, there was only a minimal improvement in the exposure nodes. There are no published studies demonstrating the public health benefits from building wastewater or faecal sludge Treatment plants alone.

In the applied diagram scenario, solving the Treatment part of the chain had even less improvement on the resultant nodes than on the conceptual diagram. This would be for several reasons: the communities were not directly impacted by discharge from Treatment works, and there is no evidence that the Barapullah Open Drain is used for this purpose (Centre for Science and Environment, 2025b). There was also no evidence found that treated or partially treated works effluent or sludge was used in agriculture. There may be some instances where this is the case in Delhi or surrounding areas, but the farming communities investigated as part of the exploration here did not utilise this resource, meaning that the risks from this use were not applicable.

8.7 Usefulness of approach/pragmatism

The conceptual and applied Amplified F-diagram is a useful approach to enrich intervention planning. Current approaches to water and sanitation are leaving communities exposed to dangerous levels of faecal pathogens due to interventions that are misaligned with their purposes. Despite the demonstrable failures, the status quo of prioritising localised solutions remains. This research provides a systematic means for identifying priorities in addressing community faecal contamination. Incremental and strategic improvements can accelerate

progress towards removing the health impacts from faecal contamination (Willets *et al.*, 2022).

Despite the expertise that went into the formulation and integration of this model, with some explanation, it should be possible for the conceptual model to be understood by anyone working in the sanitation space. This would enable the usefulness of this research to be actualised by enabling practitioners to think practically about the invisible and not gravity-mediated pathogen flows in their context. Making an applied version of the Amplified F-diagram would take a greater level of understanding and familiarity with the SankeyMATIC flow diagram tool. Yet the code for the diagram has been created, and this can facilitate a thought-provoking process of considering the reality in the local context. If someone is carrying out the desk research to complete an SFD Lite, they could potentially have the needed information to make an applied Amplified F-diagram to complement their findings. The data collection process of carrying out microbial and behavioural analysis is much more labour-intensive, but it would be ideal to be able to apply the diagram with more precision.

8.7.1 This is a conceptual approach to a very complex, physical and practical problem

Clean drinking water and safely managed sanitation remain the mainstay of public health interventions for faeco-oral diseases. However, while immediately fixing the water and sanitation systems in every context is out of reach for technical, financial and political reasons, it is important to be pragmatic. Using this model, either conceptually or applied, would allow for targeting the most problematic or heavily contaminated pathways. In these situations, benchmarks such as drinking water quality guidelines (World Health Organization, 2017) or insistence on a move away from shared sanitation facilities (Anon, n.d.) may be wasteful of resources and do communities a disservice. Pragmatic interventions that effectively interrupt faecal pathogen sources, pathways or exposures would be more likely to bring real health improvements.

Interventions around agriculture and food are recommended to be multi-barrier (D.L. Galibourg *et al.*, 2024). This means that there is an assumption that contamination could occur at any or several places along the food production chain and that each intervention only makes an incremental improvement on the exposure levels from eating the food. One of the reasons this is a good pragmatic approach is that the pathways to exposure along the food chain will vary from place to place. Much of the literature locates the problems as

relating to unsafe use of surface water, drainage water or faecal materials in irrigation and fertilisation. However, in this study, the findings were different, with the main contamination on the Fresh Produce coming from open defecation and poor washing practices.

Recommendations for reducing the contamination on the Solid Waste are difficult without having located those sources. In addition, it is probably unnecessary, as Solid Waste is supposed to be a waste product that is taken away from the communities for the very reason that it is smelly and dirty. This means that the multibarrier approach could be used to ensure that communities have fewer interactions with the Solid Waste. In this study, increasing the use of bags to Transport the Solid Waste to the bins would result in a drastic reduction in the number of hazardous exposures.

This study demonstrates that faecal contamination in Delhi is not localised, not gravity-bound, and not containable through household-level action. It is mobile, travelling on food, through Solid Waste, and in ground and surface waters, exposing communities regardless of their own sanitation status. Local interventions alone are ineffective and unjust; systematic, city-wide solutions are required. Critically, the evidence shows that public health gains will not come from Containment intervention strategies, but by tackling failures in the sanitation chain, Transport, the point at which faecal matter is amplified and redistributed throughout the urban environment.

8.8 Meaningful results from exploratory data

The data collection in this research was exploratory to find out if it is possible to make a flow diagram to represent the flows of faecal pathogens in the urban environment, and what data collection and analysis would be involved. With unlimited time and resources, more data could be collected, and could add depth and breadth to the understanding of all of the pathways and their actions and interactions. This would enable a true weighted quantification of the flows in the diagram. Yet even with unlimited data, a more interesting question is how much data is enough to say with some confidence what is important and to be able to transition from information gathering to action. In this situation, the adage of the three important numbers rings true, with numbers of zero and one only found on the drinking water. Many CFUs were found on both Raw Produce and Solid Waste, and people were found to interact with these exposure points regularly. More specificity of the data would be very unlikely to change the conclusion that these are areas to prioritise interventions to improve public health. The study demonstrates both reliability and validity

due to using a mixed-methods approach. Self-reported measures were triangulated with objective indicators, resulting in data that is effective in answering the research questions.

As informed by the exploratory progression of the work, the two focal exposure points were selected due to the microbial and behaviour data collected at the community level. They have provided an interesting lens to the complexity of urban faecal contamination due to their being very distinct from each other. Raw produce is something that you are unlikely to ever stop being exposed to, as it is a cultural norm to eat foods in this way. The contamination on the raw produce has been transported many miles across the city and emphasises how interventions to improve the public health of a community cannot be only to the bounds of that place. In contrast, Solid Waste is something that people avoid exposure to where possible, and no one would disagree that it should be contained and disposed of. The smell and the appearance are repellent and can cause some distress. The pathway that a particular wrapper or other piece of rubbish has taken before it reaches the bin will vary, but while it could have originated far away, it is likely that it changed from being a useful item (for example, enclosing a snack product) to something to be disposed of locally in the bins. The exception to this would be the Solid Waste along the banks of the Open Drain that could have floated from other locations before reaching that community.

Behaviour change interventions are difficult to execute due to resistance and a return to previous behaviours. People can express awareness of the behaviours that would be ideal for protecting health, such as washing hands after depositing Solid Waste and washing vegetables before consumption. However, in the absence of enabling infrastructure, these practices remain unachievable as individuals are structurally prevented from acting on their knowledge. Therefore, action reflects a combination of intention and opportunities.

8.9 Approach reflections.

In view of the positivist assumption that there are discoverable answers to be found, this research sought to identify patterns and results within the data (Mukherji and Albon, 2023). This orientation enabled conclusions to be developed without the restriction of a narrowly framed hypothesis, which was particularly valuable in allowing unexpected findings to surface. While evidence-based public health forms part of the researcher's foundational perspective, it served only as a broad backdrop rather than a prescriptive framework. Testing interventions against the model may, in the future, provide evidence of specific public health benefits, but the central underpinning of this study lies in systems thinking. Without adopting

a systems perspective, the unbounded, entangled, and unpredictable realities of the city could not have been adequately captured or analysed. The urban environment, in all its complexity, became the subject of analysis in its own right. These philosophical positions directly informed the methodological choices. The methods were deliberately exploratory and triangulated, designed to enquire not only what is happening, but also where and why. The multiple forms of data were essential for engaging with the non-linear and overlapping failures of urban sanitation systems. The result is a visualisation that not only reveals patterns of risk but also challenges established assumptions, demonstrating the value of systems thinking as both a conceptual and methodological foundation.

Poverty is a fundamental determinant of poor public health (Kaplan and Valles, 2021b), and addressing it requires multifaceted strategies underpinned by substantial political commitment and investment. However, WASH has also been shown to be a key step in the reduction of poverty and a driver for economic improvement (World Health Organization, 2023). Data and analysis that help us to understand really what it is about WASH that reduces exposure to faecal pathogens, with the potential for public health improvements, could be a stepping stone for this. Part of the motivation for this work was to show that the poor sanitation status of the poor has a wider impact on the health of the city. However, the richer people do not suffer as much when exposed to faecal pathogens due to better nutritional status and better access to health care. There could also be unintended consequences to this message, so rather than being inspired that their health could improve from providing good WASH facilities for slum communities, instead, the rich could then want to move informal communities further away from their dwellings and carry out clearances or other persecutions. This could also apply to the farming communities who need secure tenancy and sanitation facilities, but could result in further insecurity for them.

9 Chapter 9 - Conclusion

9.1 Fulfilment of the Research Aim and Objectives

The aim of this thesis was to develop a better understanding of the principal pathways of faecal contamination in low-income urban communities. This was achieved through the following objectives.

The first objective was to evaluate the usefulness of the F-diagram as a model for describing pathways of faecal contamination in low-income urban areas and to propose an alternative model. The evidence in the literature for source-pathway-exposure linkages was examined. The literature is sparse on linking all three of these together; however, some insights can be gained from literature that covers parts of the source-pathway-exposure connections. Published research focuses largely on exposure to faecal contamination via water, including drinking, bathing, and recreation, as well as through Fresh Produce. There was some research that identified exposures on fomites, including specifically children's toys and the floor, but this work is not extensive. The F-diagram and its applications and iterations were examined. No model was located that visualises how the sources, pathways and exposures of faecal contamination manifest in typical urban contexts in low- and middle-income city settings. The novel Amplified F-diagram was developed to fill this gap in a city-scale source-pathway-exposure modelling framework.

The second objective was to assess the relative significance of different faecal pathogen exposures on health risks in typical low-income urban communities. This was achieved through three study communities in Delhi, India. Sites were selected along the Barapullah Open Drain. Data on behaviour and levels of faecal contamination were combined to generate a better understanding of primary pathways of faecal contamination. Fresh Produce eaten raw and Solid Waste presented the communities with substantial exposure to faecal pathogens. Faecal pathogens were found to be profuse in the urban communities studied.

The third objective was to identify and explore the sources and pathways that result in the critical exposures, including those arising beyond the immediate setting of the example location. For the Fresh Produce eaten raw, a detailed exploration of the food network was achieved by tracking backwards from community members via local vendors and their marketplaces, to the produce that originates outside Delhi's boundaries, and the produce that is grown within Delhi's boundaries. Faecal contamination was found throughout this food network; however, the evidence suggests a key contribution comes from open

defecation and unsafe produce washing practices on urban farms. Human relationships with food are intricate, and identifying the actual modes of interaction is a complex process. For Solid Waste, the level of faecal contamination and modes of exposure were more easily identified and occurred within the community.

The fourth objective was to use the results from objectives one, two and three to evaluate how targeted sanitation interventions might or might not reduce faecal pathogen exposure and thereby enhance public health. The Amplified F-diagram facilitates the understanding of complex systems and has been applied to the study of communities. Applying the diagram pulled the strands of this research together and enabled an evaluation of how the modelled interventions would impact public health. Modelling revealed that interventions focused on the Transport stage of the sanitation chain have the most potential to reduce faecal exposure. This was true both for a stylised general case and for the study communities.

In addressing these research aims and objectives, this thesis contributes to addressing the key gaps identified in the sanitation and exposure literature.

9.2 Methodological Limitations and Boundaries of Generalisation

Having assessed the extent to which the research aim and objectives were fulfilled, this section draws together the methodological limitations discussed across the thesis and clarifies the boundaries within which the findings should be interpreted. This thesis adopts an integrated conceptual, empirical, and applied modelling approach to examine faecal contamination pathways in low-income urban environments. Methodological limitations associated with the research components have been discussed in each relevant results chapter. However, these are drawn together here to clarify the limitations and boundaries which impact the findings, and to support the interpretation and application of the approach.

The case study approach adopted in the empirical sections of this research further constrains the extent to which the findings can be generalised beyond similar low-income, high-density urban contexts. However, the case study contexts chosen are urban environments characterised by fragmented sanitation systems, extensive informal sanitation and Solid Waste handling, high population density and mobility. This type of community context is prevalent worldwide. Caution should be exercised in extrapolating findings to rural settings,

low-density urban areas, or contexts where containment and treatment failures dominate over a context heavy with all three, including significant transportation failures.

A limitation arises from the deliberate focus of the analysis on selected exposure routes and pathogen pathways. While these were based on evidence, it is recognised that other pathogen pathways may contribute significantly to the exposure experienced in the communities.

The limitations of Chapters 5 and 6 are common to many environmental microbial sampling and behavioural data collection research. Microbial measurements rely on snapshot measures of faecal indicator organisms as proxy measures for pathogen presence. This means relative comparative judgements can be made, but not an absolute prediction of disease or infectivity. Some indicator bacteria may be common to human and animal sources, but laboratory methods were selected to increase the specificity to human Sources. Behavioural data is similarly a snapshot, using indicators such as self-reported practices and behaviours observed in public. These limitations influence the precision of exposure risk estimation, but do not undermine the comparative identification of dominant exposure pathways across study sites. The behavioural or environmental sources of the faecal bacteria in the Solid Waste were not adequately identified here, so direct sanitation chain sources and other sources such as nappies, animal faeces and mixed household wastes (such as raw meat and cooked foods) could be contributing to the bacterial load.

Importantly, these limitations should not be interpreted as deficiencies of the approach, but rather as defining the conditions under which it is most appropriately applied. The Amplified F-Diagram is intended as a flexible and pragmatic approach for framing thinking and conversations around dominant faecal contamination Pathways, rather than a perfect representation of the exact epidemiological situation. For decision makers, the approach offers a means of prioritising realistic interventions based on locally relevant exposure patterns, while remaining adaptable to the inclusion of additional exposure routes as local data demands.

9.3 Recommendations for further research

This work has developed a conceptual framework for visualising the complexity of urban sanitation failures leading to exposures. The development of the Amplified F-diagram and the work to demonstrate how it can measure the usefulness of interventions offer a basis for further application in diverse contexts. Further research could determine if the reduction of

faecal pathogen exposures from interventions accords with the modelled reductions and, therefore, if this is an effective approach for determining focus priorities. It would also be interesting to utilise the diagram as a framework for comparing the effectiveness of baseline and post-intervention, to see if exposure reduction aims have been met.

Application of the model in outbreak situations, such as cholera epidemics, would allow for a more meaningful assessment of ways to block transmission pathways, rather than simply ensuring that water and sanitation systems are strengthened. In these situations where a specific known pathogen is causing the hazard, the model could be enhanced with the use of Quantitative Microbial Risk Assessment.

Now that the groundwork has been completed for the diagram, the task of applying the model will be less time-consuming for other research groups or practitioners. Applying the Amplified F-diagram will require some familiarisation with the SankeyMATIC web tool and local data collection. If, over time, a set of applied Amplified F-diagrams were built for different cities and contexts, this would allow conclusions to be drawn about common and unusual factors. It may be that the findings in this research around Delhi are typical of large cities in LMIC, or it may be that there is a lot of variation between cities and communities.

Further research could gather more data to systematically confirm the existence and significance of each of the plausible pathways and locate additional potential pathways to be integrated into the model. Determining the significance of different types of mobile fomite Transporters, such as vehicle wheels, shoes, and other marketable goods, would enrich the model. The addition of airborne transmission would also be an area for future expansion (Rocha-Melogno *et al.*, 2022). Broader transdisciplinary collaboration on tackling faecal contamination in urban communities would unlock work that is siloed, such as data on air, food and Solid Waste management. Development of the model to include a spatial aspect would be useful to further pinpoint intervention targets, such as whether the improvements should occur within or outside the community.

Research could be beneficial to determine the effectiveness of using the Amplified F-Diagrams in providing public health education to a variety of groups, such as politicians, nurses, teachers, and school children. These diagrams have the potential to make complex systems thinking accessible to non-technical groups, to inspire a shift in thinking towards more meaningful, effective interventions rather than infrastructure building.

The original F-diagram and SFDs have become mainstream and are changing the common thinking, away from infrastructure targets as standard, but instead considering the real

sanitation system failures. This Amplified F-Diagram approach is the first time there has been an approach to further strengthen this thinking shift towards considering the reality of the causes of the public health impacts from faecal pathogens and sanitation chain failures. This will be an important launchpad for other work.

9.4 Concluding Remarks

Fundamentally, most urban sanitation systems are complex and leaky. After two centuries, and the development of a range of credible technologies for Containment and Treatment of faecal matter, the art of managing the dynamic Transportation of faecal waste in cities remains neglected. This is particularly the case where extensive coverage of piped sewerage has not been achieved. Political will and a robust policy and regulatory environment will be needed to make these changes possible. This work also adds to the body of evidence that public health gains from clean water provision can only be realised when the sanitation system is safely managed. A more comprehensive understanding of the principal pathways of faecal contamination in low-income urban communities was achieved by combining quantitative data with conceptual analysis, thereby providing the Amplified F-diagram with empirical grounding and real-world validation. Taken together, the findings demonstrate that interventions cannot succeed when confined to the household or community scale. Faecal contamination is mobile; only systematic, city-wide approaches that address Transport can deliver meaningful public health gains. The persistent emphasis on Containment has limited impact; Transport constitutes the critical bottleneck. Faecal contamination does not conform to simple downstream logic. It circulates through cities along multiple, dynamic pathways, rendering conventional upstream–downstream framings outdated and unhelpful. Instead, the urban environment must be understood as a “faecal catchment,” a system where contamination accumulates, mixes, and redistributes across boundaries of place and space via both hydraulic and non-hydraulic pathways.

The unique contribution of this thesis lies in integrating health risk assessment with systems analysis of sanitation flows, culminating in the development of the Amplified F-diagram. This work provides new evidence that Transport is the neglected, yet decisive, stage of the sanitation chain. Flows that are not mediated by gravity cannot be dismissed. It seems, indeed, that shit also flows uphill.

10 References

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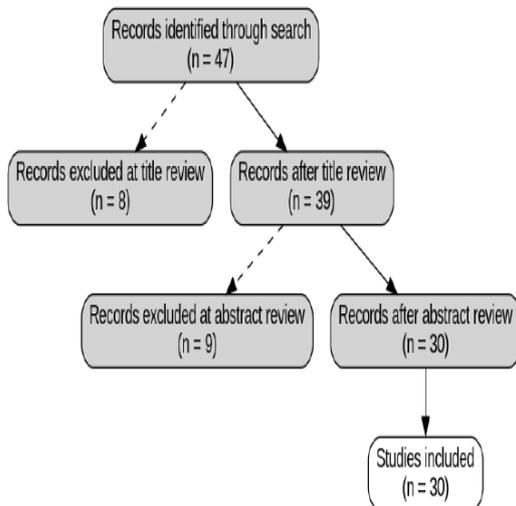
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11 Appendices

11.1 Appendix A: Scoping Literature Review Methods

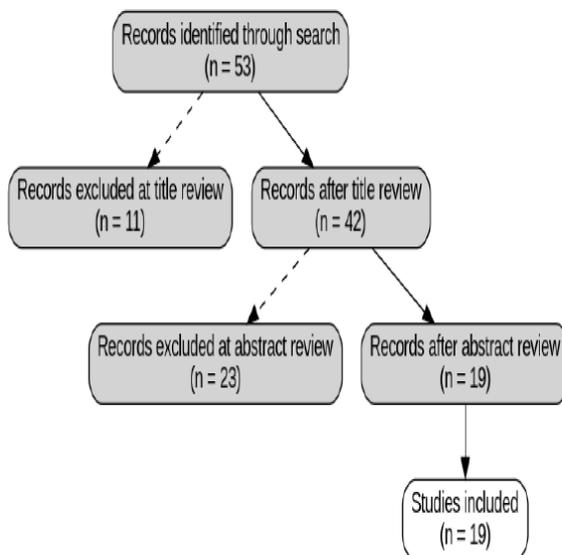
Containment

("sanitation" OR "containment" OR "toilet" OR "pit latrine" OR "septic tank" OR "onsite sanitation") AND ("failure" OR "leakage") AND ("faecal contamination" OR "faecal contamination" OR "pathogen spread" OR "waterborne disease" OR "health risk" OR "environmental contamination" OR "pathogen exposure" OR "public health risk" OR "diarrhoeal diseases" OR "E. coli" OR "cholera" OR "typhoid")



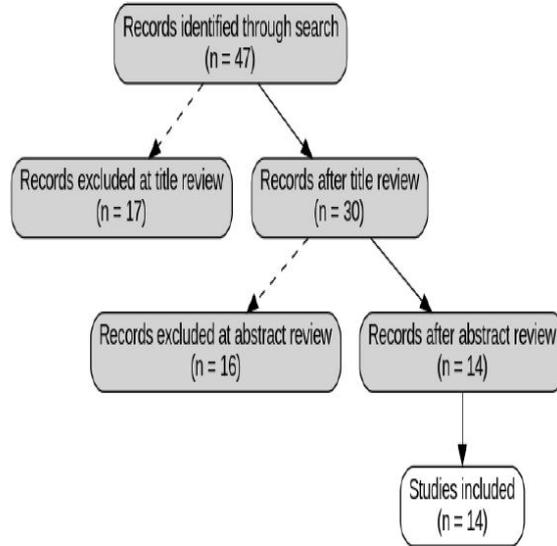
Transport

("sanitation" OR "sewer" OR "sewerage" OR "emptying" OR "emptied" OR "empty" OR "offsite sanitation" OR "sludge" OR "wastewater") AND ("failure" OR "leakage" OR "leaking" OR "leak" OR "dump" OR "discharge" OR "overflow" OR "spill" OR "unsafe") AND ("faecal contamination" OR "faecal contamination" OR "pathogen" OR "waterborne disease" OR "health risk" OR "environmental contamination" OR "exposure" OR "public health risk" OR "diarrhoea" OR "diarrhea" OR "E. coli" OR "enteric" OR "cholera" OR "typhoid")



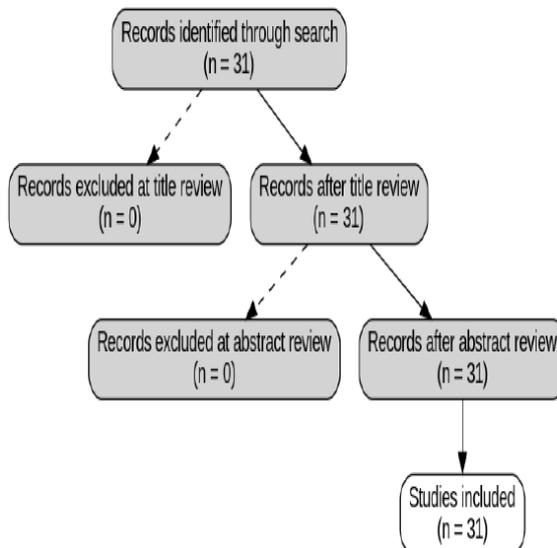
Treatment

("wastewater treatment" OR "sewage treatment" OR "sewage treatment plant" OR "wastewater treatment plant" OR "centralised treatment" OR "decentralised treatment" OR "faecal sludge treatment" OR "faecal sludge treatment") AND ("failure" OR "malfunction" OR "breakdown" OR "ineffective" OR "insufficient" OR "incomplete" OR "bypass" OR "overload" OR "non-compliance" OR "poor removal" OR "inadequate treatment") AND ("pathogen" OR "faecal contamination" OR "faecal contamination" OR "E. coli" OR "enteric" OR "cholera" OR "typhoid" OR "diarrhoea" OR "diarrhea" OR "health risk" OR "public health" OR "exposure" OR "QMRA" OR "waterborne disease" OR "contamination" OR "environmental contamination")



F-Diagram Uses

("f-diagram" OR "f diagram" OR "fdiagram") AND ("use" OR "used" OR "useful" OR "purpose" OR "apply" OR "application" OR "adapt" OR "adaptation") AND ("feces" OR "faeces" OR "fecal" OR "faecal" OR "sanitation" OR "defecation" OR "toilet")



11.2 Appendix B: SankeyMATIC code for the Amplified F-diagram

```

// SankeyMATIC diagram inputs - Saved:
21/07/2025, 21:23:21
// https://sankeymatic.com/build/

// === Nodes and Flows ===

// Source to Exposure Faecal flows - ALL
// colours of nodes and flows
// sources

:Open defecation #800080
:Broken containment #800080
:Direct discharge #800080

:Spillage during emptying #FFA500
:Direct discharge from pipes #FFA500
:Leaking from pipes #FFA500
:Dumped faecal sludge #FFA500

:Insufficiently treated WW #FF1493
:Insufficiently treated FS #FF1493

:Sources #FFFFFF
:Exposures #FFFFFF

// mid nodes

:Soil #8B4513
:Groundwater #008080
:Agriculture #006400
:Open drain #2F4F4F

// exposures

Piped water [10] Fresh produce
Fomites [10] Fresh produce
Ocean [10] Fomites

Surface water [10] Ocean
Surface water [10] Soil
Surface water [10] Groundwater
Surface water [10] Fresh produce
Surface water [10] Agriculture
Surface water [10] Fomites
Surface water [10] Groundwater

// === Settings ===
size w 600
h 600
margin l 12
r 12
t 18
b 20
bg color #ffffff
transparent N
node w 12
h 50
spacing 75
border 0
theme a
color #888888
opacity 1
flow curvature 0.5
inherit from source
color #999999
opacity 0.45
layout order automatic

:Ocean #00008B
:Fresh produce #00FF00
:Fomites #FF0000
:Surface water #0096FF
:Piped water #FFFF00
:Well water #D19C57

// Flow values
Sources [10] Exposures

// flows from failed containment
Open defecation [20] Surface water
Open defecation [20] Open drain
Open defecation [20] Ocean
Open defecation [20] Soil
Open defecation [20] Fresh produce
Open defecation [20] Fomites
Open defecation [20] Agriculture

Direct discharge [20] Surface water
Direct discharge [20] Open drain
Direct discharge [20] Ocean
Direct discharge [20] Fresh produce
Direct discharge [20] Soil
Direct discharge [20] Fomites

Broken containment [20] Surface water
Broken containment [20] Open drain
Broken containment [20] Ocean
Broken containment [20] Soil
Broken containment [20] Groundwater

// flows from failed transport

justiforigins Y
justifyends Y
reversegraph N
attachincompletesto nearest
labels color #000000
hide N
highlight 0.3
fontface sans-serif
linespacing 0.2
relativesize 128
magnify 100
labelname appears Y
size 16
weight 400
labelvalue appears N
fullprecision Y
position below
weight 400
labelposition autoalign 0
scheme per_stage
first before
breakpoint 2
value format !:
prefix "
suffix "
themoffset a 9
b 0
c 0
d 0
meta mentionsankeymatic N
listimbalances Y

// === Moved Nodes ===

Spillage during emptying [20] Surface water
Spillage during emptying [20] Open drain
Spillage during emptying [20] Soil
Spillage during emptying [20] Fomites

Dumped faecal sludge [20] Surface water
Dumped faecal sludge [20] Open drain
Dumped faecal sludge [20] Ocean
Dumped faecal sludge [20] Soil
Dumped faecal sludge [20] Fresh produce
Dumped faecal sludge [20] Fomites
Dumped faecal sludge [20] Agriculture

Direct discharge from pipes [20] Surface water
Direct discharge from pipes [20] Open drain
Direct discharge from pipes [20] Ocean
Direct discharge from pipes [20] Soil
Direct discharge from pipes [20] Groundwater
Direct discharge from pipes [20] Fomites

Leaking from pipes [20] Surface water
Leaking from pipes [20] Open drain
Leaking from pipes [20] Groundwater
Leaking from pipes [20] Piped water

// flows from failed treatment
Insufficiently treated WW [20] Surface water
Insufficiently treated WW [20] Open drain
Insufficiently treated WW [20] Ocean
Insufficiently treated WW [20] Soil
Insufficiently treated WW [20] Agriculture

Insufficiently treated FS [20] Surface water
Insufficiently treated FS [20] Open drain
Insufficiently treated FS [20] Ocean
Insufficiently treated FS [20] Soil
Insufficiently treated FS [20] Agriculture

// flows from mid nodes
Open drain [35] Surface water
Open drain [35] Ocean
Open drain [35] Soil
Open drain [35] Groundwater
Open drain [35] Agriculture
Open drain [35] Fomites

Groundwater [50] Surface water
Groundwater [50] Piped water
Groundwater [50] Well water
Groundwater [50] Ocean

Soil [57] Agriculture
Soil [57] Fresh produce
Soil [57] Fomites
Soil [57] Groundwater

Agriculture [30] Surface water
Agriculture [30] Open drain
Agriculture [30] Soil
Agriculture [30] Groundwater
Agriculture [30] Fresh produce
Agriculture [30] Fomites

// flows between exposures
Well water [10] Fresh produce

move Open defecation -0.02059, -0.05479
move Broken containment -0.01176, -0.06985
move Direct discharge -0.00588, -0.068
move Leaking from pipes -0.00588, -0.13808
move Direct discharge from pipes -0.01471, -
0.13525
move Dumped faecal sludge -0.01471, 0.15636
move Surface water 0.00294, -0.15229
move Spillage during emptying -0.01176, -0.01379
move Open drain -0.56862, -0.02362
move Soil -0.34509, 0.18728
move Well water 0.00294, 0.30389
move Piped water 0.00882, -0.04809
move Fresh produce 0.01176, 0.2334
move Groundwater -0.23515, 0.57043
move Ocean 0.01471, 0.19078
move Fomites 0.01176, -0.31665
move Sources -0.04813, -0.25115
move Exposures 0.03209, -0.06813
move Insufficiently treated WW -0.00588, 0.01712
move Insufficiently treated FS -0.01176, 0.0317
move Agriculture -0.43236, 0.04424

```

11.3 Appendix C: Ethics for Data Collection 2022 and 2023



UNIVERSITY OF LEEDS

Faculty of Engineering and Physical Sciences:
School Of Civil Engineering

Ethics Submission for 2022 Data Collection

PhD Title:

An assessment of relative risk from exposures to faecal pathogens; from proximal and distal sources by hydraulic and non-hydraulic pathways.

Jemma Phillips
201086983

Project Supervisors: Professor B. Evans
Date of registration: 2nd September 2020
Date of submission: 31st September 2024

Contents

Ethics Review Form
Appendix 1: Information Sheet
Appendix 2: Research Participant Privacy Notice
Appendix 3: Risk Assessment



Please read each question carefully, taking note of instructions and completing all parts. If a question is not applicable please indicate so. The superscripted numbers (eg²) refer to sections of the guidance notes, available at <http://ris.leeds.ac.uk/UoLEthicsApplication>. Where a question asks for information which you have previously provided in answer to another question, please just refer to your earlier answer rather than repeating information. Information about research ethics training courses: <http://ris.leeds.ac.uk/EthicsTraining>.

To help us process your application enter the following reference numbers, if known and if applicable:

Ethics reference number:	
Student number and/ or grant reference:	201086983

Part A: Summary

A.1 Which [Faculty Research Ethics Committee](#) would you like to consider this application?²

- Arts, Humanities and Cultures (AHC)
 Biological Sciences (BIOSCI)
 Business, Environment and Social Sciences (AREA)
 FS&N, Engineering and Physical Sciences (EPS)
 Medicine and Health (Please specify a subcommittee):
 - School of Dentistry (DREC)
 - School of Healthcare (SHREC)
 - School of Medicine (SoMREC)
 - School of Psychology (SoPREC)

A.2 Title of the research³

An assessment of relative risk from exposures to faecal pathogens; from proximal and distal sources by hydraulic and non-hydraulic pathways.

A.3 Principal investigator's contact details⁴

Name (Title, first name, surname)	Mrs Jemma Phillips
Position	PhD Student
Department/ School/ Institute	School of Civil Engineering
Faculty	Engineering and Physical Sciences
Work address (including postcode)	4.04 School of Chemical and Process Engineering, University of Leeds, Woodhouse, Leeds LS2 9JT
Telephone number	07704442456
University of Leeds email address	cn16jfp@leeds.ac.uk

A.4 Purpose of the research:⁵ (Tick as appropriate)

- Research
- Educational qualification: *Please specify: Water-WISER PhD*
- Educational Research & Evaluation⁶
- Medical Audit or Health Service Evaluation⁷
- Other

A.5 Select from the list below to describe your research: (You may select more than one)

- Research on or with human participants
- Research which has potential adverse [environmental impact](#).⁸ *If yes, please give details:*

- Research working with data of human participants
 - New data collected by qualitative methods
 - New data collected by quantitative methods
 - New data collected from observing individuals or populations
 - Routinely collected data or secondary data
 - Research working with aggregated or population data
 - Research using already published data or data in the public domain
- Research working with human tissue samples (*Please inform the relevant [Persons Designate](#) if the research will involve human tissue*)⁹

A.6 Will the research involve NHS staff recruited as potential research participants (by virtue of their professional role) or NHS premises/ facilities?

Yes No

If yes, ethical approval must be sought from the University of Leeds. Note that [approval](#) from the NHS Health Research Authority may also be needed, please contact FMHUniEthics@leeds.ac.uk for advice.

A.7 Will the research involve any of the following:¹⁰ (You may select more than one)

If your project is classified as [research](#) rather than service evaluation or audit and involves any of the following an application must be made to the [NHS Health Research Authority](#) via IRAS www.myresearchproject.org.uk as NHS ethics approval will be required. There is no need to complete any more of this form. Further information is available at <http://ris.leeds.ac.uk/NHSEthicalreview> and at <http://ris.leeds.ac.uk/HRAapproval>. You may also contact governance-ethics@leeds.ac.uk for advice.

- Patients and users of the NHS (including NHS patients treated in the private sector)¹¹
- Individuals identified as potential participants because of their status as relatives or carers of patients and users of the NHS
- Research involving adults in Scotland, Wales or England who lack the capacity to consent for themselves¹²
- A prison or a young offender institution in England and Wales (and is health related)¹⁴
- Clinical trial of a medicinal product or medical device¹⁵
- Access to data, organs or other bodily material of past and present NHS patients⁹
- Use of human tissue (including non-NHS sources) where the collection is not covered by a Human Tissue Authority licence⁹

<input type="checkbox"/> Foetal material and IVF involving NHS patients <input type="checkbox"/> The recently deceased under NHS care <input checked="" type="checkbox"/> None of the above <p>You must inform the Research Ethics Administrator of your NHS REC reference and approval date once approval has been obtained.</p>
<p><i>The HRA decision tool to help determine the type of approval required is available at http://www.hra-decisiontools.org.uk/ethics. If the University of Leeds is not the Lead Institution, or approval has been granted elsewhere (e.g. NHS) then you should contact the local Research Ethics Committee for guidance. The UoL Ethics Committee needs to be assured that any relevant local ethical issues have been addressed.</i></p>

<p>A.8 Will the participants be from any of the following groups? (Tick as appropriate)</p> <input type="checkbox"/> Children under 16 ¹⁶ Specify age group: _____ <input type="checkbox"/> Adults with learning disabilities ¹² <input type="checkbox"/> Adults with other forms of mental incapacity or mental illness <input type="checkbox"/> Adults in emergency situations <input type="checkbox"/> Prisoners or young offenders ¹⁴ <input type="checkbox"/> Those who could be considered to have a particularly dependent relationship with the investigator, eg members of staff, students ¹⁷ <input type="checkbox"/> Other vulnerable groups <input checked="" type="checkbox"/> No participants from any of the above groups <p><i>Please justify the inclusion of the above groups, explaining why the research cannot be conducted on non-vulnerable groups.</i></p> <p>N/A</p>
<p>It is the researcher's responsibility to check whether a DBS check (or equivalent) is required and to obtain one if it is needed. See also http://ris.leeds.ac.uk/healthandsafetyadvice and http://www.homeoffice.gov.uk/agencies-public-bodies/dbs.</p>

<p>A.9 Give a short summary of the research¹⁸</p> <p><i>This section must be completed in language comprehensible to the lay person. Do not simply reproduce or refer to the protocol, although the protocol can also be submitted to provide any technical information that you think the ethics committee may require. This section should cover the main parts of the proposal. (300 words max)</i></p> <p>In order to build more detailed models of source-pathway-exposure patterns for faecal contamination in urban areas, the assumptions and knowledge gaps need to be replaced with data. This would increase the accuracy and usefulness of current modelling, empirical and stochastic tools (such as SaniPath, Sanitation Safety Planning and the Shit Flow Diagrams).</p> <p>My interest lies in exploring the potential to place the exposed population at the heart of risk from faecal contamination; essentially describing the 'catchment' of contamination that results in population risk at a particular location. The contamination will arrive at the point of exposure by a range of pathways: these can be hydraulic (travelling with water), such as in a river or an open drain, or non-hydraulic such as the food transportation network.</p> <p>This research is focussed on the sanitation chain failures that result in contamination of common exposure points in the environment, such as surface water, open drains, and fresh produce (fruit and veg). Environmental samples will be taken from these exposure points in 4 different communities in Delhi and tested in the laboratory (with technical support from Newcastle University Empower Project) for faecal pathogens such as cholera and helminths. Household surveys will be carried out asking questions of people within those communities about the way they interact with the common exposures points and how frequently. This data will be combined within the SaniPath tool using Bayesian</p>

calculations to give a score to each exposure type based on the intensity of the hazard and the average frequency of exposure.

Additional environmental sampling will be done along the food chain from the wholesale market where the fresh produce arrives in the city in order to determine if this is a source of contamination that travels from outside of the city boundaries travelling on a non-hydraulic pathway.

As a part of the Water-WISER CDT, funding shall come from the individually assigned CDT research grant.

A.10 What are the main ethical issues with the research and how will these be addressed?¹⁹

Indicate any issues on which you would welcome advice from the ethics committee.

Consent: Participants who answer questions regarding their interactions with the pathogen exposure points of interest will have been given an explanation about the nature of the work, that their answers are anonymous, and they will verbally consent to their answers being noted down.

Data security: All data will not be person identifiable and will be saved onto a University of Leeds laptop that is password protected. The data accrued will be stored on the University of Leeds OneDrive service.

Unconscious Bias: reading widely of India authors, educating myself about white-gaze and white-privilege, and working in collaboration with the local team from Jayna Collective will help to understand and mitigate for issues that could arise from my white British context and enable me to research respectfully, and produce meaningful data that is not compromised excessively by my bias.

Part B: About the research team

B.1 To be completed by students only²⁰

Qualification working towards (eg Masters, PhD)	PhD
Supervisor's name (Title, first name, surname)	Professor Barbara Evans
Department/ School/ Institute	School of Civil Engineering
Faculty	Engineering and Physical Sciences
Work address (including postcode)	School of Chemical and Process Engineering, University of Leeds, Woodhouse, Leeds LS2 9JT
Supervisor's telephone number	+44(0)113 343 1990
Supervisor's email address	B.E.Evans@leeds.ac.uk
Module name and number (if applicable)	N/A

B.2 Other members of the research team (eg co-investigators, co-supervisors) ²¹

Name (Title, first name, surname)	
Position	
Department/ School/ Institute	
Faculty	
Work address (including postcode)	
Telephone number	
Email address	

Name (Title, first name, surname)	
Position	
Department/ School/ Institute	
Faculty	
Work address (including postcode)	
Telephone number	
Email address	

Part C: The research

C.1 What are the aims of the study?²² (Must be in language comprehensible to a lay person.)

Research Question and Project Aims:

What is the relative significance of risks to the health of urban communities in Delhi from faecal pathogens emitted proximally and distally, and those that travel by hydraulic and non-hydraulic pathways?

Specific research questions:

- 1) In a set of selected communities (along the Barapullah open drain, Delhi, India),
 - a) Using the SaniPath tool what are the principle exposures?
 - b) Do the exposures vary by community and how downstream they are along the open drain and on a different drain?
 - c) Do the exposures vary between the seasons?

- 2) Is it possible to map the 'faecal catchments' of the selected communities along the Barapullah open drain?
 - a) Using the collected SaniPath data and current knowledge what can already be mapped for the 'faecal catchments' of the communities, particularly for the proximal and hydraulic pathways?
 - b) What is the data gap to be able to map the 'faecal catchment' for pathways that follow non-hydraulic pathways?

- 3) What can be established about the significance of faecal pathogens coming to the communities from outside Delhi (distal) on the food chain (a non-hydraulic pathway)?
 - a) is fresh produce a key exposure point for the selected communities?
 - b) Where does the food become contaminated (inside or outside the city)?
 - c) How many potential points of contamination does the fresh food encounter within the city before it is eaten?

C.2 Describe the design of the research. Qualitative methods as well as quantitative methods should be included. (Must be in language comprehensible to a lay person.)

It is important that the study can provide information about the aims that it intends to address. If a study cannot answer the questions/ add to the knowledge base that it intends to, due to the way that it is designed, then wasting participants' time could be an ethical issue.

The data collected in this study will be combined with existing data in the literature and data collect in the context by other project partners such as IIT Delhi, SPA, CURE and Jayna Collective, as well as through the Empower project with Newcastle University.

Environmental samples will be taken from the identified exposure points in 4 different communities in Delhi and tested in the laboratory (with technical support from Newcastle University Empower Project) for faecal pathogens such as cholera and helminths. The exposure points are:

1. Drinking Water
2. Surface water (ponds, streams)
3. Drain Water
4. Flood water (if any standing at the time of sampling)
5. Fresh produce
6. Street food
7. Community toilet latrine swabs
8. Soil (proximal to the open drain)
9. Soil (distal to the open drain)
10. Solid waste

Household surveys will be carried out asking questions of people within those communities about the way they interact with the common exposures points and how frequently. This data will be combined within the SaniPath tool using Bayesian calculations to give a score to each exposure type based on the intensity of the hazard and the average frequency of exposure.

Additional environmental sampling will be done of produce and workers hands along the food chain from the wholesale market where the fresh produce arrives in the city in order to determine if this is a source of contamination that travels from outside of the city boundaries travelling on a non-hydraulic pathway.

C.3 What will participants be asked to do in the study?²³ (e.g. number of visits, time, travel required, interviews)

- People within the study communities will be asked simple questions about the way they interact with the common exposures points and how frequently interact with them.
- People along the food chains will be asked about their role, movements around the city transporting fresh produce, and their hands will be rinsed to test for pathogens.
- None of the participants will have to travel to take part in the surveys.
- Answering the survey or food chain questions should take less than 15 minutes per participant.

C.4 Does the research involve an international collaborator or research conducted overseas?²⁴

Yes No

If yes, describe any ethical review procedures that you will need to comply with in that country:
None required - the Water Security Hub asks for sending university ethical approval to be sought.

Describe the measures you have taken to comply with these:

N/a

Include copies of any ethical approval letters/ certificates with your application.

C.5 Proposed study dates and duration

Research start date (DD/MM/YY):	01/10/2020	Research end date (DD/MM/YY):	31/09/2024
Fieldwork start date (DD/MM/YY):	01/10/2022	Fieldwork end date (DD/MM/YY):	30/11/2022

C.6. Where will the research be undertaken? (i.e. in the street, on UoL premises, in schools)²⁵

In the capital city of New Delhi, in communities based along the open drain systems. The drains have a wide variety of housing types along it but the focus will be the slum communities due to the poor associated health outcomes of living in these environments.

RECRUITMENT & CONSENT PROCESSES

C.7 How will potential participants in the study be identified, approached and recruited?²⁶

How will you ensure an appropriately convened sample group in order to meet the aims of the research? Give details for subgroups separately, if appropriate. How will any potential pitfalls, for example dual roles or potential for coercion, be addressed?

Access to the communities will be mediated by local company Jayna Collective LLP who has worked extensively in the Delhi slums. In the target neighbourhood, houses will be chosen by dividing neighbourhoods into segments. From each segment randomly select a household at the edge of the segment and complete surveys at every eighth household. The adult who manages water in each household will be sought to answer the questions. If the person is not available then move to the next household.

Participant in the food chain work will be selected by snowballing methods from initial contacts in the wholesale market and following the routes that the fresh produce travels.

C.8 Will you be excluding any groups of people, and if so what is the rationale for that?²⁷

Excluding certain groups of people, intentionally or unintentionally may be unethical in some circumstances. It may be wholly appropriate to exclude groups of people in other cases

Excluded groups will include those who do not speak English or Hindi, people under 18, people with any other vulnerabilities where the researcher may doubt their ability to consent to participate in the research.

C.9 How many participants will be recruited and how was the number decided upon?²⁸

It is important to ensure that enough participants are recruited to be able to answer the aims of the research.

1/8th of each community as determined in the SaniPath protocols.

The food chain work is exploratory and therefore a set number of participants has not been determined. However, in order to get a preliminary understanding of the food chain in a city the size of Delhi it is likely the participants could number up to 150 people.

C10 Will the research involve any element of deception?²⁹

If yes, please describe why this is necessary and whether participants will be informed at the end of the study.

No, it will not.

C.11 Will **informed consent** be obtained from the research participants?³⁰

Yes No

If yes, **give details** of how it will be done. Give details of any particular steps to provide information (in addition to a written information sheet) e.g. videos, interactive material. If you are not going to be obtaining informed consent you will need to justify this.

As the research does not involve gathering any personal data, verbal consent will be gained to ask questions for research purposes. There will be an information sheet available in English and Hindi with contact details if anyone wants more information or to get in touch after speaking to me.

If participants are to be recruited from any of potentially vulnerable groups, **give details of extra steps** taken to assure their protection. Describe any arrangements to be made for obtaining consent from a legal representative.

Participants will not be recruited from vulnerable groups.

Will research participants be provided with a copy of the **Privacy Notice for Research**? If not, explain why not.

Guidance is available at <https://dataprotection.leeds.ac.uk/information-for-researchers>

Yes No

Copies of any written consent form, written information and all other explanatory material should accompany this application. The information sheet should make explicit that participants can withdraw from the research at any time, if the research design permits. Remember to use meaningful file names and version control to make it easier to **keep track of your documents**.

Sample information sheets and consent forms are available from the University ethical review webpage at <http://ris.leeds.ac.uk/InvolvingResearchParticipants>.

C.12 Describe whether participants will be able to withdraw from the study, and up to what point (eg if data is to be anonymised). If withdrawal is **not** possible, explain why not.

Any limits to withdrawal, eg once the results have been written up or published, should be made clear to participants in advance, preferably by specifying a date after which withdrawal would not be possible. Make sure that the information provided to participants (eg information sheets, consent forms) is consistent with the answer to C12.

Data will be anonymised from the outset and therefore the only data collected will be regarding environmental interactions and 3 meter squared locations. No personal data will be collected.

C.13 How long will the participant have to decide whether to take part in the research?³¹

It may be appropriate to recruit participants on the spot for low risk research; however consideration is usually necessary for riskier projects.

Participants will be recruited on the spot and they can decide if they wish to participate or not with no pressure.

C.14 What arrangements have been made for participants who might have difficulties understanding verbal explanations or written information, or who have particular communication needs that should be taken into account to facilitate their involvement in the research?³² *Different populations will have different information needs, different communication abilities and different levels of understanding of the research topic. Reasonable efforts should be made to include potential participants who could otherwise be prevented from participating due to disabilities or language barriers.*

Verbal and written information will be available in English and Hindi. Vulnerable populations with particular difficulties understanding will not be recruited for this study. Participants will be able to ask any questions they wish in order to secure their understanding.

C.15 Will individual or group interviews/ questionnaires discuss any topics or issues that might be sensitive, embarrassing or upsetting, or is it possible that criminal or other disclosures requiring action could take place during the study (e.g. during interviews or group discussions)?³³ *The [information sheet](#) should explain under what circumstances action may be taken.*

Yes No *If yes, give details of procedures in place to deal with these issues.*

C.16 Will individual research participants receive any payments, fees, reimbursement of expenses or any other incentives or benefits for taking part in this research?³⁴

Yes No

If Yes, please describe the amount, number and size of incentives and on what basis this was decided.

RISKS OF THE STUDY

C.17 What are the potential benefits and/ or risks for research participants in both the short and medium-term?³⁵

Benefits for the participants for taking part are contributing to important research that enables greater understanding of the environmental hazards and resulting exposure risks will be more clearly identified for the area where they live. Mapping the faecal contamination in New Delhi could have unintended consequences for homes and businesses in the affected areas, this issue will be considered and managed before the publication of any data in order to produce visualisations that are meaningful but not harmful. One way of doing this could be to combine the data from the 4 communities, or to not name which communities the sampling occurred in, but just that they were along the main open drainage networks. Despite highlighting the risks of consuming faecally contaminated fresh produce, this work is in no way intended to discourage people from eating a healthy diet, but instead to ensure that the fresh produce can be consumed safely.

C.18 Does the research involve any risks to the researchers themselves, or people not directly involved in the research? *Eg lone working*³⁶

Yes No

If yes, please describe:

Lone working will not occur, locally members of Jayna Collective LLP will work with the researcher at all times. Faecally contaminated samples will be collected but full training has been completed and appropriate personal protective equipment will be worn.

...

Is a [risk assessment](#) necessary for this research?

If you are unsure whether a risk assessment is required visit <http://ris.leeds.ac.uk/HealthAndSafetyAdvice> or contact your Faculty Health and Safety Manager for advice.

Yes No If yes, please include a copy of your risk assessment form with your application.

RESEARCH DATA

C.19 Explain what measures will be put in place to protect personal data. E.g. anonymisation procedures, secure storage and coding of data. Any potential for re-identification should be made clear to participants in advance.³⁷ Please note that research data which appears in reports or other publications is not confidential, even if it is fully anonymised. For a fuller explanation see <http://ris.leeds.ac.uk/ConfidentialityAnonymisation>. Further guidance is available at <http://ris.leeds.ac.uk/ResearchDataManagement>

- No participant's names or addresses will be used in any documents created from this research

All data for this research will be dealt with in accordance with the Data Protection Act 2018. All data will be anonymised from the point of collection with only 3m² location details. Data shall be stored on a password protected encrypted laptop and no confidential information will be transferred by email. Partners will also be informed of the data management plans. Contact details for any participants wishing to receive further information about the outcomes of the research will be stored separately from research data. Further details are available from <https://leeds.service-now.com/it>

C.20 How will you make your research data available to others in line with: the University's, funding bodies' and publishers' policies on making the results of publically funded research publically available. Explain the extent to which anonymity will be maintained. (max 200 words) Refer to <http://ris.leeds.ac.uk/ConfidentialityAnonymisation> and <http://ris.leeds.ac.uk/ResearchDataManagement> for guidance.

Data will be shared if and when ready for publishing in academic journals, all will be anonymised, in line with EPSRC policy.

C.21 Will the research involve any of the following activities at any stage (including identification of potential research participants)? (Tick as appropriate)

- Examination of personal records by those who would not normally have access
- Access to research data on individuals by people from outside the research team
- Electronic surveys, please specify survey tool: <https://www.onlinesurveys.ac.uk/> (further guidance)
- Other electronic transfer of data
- Use of personal addresses, postcodes, faxes, e-mails or telephone numbers
- Use of audio/ visual recording devices (NB this should usually be mentioned in the information for participants)
- FLASH memory or other portable storage devices

Storage of personal data on, or including, any of the following:

- [University approved](#) cloud computing services
- Other cloud computing services
- Manual files

<ul style="list-style-type: none"> <input type="checkbox"/> Private company computers <input checked="" type="checkbox"/> Laptop computers (password protected and encrypted) <input type="checkbox"/> Home or other personal computers (not recommended; data should be stored on a University of Leeds server such as your M: or N: drive where it is secure and backed up regularly: http://ris.leeds.ac.uk/ResearchDataManagement)
<p><i>Unclassified and Confidential University data must be kept on the University servers or in approved cloud services such as Office 365 (SharePoint or OneDrive). The N: Drive or Office 365 should be used for the storage of data that needs to be shared. If Highly Confidential information is kept in these shared storage areas it must be encrypted. Highly Confidential data that is not to be shared should be kept on the M: Drive. The use of non-University approved cloud services for the storage of any University data, including that which is unclassified, is forbidden without formal approval from IT. Further guidance is available via http://ris.leeds.ac.uk/ResearchDataManagement.</i></p>
<p>C.22 How do you intend to share the research data? (Indicate with an 'X') Refer to http://library.leeds.ac.uk/research-data-deposit for guidance.</p> <ul style="list-style-type: none"> <input type="checkbox"/> Exporting data outside the European Union <input checked="" type="checkbox"/> Sharing data with other organisations <input type="checkbox"/> Publication of direct quotations from respondents <input type="checkbox"/> Publication of data that might allow identification of individuals to be identified <input checked="" type="checkbox"/> Submitting to a journal to support a publication <input checked="" type="checkbox"/> Depositing in a self-archiving system or an institutional repository <input checked="" type="checkbox"/> Dissemination via a project or institutional website <input type="checkbox"/> Informal peer-to-peer exchange <input type="checkbox"/> Depositing in a specialist data centre or archive <input type="checkbox"/> Other, please state: _____ <input type="checkbox"/> No plans to report or disseminate the data
<p>C.23 How do you intend to report and disseminate the results of the study? (Indicate with an 'X') Refer to http://ris.leeds.ac.uk/ResearchDissemination and http://ris.leeds.ac.uk/Publication for guidance.</p> <ul style="list-style-type: none"> <input checked="" type="checkbox"/> Conference presentation <input checked="" type="checkbox"/> Peer reviewed journals <input checked="" type="checkbox"/> Publication as an eThesis in the Institutional repository <input checked="" type="checkbox"/> Publication on website <input type="checkbox"/> Other publication or report, please state: _____ <input type="checkbox"/> Submission to regulatory authorities <input type="checkbox"/> Other, please state: _____ <input type="checkbox"/> No plans to report or disseminate the results
<p>C.24 For how long will data from the study be stored? Please explain why this length of time has been chosen.³⁸ Refer to the RCUK Common Principles on Data Policy and http://ris.leeds.ac.uk/info/71/good_research_practice/106/research_data_guidance/5. Students: It would be reasonable to retain data for at least 2 years after publication or three years after the end of data collection, whichever is longer.</p> <p>3 years, 0 months</p>

This will be approximately 2 years after publication (giving a year to publish), and 3 years after data collection.

CONFLICTS OF INTEREST

C.25 Will any of the researchers or their institutions receive any other benefits or incentives for taking part in this research over and above normal salary or the costs of undertaking the research?³⁹

Yes No

If yes, indicate how much and on what basis this has been decided

N/A

C.26 Is there scope for any other conflict of interest?⁴⁰ For example, could the research findings affect the any ongoing relationship between any of the individuals or organisations involved and the researcher(s)? Will the research funder have control of publication of research findings? Refer to <http://ris.leeds.ac.uk/ConflictsOfInterest>.

Yes No

If so, please describe this potential conflict of interest, and outline what measures will be taken to address any ethical issues that might arise from the research.

N/A

C.27 Does the research involve external funding? (Tick as appropriate)

Yes No If yes, what is the source of this funding?

Engineering and Physical Sciences Research Council - Through the Water-WISER Centre for Doctoral Training. The Empower Project are providing benefits in kind by processing the laboratory samples without charge.

NB: If this research will be financially supported by the US Department of Health and Human Services or any of its divisions, agencies or programmes please ensure the additional funder requirements are complied with. Further guidance is available at <http://ris.leeds.ac.uk/FWacompliance> and you may also contact your [ERIQ](#) for advice.

Part D: Declarations

Declaration by Principal Investigators

1. The information in this form is accurate to the best of my knowledge and belief and I take full responsibility for it.
2. I undertake to abide by the University's ethical and health & safety guidelines, and the ethical principles underlying good practice guidelines appropriate to my discipline.
3. If the research is approved I undertake to adhere to the study protocol, the terms of this application and any conditions set out by the Research Ethics Committee (REC).
4. I undertake to seek an ethical opinion from the REC before implementing substantial amendments to the protocol.
5. I undertake to submit progress reports if required.
6. I am aware of my responsibility to be up to date and comply with the requirements of the law and relevant guidelines relating to security and confidentiality of patient or other personal data, including the need to register when necessary with the University's Data Protection Controller (further information available via <http://ris.leeds.ac.uk/ResearchDataManagement>).
7. I understand that research records/ data may be subject to inspection for audit purposes if required in future.
8. I understand that personal data about me as a researcher in this application will be held by the relevant RECs and that this will be managed according to the principles established in the Data Protection Act.
9. I understand that the REC may choose to audit this project at any point after approval.

Sharing information for training purposes: Optional – please tick as appropriate:

- I would be content for members of other Research Ethics Committees to have access to the information in the application in confidence for training purposes. All personal identifiers and references to researchers, funders and research units would be removed.

Principal Investigator:



.....
(This needs to be an actual signature rather than just typed. Electronic signatures are acceptable)

Print name: JEMMA FELICITY PHILLIPS Date: 19.08.22

Supervisor of student research: Professor Barbara Evans

I have read, edited and agree with the form above.

Supervisor's signature:
(This needs to be an actual signature rather than just typed. Electronic signatures are acceptable)

Print name: Date: 19.08.22

Please submit your form by email to the [FREC or School REC's mailbox](#).

Remember to include any supporting material such as your participant information sheet, consent form, interview questions and recruitment material with your application.

Appendix 1: Information Sheet



UNIVERSITY OF LEEDS

Title of research project:

An assessment of relative risk from exposures to faecal pathogens; from proximal and distal sources by hydraulic and non-hydraulic pathways.

Invitation

You have been invited to take part in a PhD Research Project. This project is about faecal contamination in urban areas and gathering data in order for better interventions for the improvement of public health. More data would increase the accuracy and usefulness of current tools such as SaniPath, Sanitation Safety Planning and the Excreta Flow Diagrams. My interest lies in exploring the potential to place the exposed population at the heart of risk from faecal contamination; essentially describing the 'catchment' of contamination that results in population risk at a particular location. This research is focussed on the sanitation chain failures that result in contamination of common exposure points in the environment; such as surface water, open drains, and fresh produce (fruit and vegetables).

As a part of the Water-WISER CDT, funding shall come from the individually assigned CDT research grant.

What is the purpose of the project?

- To carry out an analysis of the contamination in the environment and how members of the community interact with those exposure points
- To carry out analysis of the contamination within the fresh produce transportation chain.

Why am I asking you?

I am asking you as a member of the community who can tell me about how you live and interact with your environment as that information is helpful to the research.

What will it involve?

Speaking to the researcher with or without use of a translator for a short time (probably less than 15 minutes). The researcher will make some notes of the information you shared.

What are the possible disadvantages and risks of taking part?

At present the researcher does not foresee any discomforts, disadvantages or risks in taking part, however if you do have any reservations before, during or after, you may air these freely.

Use, dissemination and storage of research data

There are plans to publish this research once completed, as part of the PhD Degree, but any and all information and quotes will be anonymised as to not allow for individual identification of participants. All anonymised data will be stored on the server for 3 years to allow constant access throughout the end of the degree.

What will happen to the results of the research project?

All the information collected during the course of the research will be kept strictly confidential and will be stored separately from the research data. You will not be identified in any reports or publications. It is unlikely due to the nature of the research that topics depicting harm, abuse, admittance of illegal activities or any other dangerous item will come up, however, if they do, the researcher has a responsibility to report this. Results are likely to be published by the end of 2024, upon the completion of the PhD this research is being collected for. Upon publication, private and individual emails shall be sent out to all participants detailing the results. Results will also be shared with partners working in the local area, CURE and the Water Security Hub to collaborate on our research interests.

Contact for further information

Should you want to contact the researcher for any reason, do so at this email address:

Jemma Phillips cn16jfp@leeds.ac.uk

Appendix 2: Research Participant Privacy Notice

The following document is written in English, available in Hindi, and is available to be translated into further languages upon request. If additional language is needed, please contact the Lead Author (Hannah Robinson) at cn16hjr@leeds.ac.uk

Purpose of this Notice

This Notice explains how and why the University uses personal data for research; what individual rights are afforded under the Data Protection Act 2018 (DPA) and who to contact with any queries or concerns.

All research projects are different. This information is intended to supplement the specific information you will have been provided with when asked to participate in one of our research projects. The project specific information will provide details on how and why we will process your personal data, who will have access to it, any automated decision-making that affects you and for how long we will retain your personal data.

Why do we process personal data?

As a publically funded organisation we undertake scientific research which is in the public interest. The DPA requires us to have a legal basis for this processing; we rely upon "the performance of a task carried out in the public interest" as our lawful basis for processing personal data, and on "archiving in the public interest, scientific or historical research purposes, or statistical purposes" as our additional lawful basis for processing special category personal data (that which reveals racial or ethnic origin, political opinions, religious or philosophical beliefs, trade union membership, genetic or biometric data, and data concerning health, sex life or sexual orientation).

How do we follow data protection principles?

- We have lawful bases for processing personal and special category data.
- Data are used fairly and transparently; we will make it clear to individuals what their data will be used for, how it will be handled and what their rights are.
- We only collect and use personal data for our research, for research in the public interest, or to support the work of our organisation.
- We only collect the minimum amount of personal data which we need for our purposes.
- We take steps to ensure that the personal data we hold is accurate.
- We keep your personal data in an identifiable format for the minimum time required.
- We take steps to ensure that your data is held securely.
- We keep a record of our processing activities.

What do we do with personal data?

Research data can be a very valuable resource for improving public services and our understanding of the societies we live in. One way we can get the most benefit from this work is to make the data available, usually when the research has finished, to other researchers. Sometimes these researchers will be based outside the European Union. We will only ever share research data with organisations that can guarantee to store it securely. We will never sell your personal data, and any data shared cannot be used to contact individuals.

The project specific information will include more detail about how your data will be used.

Your rights as a data subject

Because we use personal data to support scientific research on the public interest, individuals participating in research do not have the same rights regarding their personal data as they would in other situations. This means that the following rights are limited for individuals who participate, or have participated in, a research project:

- The right to access the data we hold about you.
- The right to rectify the data we hold about you.
- The right to have the data we hold about you erased.
- The right to restrict how we process your data.
- The right to data portability.
- The right to object to us processing the data we hold about you.

Data security

We have put in place security measures to prevent your personal data from being accidentally lost, used or accessed in an unauthorised way and will notify you and any applicable regulator of a suspected breach where we are legally required to do so.

Retention periods

We will only retain your identifiable personal information for as long as necessary to fulfil the purposes we collected it for; we may then retain your data in anonymised or pseudonymised format. To determine the appropriate retention period for

personal data we consider the amount, nature, and sensitivity of the personal data, the potential risk of harm from unauthorised use or disclosure, the purposes for which we process your personal data and whether we can achieve those purposes through other means, and the applicable legal requirements.

Communication

In the first instance please contact the researcher who your initial contact was with Jemma Phillips, cn16jfp@leeds.ac.uk. You may also contact the Data Protection Officer for further information (see contact details below).

Please see the Information Commissioner's website for further information on the law) - You have a right to complain to the Information Commissioner's Office (ICO) about the way in which we process your personal data. Please see the ICO's website.

Concerns and contact details

If you have any concerns with regard to the way your personal data is being processed or have a query with regard to this Notice, please contact our Data Protection Officer (Alice Temple: A.C.Temple@leeds.ac.uk).

Our general postal address is University of Leeds, Leeds LS2 9JT, UK.

Our postal address for data protection issues is University of Leeds Secretariat, Room 11.72 EC Stoner Building, Leeds, LS2 9JT.

Our telephone number is +44 (0)113 2431751.

Our data controller registration number provided by the Information Commissioner's Office is Z553814X.



UNIVERSITY OF LEEDS

Faculty of Engineering and Physical Sciences:
School Of Civil Engineering

Ethics Submission for 2023 Data Collection

PhD Title:

Relative risk and faecal catchment mapping:
the investigation of community faecal pathogen exposures
from proximal and distal sources by non-hydraulic pathways of
fresh produce eaten raw and solid waste.

Jemma Phillips
201086983

Project Supervisors: Professor B. Evans, Dr. Marco-Felipe King, Dr Paul Hutchings, Professor Yun Yun Gong.

Date of registration: 2nd September 2020

Date of submission: 31st September 2024

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Ethics Review Form

Appendix 1: Information Sheet

Appendix 2: Research Participant Privacy Notice

Appendix 3: Risk Assessment



Please read each question carefully, taking note of instructions and completing all parts. If a question is not applicable please indicate so. The superscripted numbers (eg¹) refer to sections of the guidance notes, available at <http://ris.leeds.ac.uk/Work/EthicsApplication>. Where a question asks for information which you have previously provided in answer to another question, please just refer to your earlier answer rather than repeating information. Information about research ethics training courses: <http://ris.leeds.ac.uk/EthicsTraining>.

To help us process your application enter the following reference numbers, if known and if applicable:

Ethics reference number:	
Student number and/ or grant reference:	201086983

Part A: Summary

A.1 Which Faculty Research Ethics Committee would you like to consider this application?²

- Arts, Humanities and Cultures (AHC)
 Biological Sciences (BIOSCI)
 Business, Environment and Social Sciences (AREA)
 FS&N, Engineering and Physical Sciences (EPS)
 Medicine and Health (Please specify a subcommittee):
 - School of Dentistry (DREC)
 - School of Healthcare (SHREC)
 - School of Medicine (SoMREC)
 - School of Psychology (SoPREC)

A.2 Title of the research³

An assessment of relative risk from exposures to faecal pathogens; from proximal and distal sources by hydraulic and non-hydraulic pathways.

A.3 Principal investigator's contact details⁴

Name (Title, first name, surname)	Mrs Jemma Phillips
Position	PhD Student
Department/ School/ Institute	School of Civil Engineering
Faculty	Engineering and Physical Sciences
Work address (including postcode)	4.04 School of Chemical and Process Engineering, University of Leeds, Woodhouse, Leeds LS2 9JT
Telephone number	07704442456
University of Leeds email address	cn16jfp@leeds.ac.uk

A.4 Purpose of the research:⁵ (Tick as appropriate)

- Research
- Educational qualification: *Please specify: Water-WISER PhD*
- Educational Research & Evaluation⁶
- Medical Audit or Health Service Evaluation⁷
- Other

A.5 Select from the list below to describe your research: (You may select more than one)

- Research on or with human participants
- Research which has potential adverse [environmental impact](#).⁸ *If yes, please give details:*

- Research working with data of human participants
 - New data collected by qualitative methods
 - New data collected by quantitative methods
 - New data collected from observing individuals or populations**
 - Routinely collected data or secondary data
 - Research working with aggregated or population data
 - Research using already published data or data in the public domain
- Research working with human tissue samples (*Please inform the relevant [Persons Designate](#) if the research will involve human tissue*)⁹

A.6 Will the research involve NHS staff recruited as potential research participants (by virtue of their professional role) or NHS premises/ facilities?

Yes No

If yes, ethical approval must be sought from the University of Leeds. Note that [approval](#) from the NHS Health Research Authority may also be needed, please contact FMHUniEthics@leeds.ac.uk for advice.

A.7 Will the research involve any of the following:¹⁰ (You may select more than one)

If your project is classified as [research](#) rather than service evaluation or audit and involves any of the following an application must be made to the [NHS Health Research Authority](#) via IRAS www.myresearchproject.org.uk as NHS ethics approval will be required. There is no need to complete any more of this form. Further information is available at <http://ris.leeds.ac.uk/NHSEthicalreview> and at <http://ris.leeds.ac.uk/HRAapproval>. You may also contact governance-ethics@leeds.ac.uk for advice.

- Patients and users of the NHS (including NHS patients treated in the private sector)¹¹
- Individuals identified as potential participants because of their status as relatives or carers of patients and users of the NHS
- Research involving adults in Scotland, Wales or England who lack the capacity to consent for themselves¹²
- A prison or a young offender institution in England and Wales (and is health related)¹⁴
- Clinical trial of a medicinal product or medical device¹⁵
- Access to data, organs or other bodily material of past and present NHS patients⁹
- Use of human tissue (including non-NHS sources) where the collection is not covered by a Human Tissue Authority licence⁹

Foetal material and IVF involving NHS patients
 The recently deceased under NHS care
 None of the above
You must inform the Research Ethics Administrator of your NHS REC reference and approval date once approval has been obtained.

The HRA decision tool to help determine the type of approval required is available at <http://www.hra-decisiontools.org.uk/ethics>. If the University of Leeds is not the Lead Institution, or approval has been granted elsewhere (e.g. NHS) then you should contact the local Research Ethics Committee for guidance. The UoL Ethics Committee needs to be assured that any relevant local ethical issues have been addressed.

A.8 Will the participants be from any of the following groups? (Tick as appropriate)

Children under 16¹⁶ Specify age group: all ages
 Adults with learning disabilities¹²
 Adults with other forms of mental incapacity or mental illness
 Adults in emergency situations
 Prisoners or young offenders¹⁴
 Those who could be considered to have a particularly dependent relationship with the investigator, eg members of staff, students¹⁷
 Other vulnerable groups
 No participants from any of the above groups

Please justify the inclusion of the above groups, explaining why the research cannot be conducted on non-vulnerable groups.

N/A

It is the researcher's responsibility to check whether a DBS check (or equivalent) is required and to obtain one if it is needed. See also <http://ris.leeds.ac.uk/healthandsafetyadvice> and <http://www.homeoffice.gov.uk/agencies-public-bodies/dbs>.

A.9 Give a short summary of the research¹⁸

This section must be completed in language comprehensible to the lay person. Do not simply reproduce or refer to the protocol, although the protocol can also be submitted to provide any technical information that you think the ethics committee may require. This section should cover the main parts of the proposal. (300 words max)

In order to build more detailed models of source-pathway-exposure patterns for faecal contamination in urban areas, the assumptions and knowledge gaps need to be replaced with data. This would increase the accuracy and usefulness of current modelling, empirical and stochastic tools (such as SaniPath, Sanitation Safety Planning and the Shit Flow Diagrams).

My interest lies in exploring the potential to place the exposed population at the heart of risk from faecal contamination; essentially describing the 'catchment' of contamination that results in population risk at a particular location. The contamination will arrive at the point of exposure by a range of pathways: these can be hydraulic (travelling with water), such as in a river or an open drain, or non-hydraulic such as solid waste in the community.

This research is focussed on the sanitation chain failures that result in contamination of common exposure points in the environment. **This next piece of data collection will focus on solid waste.**

As a part of the Water-WISER CDT, funding shall come from the individually assigned CDT research grant.

A.10 What are the main ethical issues with the research and how will these be addressed?¹⁹

Indicate any issues on which you would welcome advice from the ethics committee.

Consent: Participants who take part in Key informant interviews or Focus Group Discussions will answer questions regarding their interactions with the pathogen exposure points of interest. They will have been given an explanation about the nature of the work, that their answers are anonymous, and they will verbally consent to their answers being noted down. **Members of the public (including children) will behave normally and be observed in public spaces, no personally identifiable details will be taken.**

Data security: All data will not be person identifiable and will be saved onto a University of Leeds laptop that is password protected. The data accrued will be stored on the University of Leeds OneDrive service.

Unconscious Bias: reading widely of India authors, educating myself about white-gaze and white-privilege, and working in collaboration with the local team from Jayna Collective will help to understand and mitigate for issues that could arise from my white British context and enable me to research respectfully, and produce meaningful data that is not compromised excessively by my bias.

Part B: About the research team

B.1 To be completed by students only²⁰

Qualification working towards (eg Masters, PhD)	PhD
Supervisor's name (Title, first name, surname)	Professor Barbara Evans
Department/ School/ Institute	School of Civil Engineering
Faculty	Engineering and Physical Sciences
Work address (including postcode)	School of Chemical and Process Engineering, University of Leeds, Woodhouse, Leeds LS2 9JT
Supervisor's telephone number	+44(0)113 343 1990
Supervisor's email address	B.E.Evans@leeds.ac.uk
Module name and number (if applicable)	N/A

B.2 Other members of the research team (eg co-investigators, co-supervisors) ²¹

Name (Title, first name, surname)	
Position	
Department/ School/ Institute	
Faculty	
Work address (including postcode)	
Telephone number	
Email address	

Name (Title, first name, surname)	
Position	
Department/ School/ Institute	
Faculty	
Work address (including postcode)	
Telephone number	
Email address	

Part C: The research

C.1 What are the aims of the study?²² (Must be in language comprehensible to a lay person.)

Research Question and Project Aims:

What is the relative significance of risks to the health of urban communities in Delhi from faecal pathogens emitted proximally and distally, and those that travel by hydraulic and non-hydraulic pathways?

Specific research questions:

1) In a set of selected communities (along the Barapullah open drain, Delhi, India),

a) Establish the significance and pathways of contamination on solid waste as a proximal non-hydraulic pathway.

C.2 Describe the design of the research. Qualitative methods as well as quantitative methods should be included. (Must be in language comprehensible to a lay person.)
It is important that the study can provide information about the aims that it intends to address. If a study cannot answer the questions/ add to the knowledge base that it intends to, due to the way that it is designed, then wasting participants' time could be an ethical issue.

When?	Field visit October 2023.
Where?	Settlements: 1. Madrasi Camp- Juggi Jhopri Colony, established 1982; 483 households. 2. Andrews Ganj - Juggi Jhopri Colony, established 1978; 904 Households 3. Jagdamba Camp - Juggi Jhopri Colony, established 1975; 1099 Households. Possibly solid waste from trucks and sorting centres
Samples to be taken	1. Solid waste from around communities 2. Hand rinses of waste workers
All samples to be tested for:	Plating for E.coli/ESBL E.coli or Faecal coliforms
Observations	1. Observing community members behaviour regarding how they interact with solid waste around the communities.
Focus Groups	1. Asking what they put on the solid waste piles (ie does it include flying toilets, diapers, children's faeces, animal faeces) 2. Finding out how much the communities perceive that they interact with the communal solid waste piles 3. If they perceive it to be dirty 4. If they are careful not to touch it when they put their own waste on the piles 5. How often the piles are collected 6. What happens to solid waste dredged out of the Open Drains

C.3 What will participants be asked to do in the study?²³ (e.g. number of visits, time, travel required, interviews)

- People within the study communities will be asked simple questions in Focus Groups about the way they interact with the solid waste, how frequently interact with them and if they perceive any risks.
- People working with the solid waste will be asked about their role and their hands will be rinsed to test for pathogens.
- None of the participants will have to travel to take part in the surveys.
- Involvement in the interviews or Focus Groups should take less than 15 minutes per participant.

C.4 Does the research involve an international collaborator or research conducted overseas?²⁴
 Yes No
If yes, describe any ethical review procedures that you will need to comply with in that country:
None required - the Water Security Hub asks for sending university ethical approval to be sought.
Describe the measures you have taken to comply with these:
N/a
Include copies of any ethical approval letters/ certificates with your application.

C.5 Proposed study dates and duration			
Research start date (DD/MM/YY):	01/10/2020	Research end date (DD/MM/YY):	31/09/2024
Fieldwork start date (DD/MM/YY):	11/10/2023	Fieldwork end date (DD/MM/YY):	30/10/2023

C.6. Where will the research be undertaken? (i.e. in the street, on UoL premises, in schools)²⁵

In the capital city of New Delhi, in communities based along the open drain systems. The drains have a wide variety of housing types along it but the focus will be the slum communities due to the poor associated health outcomes of living in these environments.

RECRUITMENT & CONSENT PROCESSES

C.7 How will potential participants in the study be identified, approached and recruited?²⁶
How will you ensure an appropriately convened sample group in order to meet the aims of the research? Give details for subgroups separately, if appropriate. How will any potential pitfalls, for example dual roles or potential for coercion, be addressed?

Access to the communities will be mediated by local company Jayna Collective LLP who has worked extensively in the Delhi slums. In the target neighbourhood, focus groups will be arranged by dividing neighbourhoods into segments. From each segment participants can respond to a request to participate if they wish.

The person or people working on Solid Waste at the time of data collection will be asked questions if they are happy to answer for a few minutes.

The observations will be in a public place where people are aware that other people can see them.

C.8 Will you be excluding any groups of people, and if so what is the rationale for that?²⁷
Excluding certain groups of people, intentionally or unintentionally may be unethical in some circumstances. It may be wholly appropriate to exclude groups of people in other cases

Excluded groups for the interviews and Focus Groups will be those who do not speak English or Hindi, people under 18, people with any other vulnerabilities where the researcher may doubt their ability to consent to participate in the research. Anyone interacting with the solid waste will be included in the observations.

C.9 How many participants will be recruited and how was the number decided upon?²⁸
It is important to ensure that enough participants are recruited to be able to answer the aims of the research.

The solid waste work is exploratory and therefore a set number of participants has not been determined. However, in order to get a preliminary understanding of the situation across three communities in a city the size of Delhi it is likely the participants could number up to 150 people.

C10 Will the research involve any element of deception?²⁹
If yes, please describe why this is necessary and whether participants will be informed at the end of the study.

No, it will not.

C.11 Will informed consent be obtained from the research participants?³⁰

Yes No

If yes, give details of how it will be done. Give details of any particular steps to provide information (in addition to a written information sheet) e.g. videos, interactive material. If you are not going to be obtaining informed consent you will need to justify this.

As the research does not involve gathering any personal data, verbal consent will be gained to ask questions for research purposes. There will be an information sheet available in English and Hindi with contact details if anyone wants more information or to get in touch after speaking to me.

If participants are to be recruited from any of potentially vulnerable groups, give details of extra steps taken to assure their protection. Describe any arrangements to be made for obtaining consent from a legal representative.

Participants will not be recruited from vulnerable groups.

Will research participants be provided with a copy of the [Privacy Notice for Research](#)? If not, explain why not. Guidance is available at <https://dataprotection.leeds.ac.uk/information-for-researchers>.

Yes No

Copies of any written consent form, written information and all other explanatory material should accompany this application. The information sheet should make explicit that participants can withdraw from the research at any time, if the research design permits. Remember to use meaningful file names and version control to make it easier to [keep track of your documents](#).

Sample information sheets and consent forms are available from the University ethical review webpage at <http://ris.leeds.ac.uk/InvolvingResearchParticipants>.

C.12 Describe whether participants will be able to withdraw from the study, and up to what point (eg if data is to be anonymised). If withdrawal is not possible, explain why not.

Any limits to withdrawal, eg once the results have been written up or published, should be made clear to participants in advance, preferably by specifying a date after which withdrawal would not be possible. Make sure that the information provided to participants (eg information sheets, consent forms) is consistent with the answer to C12.

Data will be anonymised from the outset and therefore the only data collected will be regarding environmental interactions and 3 meter squared locations. No personal data will be collected.

C.13 How long will the participant have to decide whether to take part in the research?³¹

It may be appropriate to recruit participants on the spot for low risk research; however consideration is usually necessary for riskier projects.

Participants will be recruited on the spot and they can decide if they wish to participate or not with no pressure.

C.14 What arrangements have been made for participants who might have difficulties understanding verbal explanations or written information, or who have particular communication needs that should be taken into account to facilitate their involvement in the research?³² *Different populations will have different information needs, different communication abilities and different levels of understanding of the research topic. Reasonable efforts should be made to include potential participants who could otherwise be prevented from participating due to disabilities or language barriers.*

Verbal and written information will be available in English and Hindi. Vulnerable populations with particular difficulties understanding will not be recruited for this study. Participants will be able to ask any questions they wish in order to secure their understanding.

C.15 Will individual or group interviews/ questionnaires discuss any topics or issues that might be sensitive, embarrassing or upsetting, or is it possible that criminal or other disclosures requiring action could take place during the study (e.g. during interviews or group discussions)?³³ *The [information sheet](#) should explain under what circumstances action may be taken.*

Yes No *If yes, give details of procedures in place to deal with these issues.*

C.16 Will individual research participants receive any payments, fees, reimbursement of expenses or any other incentives or benefits for taking part in this research?³⁴

Yes No
If Yes, please describe the amount, number and size of incentives and on what basis this was decided.

RISKS OF THE STUDY

C.17 What are the potential benefits and/ or risks for research participants in both the short and medium-term?³⁵

Benefits for the participants for taking part are contributing to important research that enables greater understanding of the environmental hazards and resulting exposure risks will be more clearly identified for the area where they live. Mapping the faecal contamination in New Delhi could have unintended consequences for homes and businesses in the affected areas, this issue will be considered and managed before the publication of any data in order to produce visualisations that are meaningful but not harmful. One way of doing this could be to combine the data from the 3 communities, or to not name which communities the sampling occurred in, but just that they were along the main open drainage networks.

C.18 Does the research involve any risks to the researchers themselves, or people not directly involved in the research? *Eg lone working*³⁶

Yes No

If yes, please describe:

Lone working will not occur, locally members of Jayna Collective LLP will work with the researcher at all times. Faecally contaminated samples will be collected but full training has been completed and appropriate personal protective equipment will be worn.

...

Is a [risk assessment](#) necessary for this research?

If you are unsure whether a risk assessment is required visit <http://ris.leeds.ac.uk/HealthAndSafetyAdvice> or contact your Faculty Health and Safety Manager for advice.

Yes No *If yes, please include a copy of your risk assessment form with your application.*

RESEARCH DATA

C.19 Explain what measures will be put in place to protect personal data. E.g. anonymisation procedures, secure storage and coding of data. Any potential for re-identification should be made clear to participants in advance.³⁷ Please note that research data which appears in reports or other publications is not confidential, even if it is fully anonymised. For a fuller explanation see <http://ris.leeds.ac.uk/ConfidentialityAnonymisation>. Further guidance is available at <http://ris.leeds.ac.uk/ResearchDataManagement>.

- No participant's names or addresses will be used in any documents created from this research

All data for this research will be dealt with in accordance with the Data Protection Act 2018. All data will be anonymised from the point of collection with only 3m² location details. Data shall be stored on a password protected encrypted laptop and no confidential information will be transferred by email. Partners will also be informed of the data management plans. Contact details for any participants wishing to receive further information about the outcomes of the research will be stored separately from research data. Further details are available from <https://leeds.service-now.com/it>.

C.20 How will you make your research data available to others in line with: the University's, funding bodies' and publishers' policies on making the results of publically funded research publically available. Explain the extent to which anonymity will be maintained. (max 200 words) Refer to <http://ris.leeds.ac.uk/ConfidentialityAnonymisation> and <http://ris.leeds.ac.uk/ResearchDataManagement> for guidance.

Data will be shared if and when ready for publishing in academic journals, all will be anonymised, in line with EPSRC policy.

C.21 Will the research involve any of the following activities at any stage (including identification of potential research participants)? (Tick as appropriate)

- Examination of personal records by those who would not normally have access
 - Access to research data on individuals by people from outside the research team
 - Electronic surveys, please specify survey tool: <https://www.onlinesurveys.ac.uk/> (further guidance)
 - Other electronic transfer of data
 - Use of personal addresses, postcodes, faxes, e-mails or telephone numbers
 - Use of audio/ visual recording devices (NB this should usually be mentioned in the information for participants)
 - FLASH memory or other portable storage devices
- Storage of personal data on, or including, any of the following:
- [University approved](#) cloud computing services
 - Other cloud computing services
 - Manual files
 - Private company computers
 - Laptop computers (password protected and encrypted)
 - Home or other personal computers (not recommended; data should be stored on a University of Leeds server such as your M: or N: drive where it is secure and backed up regularly: <http://ris.leeds.ac.uk/ResearchDataManagement>)

Unclassified and Confidential University data must be kept on the University servers or in approved cloud services such as Office 365 (SharePoint or OneDrive). The N: Drive or Office 365 should be used for the storage of data that needs to be shared. If Highly Confidential information is kept in these shared storage areas it must be encrypted. Highly Confidential data that is not to be shared should be kept on the M: Drive. The use of non-University approved cloud services for the

storage of any University data, including that which is unclassified, is forbidden without formal approval from IT. Further guidance is available via <http://ris.leeds.ac.uk/ResearchDataManagement>.

C.22 How do you intend to share the research data? (Indicate with an 'X') Refer to <http://library.leeds.ac.uk/research-data-deposit> for guidance.

- Exporting data outside the European Union
- Sharing data with other organisations
- Publication of direct quotations from respondents
- Publication of data that might allow identification of individuals to be identified
- Submitting to a journal to support a publication
- Depositing in a self-archiving system or an institutional repository
- Dissemination via a project or institutional website
- Informal peer-to-peer exchange
- Depositing in a specialist data centre or archive
- Other, please state: _____.
- No plans to report or disseminate the data

C.23 How do you intend to report and disseminate the results of the study? (Indicate with an 'X') Refer to <http://ris.leeds.ac.uk/ResearchDissemination> and <http://ris.leeds.ac.uk/Publication> for guidance.

- Conference presentation
- Peer reviewed journals
- Publication as an eThesis in the Institutional repository
- Publication on website
- Other publication or report, please state: _____
- Submission to regulatory authorities
- Other, please state: _____
- No plans to report or disseminate the results

**C.24 For how long will data from the study be stored? Please explain why this length of time has been chosen.²⁸ Refer to the [RCUK Common Principles on Data Policy](#) and http://ris.leeds.ac.uk/info/71/good_research_practice/106/research_data_guidance/5.
Students: It would be reasonable to retain data for at least 2 years after publication or three years after the end of data collection, whichever is longer.**

3 years, 0 months

This will be approximately 2 years after publication (giving a year to publish), and 3 years after data collection.

CONFLICTS OF INTEREST

C.25 Will any of the researchers or their institutions receive any other benefits or incentives for taking part in this research over and above normal salary or the costs of undertaking the research?²⁹

Yes No

If yes, indicate how much and on what basis this has been decided

N/A

C.26 Is there scope for any other conflict of interest?⁴⁰ For example, could the research findings affect the any ongoing relationship between any of the individuals or organisations involved and the researcher(s)? Will the research funder have control of publication of research findings? Refer to <http://ris.leeds.ac.uk/ConflictsOfInterest>

Yes No

If so, please describe this potential conflict of interest, and outline what measures will be taken to address any ethical issues that might arise from the research.

N/A

C.27 Does the research involve external funding? (Tick as appropriate)

Yes No *If yes, what is the source of this funding?*

Engineering and Physical Sciences Research Council - Through the Water-WISER Centre for Doctoral Training.

NB: If this research will be financially supported by the US Department of Health and Human Services or any of its divisions, agencies or programmes please ensure the additional funder requirements are complied with. Further guidance is available at <http://ris.leeds.ac.uk/FWAcompliance> and you may also contact your [FRIO](#) for advice.

Part D: Declarations

Declaration by Principal Investigators

1. The information in this form is accurate to the best of my knowledge and belief and I take full responsibility for it.
2. I undertake to abide by the University's ethical and health & safety guidelines, and the ethical principles underlying good practice guidelines appropriate to my discipline.
3. If the research is approved I undertake to adhere to the study protocol, the terms of this application and any conditions set out by the Research Ethics Committee (REC).
4. I undertake to seek an ethical opinion from the REC before implementing substantial amendments to the protocol.
5. I undertake to submit progress reports if required.
6. I am aware of my responsibility to be up to date and comply with the requirements of the law and relevant guidelines relating to security and confidentiality of patient or other personal data, including the need to register when necessary with the University's Data Protection Controller (further information available via <http://ris.leeds.ac.uk/ResearchDataManagement>).
7. I understand that research records/ data may be subject to inspection for audit purposes if required in future.
8. I understand that personal data about me as a researcher in this application will be held by the relevant RECs and that this will be managed according to the principles established in the Data Protection Act.
9. I understand that the REC may choose to audit this project at any point after approval.

Sharing information for training purposes: Optional – please tick as appropriate:

- I would be content for members of other Research Ethics Committees to have access to the information in the application in confidence for training purposes. All personal identifiers and references to researchers, funders and research units would be removed.

Principal Investigator:



.....
(This needs to be an actual signature rather than just typed. Electronic signatures are acceptable)

Print name: JEMMA FELICITY PHILLIPS Date: 19.08.22

Supervisor of student research: Professor Barbara Evans

I have read, edited and agree with the form above.

Supervisor's signature: 
(This needs to be an actual signature rather than just typed. Electronic signatures are acceptable)

Print name: ...BARBARA EVANS..... Date: 19.08.22

Please submit your form by email to the [FREC or School REC's mailbox](#).
Remember to include any supporting material such as your participant information sheet, consent form, interview questions and recruitment material with your application.

Appendix 1: Information Sheet



UNIVERSITY OF LEEDS

Title of research project:

An assessment of relative risk from exposures to faecal pathogens; from proximal and distal sources by hydraulic and non-hydraulic pathways.

Invitation

You have been invited to take part in a PhD Research Project. This project is about faecal contamination in urban areas and gathering data in order for better interventions for the improvement of public health. More data would increase the accuracy and usefulness of current tools such as SaniPath, Sanitation Safety Planning and the Excreta Flow Diagrams. My interest lies in exploring the potential to place the exposed population at the heart of risk from faecal contamination; essentially describing the 'catchment' of contamination that results in population risk at a particular location. This research is focussed on the sanitation chain failures that result in contamination of common exposure points in the environment; such as surface water, open drains, and fresh produce (fruit and vegetables).

As a part of the Water-WISER CDT, funding shall come from the individually assigned CDT research grant.

What is the purpose of the project?

- To carry out an analysis of the contamination in the environment and how members of the community interact with those exposure points
- To carry out analysis of the contamination within the fresh produce transportation chain.

Why am I asking you?

I am asking you as a member of the community who can tell me about how you live and interact with your environment as that information is helpful to the research.

What will it involve?

Speaking to the researcher with or without use of a translator for a short time (probably less than 15 minutes). The researcher will make some notes of the information you shared.

What are the possible disadvantages and risks of taking part?

At present the researcher does not foresee any discomforts, disadvantages or risks in taking part, however if you do have any reservations before, during or after, you may air these freely.

Use, dissemination and storage of research data

There are plans to publish this research once completed, as part of the PhD Degree, but any and all information and quotes will be anonymised as to not allow for individual identification of participants. All anonymised data will be stored on the server for 3 years to allow constant access throughout the end of the degree.

What will happen to the results of the research project?

All the information collected during the course of the research will be kept strictly confidential and will stored separately from the research data. You will not be identified in any reports or publications. It is unlikely due to the nature of the research that topics depicting harm, abuse, admittance of illegal activities or any other dangerous item will come up, however, if they do, the researcher has a responsibility to report this. Results are likely to be published by the end of 2024, upon the completion of the PhD this research is being collected for. Upon publication, private and individual emails shall be sent out to all participants detailing the results. Results will also be shared with partners working in the local area, CURE and the Water Security Hub to collaborate on our research interests.

Contact for further information

Should you want to contact the researcher for any reason, do so at this email address:

Jemma Phillips cn16jfp@leeds.ac.uk

Appendix 2: Research Participant Privacy Notice

The following document is written in English, available in Hindi, and is available to be translated into further languages upon request. If additional language is needed, please contact the Lead Author (Hannah Robinson) at cn16hjr@leeds.ac.uk

Purpose of this Notice

This Notice explains how and why the University uses personal data for research; what individual rights are afforded under the Data Protection Act 2018 (DPA) and who to contact with any queries or concerns.

All research projects are different. This information is intended to supplement the specific information you will have been provided with when asked to participate in one of our research projects. The project specific information will provide details on how and why we will process your personal data, who will have access to it, any automated decision-making that affects you and for how long we will retain your personal data.

Why do we process personal data?

As a publically funded organisation we undertake scientific research which is in the public interest. The DPA requires us to have a legal basis for this processing; we rely upon "the performance of a task carried out in the public interest" as our lawful basis for processing personal data, and on "archiving in the public interest, scientific or historical research purposes, or statistical purposes" as our additional lawful basis for processing special category personal data (that which reveals racial or ethnic origin, political opinions, religious or philosophical beliefs, trade union membership, genetic or biometric data, and data concerning health, sex life or sexual orientation).

How do we follow data protection principles?

- We have lawful bases for processing personal and special category data.
- Data are used fairly and transparently; we will make it clear to individuals what their data will be used for, how it will be handled and what their rights are.
- We only collect and use personal data for our research, for research in the public interest, or to support the work of our organisation.
- We only collect the minimum amount of personal data which we need for our purposes.
- We take steps to ensure that the personal data we hold is accurate.
- We keep your personal data in an identifiable format for the minimum time required.
- We take steps to ensure that your data is held securely.
- We keep a record of our processing activities.

What do we do with personal data?

Research data can be a very valuable resource for improving public services and our understanding of the societies we live in. One way we can get the most benefit from this work is to make the data available, usually when the research has finished, to other researchers. Sometimes these researchers will be based outside the European Union. We will only ever share research data with organisations that can guarantee to store it securely. We will never sell your personal data, and any data shared cannot be used to contact individuals.

The project specific information will include more detail about how your data will be used.

Your rights as a data subject

Because we use personal data to support scientific research on the public interest, individuals participating in research do not have the same rights regarding their personal data as they would in other situations. This means that the following rights are limited for individuals who participate, or have participated in, a research project:

- The right to access the data we hold about you.
- The right to rectify the data we hold about you.
- The right to have the data we hold about you erased.
- The right to restrict how we process your data.
- The right to data portability.
- The right to object to us processing the data we hold about you.

Data security

We have put in place security measures to prevent your personal data from being accidentally lost, used or accessed in an unauthorised way and will notify you and any applicable regulator of a suspected breach where we are legally required to do so.

Retention periods

We will only retain your identifiable personal information for as long as necessary to fulfil the purposes we collected it for; we may then retain your data in anonymised or pseudonymised format. To determine the appropriate retention period for

personal data we consider the amount, nature, and sensitivity of the personal data, the potential risk of harm from unauthorised use or disclosure, the purposes for which we process your personal data and whether we can achieve those purposes through other means, and the applicable legal requirements.

Communication

In the first instance please contact the researcher who your initial contact was with Jemma Phillips, cn16jfp@leeds.ac.uk. You may also contact the Data Protection Officer for further information (see contact details below).

Please see the Information Commissioner's website for further information on the law) - You have a right to complain to the Information Commissioner's Office (ICO) about the way in which we process your personal data. Please see the ICO's website.

Concerns and contact details

If you have any concerns with regard to the way your personal data is being processed or have a query with regard to this Notice, please contact our Data Protection Officer (Alice Temple: A.C.Temple@leeds.ac.uk).

Our general postal address is University of Leeds, Leeds LS2 9JT, UK.

Our postal address for data protection issues is University of Leeds Secretariat, Room 11.72 EC Stoner Building, Leeds, LS2 9JT.

Our telephone number is +44 (0)113 2431751.

Our data controller registration number provided by the Information Commissioner's Office is Z553814X.

11.4 Appendix D: Risk Assessment for Data Collection 2022 and 2023

Appendix 3: Risk Assessment

Fieldwork Risk Assessment Form.



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This form must be used for all Fieldwork Activities including Fieldwork Activities and Travel Plans subject to Foreign and Commonwealth Office Travel Advice.

It may not be necessary to complete every section – where not applicable n/a, please indicate why.

Fieldwork Project Details	
Faculty School/ Service	School of Civil Engineering, Faculty of Engineering and Physical Sciences
Location of Fieldwork Is the location subject to Foreign and Commonwealth Office (FCO) Travel Advice? No. <i>If Y, complete the FCO Advice section and refer to the Procedure for travel against FCO advice</i>	Delhi, India
Brief description of Fieldwork activity and purpose <i>(Include country, location, area, and grid reference and map where applicable).</i>	PhD researcher Jemma Phillips will be travelling to Delhi, India. This work will be in collaboration with Jayna Collective LLP, Newcastle University, Empower Project, the Water Security Hub and the Centre for Urban and Regional Excellence (CURE) organisation. The researcher will be carrying out fieldwork related to her PhD project in the Barapullah sub basin area. Activities will include: walking around and observing living conditions in the slums/ informal settlements of the Barapullah sub basin area; observations of sanitation conditions in the slum/informal environment, interacting with local communities and working alongside local staff in order to collect environmental samples and conduct household surveys.
Fieldwork itinerary <i>E.g. flight details, hotel address, dates of travel, mode of transport etc.</i>	<i>Neither Flights nor Hotels have been booked, and will not be booked until final approval of Ethics and Risk Assessment due to the ever-changing global coronavirus situation; as of 29th September 2020, the University's travel insurance will not cover cancellation or curtailment of travel as a consequence of Covid-19. These are therefore approximations of what I will use, and what my current intention is. This risk assessment will be updated as I continue so it holds the latest information.</i> <i>Travel is likely to be the 15th October 2022 – 16th November 2022.</i>

<p>University Travel Insurance Policy Information</p>	<p>Aviva Business Travel Policy Number 100003814GPA</p> <p>http://www.leeds.ac.uk/insurance/travel.htm</p> <p>Advisory Note: Check that the country you intend to travel to is covered by the University travel insurance before you go. Take a copy of the Summary of Cover with you which includes Emergency Contact Numbers.</p> <p>https://www.leeds.ac.uk/insurance/documents/summary_of_cover.pdf</p>
<p>Organiser Details</p>	<p>Contact details <i>Including Name, Email, Telephone Number.</i></p>
<p>Fieldwork Activity Organiser / Course Leader</p>	<p>Barbara Evans B.E.Evans@leeds.ac.uk +44 1625 263363; 07747196126</p>
<p>Departmental Co-ordinator</p>	<p>Timothy Nadin T.J.Nadin@leeds.ac.uk 0113-34-37330</p>
<p>Nature of visit <i>Size of Group, lone working, staff, postgraduate, undergraduate.</i></p>	<p>PhD researcher Jemma Phillips will be spending up to 6 weeks in Delhi to carry out fieldwork in the Barapullah sub basin area and work alongside local staff from Jayna Collective and in collaboration with staff from Newcastle University who's trip to Delhi will also be for overlapping dates.</p>
<p>Participant Details <i>Attach information as separate list if required.</i></p>	<p>Contact details <i>Name, Address, email, telephone, gender and next of kin contact details</i></p>
	<p>Jemma Phillips 29 The Quarry, Leeds, LS17 7NH cn16jfp@leeds.ac.uk 07704442456 Female</p> <p>Next of Kin: Arinze Phillips (husband) 07413209132 / 07477193761 arinzetobias@hotmail.com</p>

HAZARD IDENTIFICATION										
<i>Identify all hazards specific to fieldwork activities and travel plans, describe existing control measures and identify any further measures required.</i>										
HAZARD(S) IDENTIFIED	CONTROL MEASURES <i>(e.g. alternative work methods, training, supervision, protective equipment)</i>									
<p>1. Nature of the site <i>School, college, university, remote area, laboratory, office, workshop, construction site, farm, etc.</i></p> <ul style="list-style-type: none"> ● General: <ul style="list-style-type: none"> ○ Offices ○ Informal Settlements ○ River ○ Agricultural sites ○ Food Markets ○ Communal / Public Toilets ● Nearest local contact point - accommodation. ● System for contact appropriate to the location (and contact times) 	<p>Research will take place in slum communities, meetings in professional and academic offices, food wholesalers, potentially some urban agriculture settings.</p> <p>The key local contact points will be the Jayna Collective LLP team, and the group accommodation.</p> <p>The researcher will have a local SIM card in her phone that ensure she is reachable at all times.</p>									
<p>2. Environmental conditions <i>Extremes of temperature, climate, altitude, exposure to sunlight, potential weather conditions, tidal conditions etc.</i></p> <p>As Delhi is a humid subtropical region, the following environmental conditions will need to be considered:</p> <ul style="list-style-type: none"> ● Climate Related Risks ● Poor air quality (smog) ● Access to adequate supply of food and potable drinking water 	<table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 20%; vertical-align: top;">Climate Related Risks</td> <td style="width: 30%; vertical-align: top;"> Temperature extremes (up to 40'c) <ul style="list-style-type: none"> ● Sunburn ● Sunstroke ● Dehydration </td> <td style="width: 50%; vertical-align: top;"> Drinking water, avoiding mid-day direct sun, carrying a sunhat, finding shade whenever possible, being active at the beginning and end of the day before the sun reaches peak warmth, not over-exercising / over-exerting, wearing light / loose clothing </td> </tr> <tr> <td></td> <td style="vertical-align: top;"> <ul style="list-style-type: none"> ● Flooding </td> <td style="vertical-align: top;"> Looking at flood maps to understand riskier areas, having accommodation above the ground floor if possible </td> </tr> <tr> <td style="vertical-align: top;">Poor Air Quality</td> <td style="vertical-align: top;"> <ul style="list-style-type: none"> ● Humidity ● Smog </td> <td style="vertical-align: top;"> H: Having lots of water, shade and cool air to keep body temperatures low S: Wearing facemasks </td> </tr> </table>	Climate Related Risks	Temperature extremes (up to 40'c) <ul style="list-style-type: none"> ● Sunburn ● Sunstroke ● Dehydration 	Drinking water, avoiding mid-day direct sun, carrying a sunhat, finding shade whenever possible, being active at the beginning and end of the day before the sun reaches peak warmth, not over-exercising / over-exerting, wearing light / loose clothing		<ul style="list-style-type: none"> ● Flooding 	Looking at flood maps to understand riskier areas, having accommodation above the ground floor if possible	Poor Air Quality	<ul style="list-style-type: none"> ● Humidity ● Smog 	H: Having lots of water, shade and cool air to keep body temperatures low S: Wearing facemasks
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	<ul style="list-style-type: none"> ● Flooding 	Looking at flood maps to understand riskier areas, having accommodation above the ground floor if possible								
Poor Air Quality	<ul style="list-style-type: none"> ● Humidity ● Smog 	H: Having lots of water, shade and cool air to keep body temperatures low S: Wearing facemasks								

			when in congested smoggy areas
	Access to Water and food		<ul style="list-style-type: none"> Ensuring adequate food and potable water (especially in slum / informal areas)
3. Site-specific conditions <i>E.g. cliffs, scree, bogs, featureless landscapes, local endemic infectious diseases, zoonoses etc.</i>			
	<i>Location</i>	<i>Risk</i>	<i>Measures</i>
<ul style="list-style-type: none"> Accommodation Slum/ Informal Neighbourhoods CURE office Government offices and municipalities in Delhi and Chennai Communal and public toilets Yamuna River Urban agricultural sites in Delhi Food markets in Delhi Food wholesalers in Delhi 	Accommodation	<ul style="list-style-type: none"> Fire safety Personal security General safety of structure and facilities 	The researcher will familiarise herself with the fire safety protocol and emergency escape routes in the accommodation. All personal valuable belongings will be locked away in a safe. All hazards kept to a minimum by ensuring any faults/issues are reported to hosts.
	Slum/ Informal Neighbourhoods	<ul style="list-style-type: none"> Heavy traffic flow Safety/ security concerns of physical/sexual violence or abuse Stray dogs 	Being in a group where possible, only travelling alone in daylight, having rabies vaccination
	Office environments	<ul style="list-style-type: none"> Office - related hazards 	Wearing glasses to prevent eye strain (if appropriate), watching for potentially dangerous/ slippery surfaces, familiarise fire escape routes upon entering new buildings

	<table border="1"> <tr> <td>Communal and public toilets</td> <td> <ul style="list-style-type: none"> • Safety /security concerns of physical/sexual violence or abuse </td> <td>Only going into these spaces in daylight, always ensuring a charged phone is available</td> </tr> <tr> <td>Open water such as rivers and drains</td> <td> <ul style="list-style-type: none"> • Flooding • High levels of pollution • Risk of drowning • Infection from contact to water bodies </td> <td>Remaining at least 2m from the banks of the river at all time, no swimming, vaccinations for water related diseases. Wearing PPE for sampling activities.</td> </tr> <tr> <td>Urban agricultural sites in Delhi</td> <td> <ul style="list-style-type: none"> • Mechanical hazards from farm machinery • Chemicals such as pesticides and crop sprays • Aggression from domestic animals </td> <td>Staying away from machinery that could be potentially dangerous, wearing long sleeve tops, and long trousers/skirts so less skin is on show to come into contact with potentially dangerous chemicals, not provoking / approaching wild / unknown animals</td> </tr> </table>	Communal and public toilets	<ul style="list-style-type: none"> • Safety /security concerns of physical/sexual violence or abuse 	Only going into these spaces in daylight, always ensuring a charged phone is available	Open water such as rivers and drains	<ul style="list-style-type: none"> • Flooding • High levels of pollution • Risk of drowning • Infection from contact to water bodies 	Remaining at least 2m from the banks of the river at all time, no swimming, vaccinations for water related diseases. Wearing PPE for sampling activities.	Urban agricultural sites in Delhi	<ul style="list-style-type: none"> • Mechanical hazards from farm machinery • Chemicals such as pesticides and crop sprays • Aggression from domestic animals 	Staying away from machinery that could be potentially dangerous, wearing long sleeve tops, and long trousers/skirts so less skin is on show to come into contact with potentially dangerous chemicals, not provoking / approaching wild / unknown animals
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Urban agricultural sites in Delhi	<ul style="list-style-type: none"> • Mechanical hazards from farm machinery • Chemicals such as pesticides and crop sprays • Aggression from domestic animals 	Staying away from machinery that could be potentially dangerous, wearing long sleeve tops, and long trousers/skirts so less skin is on show to come into contact with potentially dangerous chemicals, not provoking / approaching wild / unknown animals								

	<p>Food markets in Delhi</p> <ul style="list-style-type: none"> ● Heavy traffic ● Human congestion ● Theft ● Physical violence or abuse ● Hygiene concern of produce ● Lack of safe infrastructure ● Stray dogs <p>Avoiding buying street food where possible (especially if not piping hot/fried which would reduce risk of harm), not getting out expensive items (phone, camera, laptop) in busy and congested areas, only being in crowded areas in daylight, using common sense to assess the safety of the area, having rabies vaccination</p> <p>Food wholesalers in Delhi</p> <ul style="list-style-type: none"> ● Traffic including commercial vehicles such as forklift trucks ● Hygiene concerns of produce ● Physical violence or abuse <p>Being vigilant for any hazards and keeping away from harm's way at all times. Avoid touching produce where possible, especially unpackaged foods to reduce risk of harm. Visit during daytime, if possible in pairs or a group to reduce chances of being alone and at risk.</p>
<p>4. Process <i>Operating machinery, electrical equipment, driving vehicles, handling or working with animals etc.</i></p> <ul style="list-style-type: none"> ● Sampling at sites of interest ● Communicating/interacting with local people ● Communicating/interacting with Jayna Collective staff members 	<p>There are no particularly high-risk activities (e.g. operating machinery, electrical equipment, driving vehicles, handling or working with animals) that will be carried out for the duration of the trip. Minor process risks include:</p> <p>Informal observation and communication:</p> <ul style="list-style-type: none"> ● Listening carefully and asking to repeat items if unclear as to reduce misinterpretation conversation/actions ● Getting assistance from a local interpreter to reduce misunderstanding/misinterpretation
<p>5. Transport <i>Mode of transport while on site, to and from site, carriage of dangerous goods etc.</i></p>	<p>International Travel:</p> <ul style="list-style-type: none"> ● Prioritising reputable airlines

<p>Travel to and from Delhi: Flights from Manchester to Delhi</p> <p>Transport during time in Delhi: Car/taxi: local driver to transport the group to sites of interest</p>	<p>Internal Travel:</p> <ul style="list-style-type: none"> • Arrange for private local driver/s to transportation around Delhi
<p>6. Equipment <i>Manual handling risks, operation of machinery, tools, use of specialist equipment etc.</i></p>	<p>Laboratory equipment may be heavy and therefore manual handling procedures will be adhered to and supporting equipment such as trolleys shall be used as much as possible. Full PPE will be used and only trained personal will enter labs and use any lab equipment.</p>
<p>7. Violence <i>Potential for violence in location, political and social unrest; against participants, lone working, interviewing (previous incidents etc.)</i></p> <p>PhD researchers could be carrying out some lone work- this could pose risk of violence, particularly sexual violence/ abuse against women</p> <p>Mugging in crowded spaces such as food markets and slum/informal neighbourhoods</p> <p>Conflict/hostility from local people regarding observations and interaction</p>	<p>When working alone, work should be carried out in daylight hours and in public places to minimise risks of being alone in the dark. Researchers should also always use private car hire where possible to reduce the need to use rickshaws and other less safe modes of transport.</p> <p>Researchers should try to always use secure bags with several fastenings to keep belongings and valuables safe (e.g. no tote bags).</p> <p>Researchers need to use common sense whilst documenting observational data to ensure that they do not encroach on others' privacy (e.g. not taking direct photos of people without consent).</p>
<p>8. Cultural Considerations <i>Specific to the activity or participants.</i></p> <p>Maintaining appropriate attire and behaviour in traditional neighbourhoods</p> <p>Religious and dietary considerations</p>	<p>We will ensure that general attire is appropriate (e.g. no short skirts), to make sure that we are culturally sensitive, but also weather appropriate (e.g. ensuring we have sunhats to minimise sunburn risks).</p> <p>We need to be aware of the potential risks associated with religious considerations as the researcher is Christian and the majority religions are Hindu and Islam. The researcher will be respectful at all times.</p>
<p>9. Individual(s) <i>Medical condition(s), young, inexperienced, disabilities etc.</i></p>	<p>Medical conditions None.</p>

<ul style="list-style-type: none"> • Medical conditions • No disabilities • Inexperienced Researcher 	<p>Researcher has been to Delhi in a group trip with PhD supervisor in April 2022 therefore is familiar with the context.</p>
<p>10. Work Pattern <i>Time and location e.g. shift work, work at night, working day (including lunch breaks and rest breaks), personal time and down time.</i></p> <p>Standard work pattern:</p> <ul style="list-style-type: none"> • Breakfast • Work • Lunch • Work • Dinner 	<p>Researchers should be working standard hours (approximately 9am-5pm), no night shifts will be done, and long hours will be avoided.</p> <p>This will reduce the chance of lack of sleep and exhaustion negatively affecting the data collection.</p> <p>When possible, all researchers should be able to take the weekend off for personal travel/down time in order to recuperate.</p>
<p>11. Permissions Required <i>Contact details, visas, and letters of permission, restrictions and other details of permissions.</i></p> <p>Business visas required for travel</p>	<ul style="list-style-type: none"> • Business visa is in place. • Business Cards will be taken as recommended by the Embassy to show formal affiliation to our home institutions (University of Leeds)
<p>12. Other Specific Risk Assessments <i>E.g. COSHH, Manual Handling, Lone Working if so what is identified in these assessments? Are there training requirements? (Cross reference where appropriate).</i></p> <p>Lone-working</p>	<p>During the trip, several researchers may undertake individual day-trips to different parts of the city. In this event, they will follow the listed procedures as specified by the lone-working policy guidance:</p> <ul style="list-style-type: none"> • Formal permission from supervisors to work alone • The work is classified as low risk • Supervisors will be aware of work hours, and will be checked in with regularly • Competency to work alone, and ability to use any software I need for the duration of the trip • A mobile phone will always be on and charged (a charger and a portable charger shall be carried to ensure the phone has battery in order for others to check in with us, and for us to check in with others).
<p>13. Health Questionnaire Completed <i>Is it required and has it been completed, who by and where is it recorded?</i></p>	<p>Health questionnaires have been filled out by the team, and where required GP proof has been given to back up these responses.</p>
<p>14. Health Surveillance Required <i>Is it required and has it been completed, who by and recorded? Referral to Occupational Health for staff required? (Student Medical Practice for students).</i></p> <p>There should be no reason to come into contact with the following substances that would cause concern.</p>	<p>N/A</p>

<ul style="list-style-type: none"> • Specified biological agents (human or transmissible animal pathogens "zoonoses"). • Carcinogens. • Toxic chemicals (with both short term acute and long term "chronic" effects). • Allergenic substances (some wood dusts, paint vapours, lubricants and animal fur). • Radioactive chemicals. 	
<p>15. Vaccinations Required <i>Obtained and certificated where applicable.</i></p>	<p>Provided by University's Occupational Health Team: Rabies, Hep A, Typhoid, diphtheria, tetanus and polio</p>
<p>Suggested: Hepatitis A, Hepatitis B, Tetanus, Polio, Typhoid, Cholera, Yellow Fever, Japanese Encephalitis, Rabies, Anti-Malaria Medication</p>	<p>Researcher has been in contact with her GP to provide their medical and vaccination history, and are currently in the process of being booked in for the required vaccines by the Occupational Health Team.</p> <p>In addition to vaccinations, anti-malaria medication is needed for the duration of this trip:</p> <ul style="list-style-type: none"> - Atovaquone/Proguanil (Malarone) – (AntiMalarial) <ul style="list-style-type: none"> - This is needed as according to World Health Organization (WHO), India contributes 77% of the total malaria cases in Southeast Asia. - Respective PhD budgets will be used to pay for Malarone (the more expensive option) due to its prevalence of fewer side common effects, which is needed to ensure data collection time is not lost.)
<p>16. First Aid Provision <i>Requirement for first aid or specialist first aid equipment, access to medical equipment and hospitals.</i></p>	<p>The researcher will carry a small first aid kit.</p>
<p>No Specialist Equipment is needed</p>	<p>Research will be in the capital city of New Delhi, and therefore have good connections to available hospitals if needed.</p>
Additional Supporting Information	
<p>17. Pre-departure Briefing <i>Carried out and attended.</i></p> <p><i>The Specifics of the briefing are to be decided upon 1 month before flying out. The briefing itself will happen 2 days before the flight, with most important reminders recapped in the airport when waiting for flights.</i></p>	<p>A pre-departure briefing consisting of:</p> <ul style="list-style-type: none"> - Recapping the trip Itinerary - Hazards and associated control mentioned here <ul style="list-style-type: none"> - Especially food, hygiene, and climate related diseases (Dehydration, heat stroke etc) - Contingency and Emergency Plans - FCO Advice - Appropriate dress / Cultural differences
<p>18. Training <i>Identify level and extent of information; instruction and training required consider experience of workers, details of relevant training.</i></p>	<p>Researcher is aware of operating procedures of the University and of how to implement the emergency plan.</p>

<p>19. FCO Advice <i>Where travel may be against all travel and all but essential travel, refer to the Procedure for travel against FCO advice.</i></p> <p><i>Include current FCO advice for travel to the country / area where applicable.</i></p>	<p>The FCO does not currently have any restrictions that would prohibit travel to India from the UK.</p> <p>Within India, it advises against travel to the Pakistan border, as well as the state of Jammu and Kashmir, and areas including Pahalgam, Gulmarg and Sonamarg, the city of Srinagar and the Jammu-Srinagar national highway. This trip is not planning on going to these areas (or near them), so there is no danger of going against FCO advice.</p>
<p>20. Supervision and Communication <i>Will you be Lone Working? Type Yes or No.</i> <i>Please provide further details including controls, arrangements and levels of supervision</i></p> <p><i>Identify level of supervision required e.g. full time, direct supervision or indirect supervision. Also names of people supervising, their specialist responsibility, qualification, training, in-house training and previous experience; also identify those they are supervising.</i></p> <p><i>Specify arrangements for communication e.g., periodic telephone/email contact.</i></p> <p>Yes</p>	<p>Supervision:</p> <ul style="list-style-type: none"> • Prof Barbara Evans available by whats app, email and telephone. • Further formal support from Jayna Collective, Empower Project and Newcastle University. • Information support from friends and acquaintances in Delhi from previous trip.
<p>21. Emergency/ Contingency Plans <i>Consider and identify the plans you may need to have in place in the event of emergency e.g. medical emergency, Accident/incident reporting. Include Emergency Contact details as applicable to country visited.</i></p>	<p>Upon entering the country we will purchase local SIM cards so that our phones are able to access the data and call networks so we are able to contact people freely upon need.</p> <p>Important Contact Details:</p> <p>Non-emergency Number: 0113 343 5494/5 Emergency Number: 0113 3432222 Emergency Medical assistance number: 01243 621066 CURE Team +91 011-40535541</p> <p>India Specific Emergency Numbers: Police – 100, Fire – 101, Ambulance – 102 Air Ambulance - 9540161344</p>

	<p>Emergency Procedures: In the event of an incident, the following procedure will be followed:</p> <ul style="list-style-type: none"> • The proper emergency services will be called (police, fire, ambulance - if needed) • The First aider (if present) will address the situation and perform any needed tasks (e.g. bandaging) • The Medical/Travel insurance team will be notified so that we are able to know what we can access • Following these steps, all incidents will be reported back to health and safety services, other researchers on the trip (if not present) and supervisory team of the injured (if unable to notify the team themselves)
<p>22. Other Controls <i>E.g. background checks for site visits, embassy registration.</i></p>	N/A
N/A	
<p>23. Identify Other Persons at Risk <i>This may include more individuals than the fieldwork participants e.g. other employees of partner organisations.</i></p> <p><i>Copy of other Organisation's risk assessment attached?</i></p>	No risks to partners.
<p>24. Additional Information <i>Please use this section to record any additional information not covered by the other sections.</i></p> <p><i>Contact details for Embassies / Consulates.</i></p> <p><i>Information and instruction received, waste, PPE, clothing and footwear, accommodation, security, increased lighting, access to potable water etc.</i></p> <p>Click or tap here to enter text.</p>	<p><i>Contact details for Embassies / Consulates</i></p> <p>British Consulate: Tel: +91 11 2419 2100; Email: web.newdelhi@fco.gov.uk; Address: Shantipath, Chanakyapuri, New Delhi, Delhi 110021, India</p> <p>Formal PPE will be required for environmental sampling. Additionally, a sturdy pair of shoes (e.g. walking boots) to use as protective footwear if the need arises.</p> <p>As India is a tropical country with dramatic weather changes, I will carry waterproofs as well as sun cream and sun hats to ensure that we are prepared for whatever the day may bring.</p> <p>The accommodation being sorted will be a guesthouse with secure entry which is the same place stayed at last time. Upon arrival, the accommodation must be checked to ensure checks on fire safety, personal security, general safety, and emergency exits are complete before agreeing to stay - if accommodation fails these basic checks and an informed decision is made that identifies the accommodation as unsuitable, the fieldwork activity officer must change the booking.</p> <p>Covid-19 guidance in Delhi will be adhered to. Face masks will be worn where required and social distancing will be followed where it is recommended. The researcher will have Lateral</p>

	Flow Tests with them to regularly test during their stay in India. The researcher is fully vaccinated against Covid-19 and has recovered from Covid-19 recently.

Residual Risk <i>Is the residual risk acceptable with the identified controls?</i>	Yes	The residual risks are acceptable given the given controls
	No	N/A

Assessment carried out by	Name:	Jemma Phillips	
	Signature:		
	Date:	19/08/22	
	Name:		
	Signature:		
	Date:	01.03.2022	
Names of person(s) involved in Fieldwork <i>N.B: This can take the form of a signed class register when large group work</i>	Name:	Jemma Phillips	
	Signature:		
	Date:	19/08/22	

Academic Leader/ Academic Tutor / Line Manager		
	Name:	Barbara Evans
	Signature:	
Date:	11.03.22	

Where Fieldwork Activities and Travel Plans are subject to FCO Advice, approval must be obtained from the Head of School or Service, the relevant UEG member and the University Deputy Secretary (Secretariat).

The Data collection does not take place in an area that is against current advice, therefore the following section is irrelevant for this fieldwork.

Head of School / Service	Name:	N/A
	Signature:	N/A
	Date:	N/A
Member of UEG	Name:	N/A
	Signature:	N/A
	Date:	N/A
University Deputy Secretary	Name:	N/A
	Signature:	N/A
	Date:	N/A

Appendix 3: Risk Assessment



UNIVERSITY OF LEEDS
Fieldwork Risk Assessment Form.

This form must be used for all Fieldwork Activities including Fieldwork Activities and Travel Plans subject to Foreign and Commonwealth Office Travel Advice.

It may not be necessary to complete every section – where not applicable n/a, please indicate why.

Fieldwork Project Details	
Faculty School/ Service	School of Civil Engineering, Faculty of Engineering and Physical Sciences
Location of Fieldwork Is the location subject to Foreign and Commonwealth Office (FCO) Travel Advice? No. <i>If Y, complete the FCO Advice section and refer to the Procedure for travel against FCO advice</i>	Delhi, India
Brief description of Fieldwork activity and purpose <i>(Include country, location, area, and grid reference and map where applicable).</i>	PhD researcher Jemma Phillips will be travelling to Delhi, India. This work will be in collaboration with Jayna Collective LLP, Newcastle University, Empower Project, the Water Security Hub and the Centre for Urban and Regional Excellence (CURE) organisation. The researcher will be carrying out fieldwork related to her PhD project in the Barapullah sub basin area. Activities will include: walking around and observing living conditions in the slums/ informal settlements of the Barapullah sub basin area; observations of sanitation conditions in the slum/informal environment, interacting with local communities and working alongside local staff in order to collect environmental samples, observations, focus group discussions and key informant interviews.
Fieldwork itinerary <i>E.g. flight details, hotel address, dates of travel, mode of transport etc.</i>	<p><i>Neither Flights nor Hotels have been booked, and will not be booked until final approval of Ethics and Risk Assessment due to the ever-changing global coronavirus situation; as of 29th September 2020, the University's travel insurance will not cover cancellation or curtailment of travel as a consequence of Covid-19. These are therefore approximations of what I will use, and what my current intention is. This risk assessment will be updated as I continue so it holds the latest information.</i></p> <p><i>Travel is likely to be the 11th October 2023 – 30th October 2023.</i></p>

<p>University Travel Insurance Policy Information</p>	<p>Aviva Business Travel Policy Number 100003814GPA http://www.leeds.ac.uk/insurance/travel.htm Advisory Note: Check that the country you intend to travel to is covered by the University travel insurance before you go. Take a copy of the Summary of Cover with you which includes Emergency Contact Numbers. https://www.leeds.ac.uk/insurance/documents/summary_of_cover.pdf</p>
<p>Organiser Details</p>	<p>Contact details <i>Including Name, Email, Telephone Number.</i></p>
<p>Fieldwork Activity Organiser / Course Leader</p>	<p>Barbara Evans B.E.Evans@leeds.ac.uk +44 1625 263363; 07747196126</p>
<p>Departmental Co-ordinator</p>	<p>Timothy Nadin T.J.Nadin@leeds.ac.uk 0113-34-37330</p>
<p>Nature of visit <i>Size of Group, lone working, staff, postgraduate, undergraduate.</i></p>	<p>PhD researcher Jemma Phillips will be spending up to 2 weeks in Delhi to carry out fieldwork in the Barapullah sub basin area and work alongside local staff from Jayna Collective and in collaboration with staff from Newcastle University on the Water Security Hub.</p>
<p>Participant Details <i>Attach information as separate list if required.</i></p>	<p>Contact details <i>Name, Address, email, telephone, gender and next of kin contact details</i></p> <p>Jemma Phillips 7 Falling Foss Way, Bramhope, LS16 9FP cn16jfp@leeds.ac.uk 07704442456 Female</p> <p>Next of Kin: Arinze Phillips (husband) 07477193761 arinzetobias@hotmail.com</p>

HAZARD IDENTIFICATION

Identify all hazards specific to fieldwork activities and travel plans, describe existing control measures and identify any further measures required.

HAZARD(S) IDENTIFIED

CONTROL MEASURES

(e.g. alternative work methods, training, supervision, protective equipment)

1. Nature of the site

School, college, university, remote area, laboratory, office, workshop, construction site, farm, etc.

- General:
 - Offices
 - Informal Settlements
- Nearest local contact point - accommodation.
- System for contact appropriate to the location (and contact times)

Research will take place in slum communities, meetings in professional and academic offices.

The key local contact points will be the Jayna Collective LLP team and the Delhi School of Planning and Architecture (SPA) team who are working with the Water Security Hub.

The researcher will have a local SIM card in her phone that ensure she is reachable at all times.

2. Environmental conditions

Extremes of temperature, climate, altitude, exposure to sunlight, potential weather conditions, tidal conditions etc.

As Delhi is a humid subtropical region, the following environmental conditions will need to be considered:

- Climate Related Risks
- Poor air quality (smog)
- Access to adequate supply of food and potable drinking water

Climate Related Risks	Temperature extremes (up to 40°C) <ul style="list-style-type: none"> ● Sunburn ● Sunstroke ● Dehydration 	Drinking water, avoiding mid-day direct sun, carrying a sunhat, finding shade whenever possible, being active at the beginning and end of the day before the sun reaches peak warmth, not over-exercising / over-exerting, wearing light / loose clothing
	<ul style="list-style-type: none"> ● Flooding 	Looking at flood maps to understand riskier areas, having accommodation above the ground floor if possible
Poor Air Quality	<ul style="list-style-type: none"> ● Humidity ● Smog 	H: Having lots of water, shade and cool air to keep body temperatures low S: Wearing facemasks when in congested smoggy areas
Access to Water and food		<ul style="list-style-type: none"> ● Ensuring adequate food and potable

			water (especially in slum / informal areas)
3. Site-specific conditions <i>E.g. cliffs, scree, bogs, featureless landscapes, local endemic infectious diseases, zoonoses etc.</i>			
<ul style="list-style-type: none"> ● Accommodation ● Slum/ Informal Neighbourhoods ● CURE office ● Government offices and municipalities in Delhi and Chennai ● Communal and public toilets ● Yamuna River ● Urban agricultural sites in Delhi ● Food markets in Delhi ● Food wholesalers in Delhi 	<i>Location</i>	<i>Risk</i>	<i>Measures</i>
	Accommodation	<ul style="list-style-type: none"> ● Fire safety ● Personal security ● General safety of structure and facilities 	The researcher will familiarise herself with the fire safety protocol and emergency escape routes in the accommodation. All personal valuable belongings will be locked away in a safe. All hazards kept to a minimum by ensuring any faults/issues are reported to hosts.
	Slum/ Informal Neighbourhoods	<ul style="list-style-type: none"> ● Heavy traffic flow ● Safety/ security concerns of physical/sexual violence or abuse ● Stray dogs 	Being in a group where possible, only travelling alone in daylight, having rabies vaccination
	Office environments	<ul style="list-style-type: none"> ● Office - related hazards 	Wearing glasses to prevent eye strain (if appropriate), watching for potentially dangerous/ slippery surfaces, familiarise fire escape routes upon entering new buildings

	<p>Open water such as rivers and drains</p> <ul style="list-style-type: none"> • Flooding • High levels of pollution • Risk of drowning • Infection from contact to water bodies <p>Remaining at least 2m from the banks of the river at all time, no swimming, vaccinations for water related diseases. Wearing PPE for sampling activities.</p> <hr/> <ul style="list-style-type: none"> • •
<p>4. Process <i>Operating machinery, electrical equipment, driving vehicles, handling or working with animals etc.</i></p>	<p>There are no particularly high-risk activities (e.g. operating machinery, electrical equipment, driving vehicles,</p>

<ul style="list-style-type: none"> ● Sampling at sites of interest ● Communicating/interacting with local people ● Communicating/interacting with Jayna Collective staff members 	<p>handling or working with animals) that will be carried out for the duration of the trip. Minor process risks include:</p> <p>Informal observation and communication:</p> <ul style="list-style-type: none"> ● Listening carefully and asking to repeat items if unclear as to reduce misinterpretation conversation/actions ● Getting assistance from a local interpreter to reduce misunderstanding/misinterpretation
<p>5. Transport <i>Mode of transport while on site, to and from site, carriage of dangerous goods etc.</i></p> <p>Travel to and from Delhi: Flights from Manchester to Delhi</p> <p>Transport during time in Delhi: Car/taxi: local driver to transport the group to sites of interest</p>	<p>International Travel:</p> <ul style="list-style-type: none"> ● Prioritising reputable airlines <p>Internal Travel:</p> <ul style="list-style-type: none"> ● Arrange for private local driver/s to transportation around Delhi
<p>6. Equipment <i>Manual handling risks, operation of machinery, tools, use of specialist equipment etc.</i></p>	<p>Laboratory equipment may be heavy and therefore manual handling procedures will be adhered to and supporting equipment such as trolleys shall be used as much as possible. Full PPE will be used and only trained personal will enter labs and use any lab equipment.</p>
<p>7. Violence <i>Potential for violence in location, political and social unrest; against participants, lone working, interviewing (previous incidents etc.)</i></p> <p>PhD researchers could be carrying out some lone work- this could pose risk of violence, particularly sexual violence/ abuse against women</p> <p>Mugging in crowded spaces such as food markets and slum/informal neighbourhoods</p> <p>Conflict/hostility from local people regarding observations and interaction</p>	<p>When working alone, work should be carried out in daylight hours and in public places to minimise risks of being alone in the dark. Researchers should also always use private car hire where possible to reduce the need to use rickshaws and other less safe modes of transport.</p> <p>Researchers should try to always use secure bags with several fastenings to keep belongings and valuables safe (e.g. no tote bags).</p> <p>Researchers need to use common sense whilst documenting observational data to ensure that they do not encroach on others' privacy (e.g. not taking direct photos of people without consent).</p>
<p>8. Cultural Considerations <i>Specific to the activity or participants.</i></p>	

<p>Maintaining appropriate attire and behaviour in traditional neighbourhoods</p> <p>Religious and dietary considerations</p>	<p>Will ensure that general attire is appropriate (e.g. no short skirts), to make sure that we are culturally sensitive, but also weather appropriate (e.g. ensuring we have sunhats to minimise sunburn risks).</p> <p>Will need to be aware of the potential risks associated with religious considerations as the researcher is Christian and the majority religions are Hindu and Islam. The researcher will be respectful at all times.</p>
<p>9. Individual(s) <i>Medical condition(s), young, inexperienced, disabilities etc.</i></p> <ul style="list-style-type: none"> • Medical conditions • No disabilities • Inexperienced Researcher 	<p>Medical conditions None.</p> <p>Researcher has been to Delhi in a group trip with PhD supervisor in April 2022 and for data collection alone in November 2022, therefore is familiar with the context.</p>
<p>10. Work Pattern <i>Time and location e.g. shift work, work at night, working day (including lunch breaks and rest breaks), personal time and down time.</i></p> <p>Standard work pattern:</p> <ul style="list-style-type: none"> • Breakfast • Work • Lunch • Work • Dinner 	<p>Researchers should be working standard hours (approximately 9am-5pm), no night shifts will be done, and long hours will be avoided.</p> <p>This will reduce the chance of lack of sleep and exhaustion negatively affecting the data collection.</p> <p>When possible, all researchers should be able to take the weekend off for personal travel/down time in order to recuperate.</p>
<p>11. Permissions Required <i>Contact details, visas, and letters of permission, restrictions and other details of permissions.</i></p> <p>Business visas required for travel</p>	<ul style="list-style-type: none"> • Business visa is in place. • Business Cards will be taken as recommended by the Embassy to show formal affiliation to our home institutions (University of Leeds)
<p>12. Other Specific Risk Assessments <i>E.g. COSHH, Manual Handling, Lone Working if so what is identified in these assessments? Are there training requirements? (Cross reference where appropriate).</i></p> <p>Lone-working</p>	<p>During the trip, researchers may undertake individual day-trips to different parts of the city. In this event, they will follow the listed procedures as specified by the lone-working policy guidance:</p> <ul style="list-style-type: none"> • Formal permission from supervisors to work alone • The work is classified as low risk • Supervisors will be aware of work hours, and will be checked in with regularly • Competency to work alone, and ability to use any software I need for the duration of the trip • A mobile phone will always be on and charged (a charger and a portable charger shall be carried to

	ensure the phone has battery in order for others to check in with us, and for us to check in with others).
13. Health Questionnaire Completed <i>Is it required and has it been completed, who by and where is it recorded?</i>	Health questionnaires have been filled out by the team, and where required GP proof has been given to back up these responses. Occupational Health team are satisfied with all vaccinations administered.
14. Health Surveillance Required <i>Is it required and has it been completed, who by and recorded? Referral to Occupational Health for staff required? (Student Medical Practice for students).</i> There should be no reason to come into contact with the following substances that would cause concern. <ul style="list-style-type: none"> • Specified biological agents (human or transmissible animal pathogens "zoonoses"). • Carcinogens. • Toxic chemicals (with both short term acute and long term "chronic" effects). • Allergenic substances (some wood dusts, paint vapours, lubricants and animal fur). • Radioactive chemicals. 	N/A
15. Vaccinations Required <i>Obtained and certificated where applicable.</i>	Provided by University's Occupational Health Team: Rabies, Hep A, Typhoid, diphtheria, tetanus and polio
Suggested: Hepatitis A, Hepatitis B, Tetanus, Polio, Typhoid, Cholera, Yellow Fever, Japanese Encephalitis, Rabies, Anti-Malaria Medication	<p>Researcher has been in contact with her GP to provide their medical and vaccination history, and are currently in the process of being booked in for the required vaccines by the Occupational Health Team.</p> <p>In addition to vaccinations, anti-malaria medication is needed for the duration of this trip:</p> <ul style="list-style-type: none"> - Atovaquone/Proguanil (Malarone) – (AntiMalarial) <ul style="list-style-type: none"> - This is needed as according to World Health Organization (WHO), India contributes 77% of the total malaria cases in Southeast Asia. - Respective PhD budgets will be used to pay for Malarone (the more expensive option) due to its prevalence of fewer side common effects, which is needed to ensure data collection time is not lost.)
16. First Aid Provision <i>Requirement for first aid or specialist first aid equipment, access to medical equipment and hospitals.</i>	The researcher will carry a small first aid kit.
No Specialist Equipment is needed	Research will be in the capital city of New Delhi, and therefore have good connections to available hospitals if needed.

Additional Supporting Information	
<p>17. Pre-departure Briefing <i>Carried out and attended.</i></p> <p><i>The Specifics of the briefing are to be decided upon 1 month before flying out. The briefing itself will happen 2 days before the flight, with most important reminders recapped in the airport when waiting for flights.</i></p>	<p>A pre-departure briefing consisting of:</p> <ul style="list-style-type: none"> - Recapping the trip Itinerary - Hazards and associated control mentioned here <ul style="list-style-type: none"> - Especially food, hygiene, and climate related diseases (Dehydration, heat stroke etc) - Contingency and Emergency Plans - FCO Advice - Appropriate dress / Cultural differences
<p>18. Training <i>Identify level and extent of information; instruction and training required consider experience of workers, details of relevant training.</i></p>	<p>Researcher is aware of operating procedures of the University and of how to implement the emergency plan.</p>
<p>19. FCO Advice <i>Where travel may be against all travel and all but essential travel, refer to the Procedure for travel against FCO advice.</i></p> <p><i>Include current FCO advice for travel to the country / area where applicable.</i></p>	<p>The FCO does not currently have any restrictions that would prohibit travel to India from the UK.</p> <p>Within India, it advises against travel to the Pakistan border, as well as the state of Jammu and Kashmir, and areas including Pahalgam, Gulmarg and Sonamarg, the city of Srinagar and the Jammu-Srinagar national highway. This trip is not planning on going to these areas (or near them), so there is no danger of going against FCO advice.</p>
<p>20. Supervision and Communication <i>Will you be Lone Working? Type Yes or No.</i></p> <p><i>Please provide further details including controls, arrangements and levels of supervision</i></p> <p><i>Identify level of supervision required e.g. full time, direct supervision or indirect supervision. Also names of people supervising, their specialist responsibility, qualification, training, in-house training and previous experience; also identify those they are supervising.</i></p> <p><i>Specify arrangements for communication e.g., periodic telephone/email contact.</i></p>	<p>Supervision:</p> <ul style="list-style-type: none"> ● Prof Barbara Evans, Dr Paul Hunter, Dr Marco Felipe-King available by whats app, email and telephone. ● Further formal support from Jayna Collective and the Water Security Hub. ● Information support from friends and acquaintances in Delhi from previous trip.

Yes	
<p>21. Emergency/ Contingency Plans <i>Consider and identify the plans you may need to have in place in the event of emergency e.g. medical emergency. Accident/ incident reporting. Include Emergency Contact details as applicable to country visited.</i></p>	<p>Upon entering the country we will purchase local SIM cards so that our phones are able to access the data and call networks so we are able to contact people freely upon need.</p> <p>Important Contact Details: Non-emergency Number: 0113 343 5494/5 Emergency Number: 0113 3432222 Emergency Medical assistance number: 01243 621066 CURE Team +91 011-40535541</p> <p>India Specific Emergency Numbers: Police – 100, Fire – 101, Ambulance – 102 Air Ambulance - 9540161344</p> <p>Emergency Procedures: In the event of an incident, the following procedure will be followed:</p> <ul style="list-style-type: none"> • The proper emergency services will be called (police, fire, ambulance - if needed) • The First aider (if present) will address the situation and perform any needed tasks (e.g. bandaging) • The Medical/Travel insurance team will be notified so that we are able to know what we can access • Following these steps, all incidents will be reported back to health and safety services, other researchers on the trip (if not present) and supervisory team of the injured (if unable to notify the team themselves)
<p>22. Other Controls <i>E.g. background checks for site visits, embassy registration.</i></p>	N/A
N/A	
<p>23. Identify Other Persons at Risk <i>This may include more individuals than the fieldwork participants e.g. other employees of partner organisations.</i></p> <p><i>Copy of other Organisation's risk assessment attached?</i></p>	No risks to partners.
<p>24. Additional Information <i>Please use this section to record any additional information not covered by the other sections.</i></p> <p><i>Contact details for Embassies / Consulates.</i></p> <p><i>Information and instruction received, waste, PPE, clothing and footwear, accommodation, security, increased lighting, access to potable water etc.</i></p>	<p>Contact details for Embassies / Consulates</p> <p>British Consulate: Tel: +91 11 2419 2100; Email: web.newdelhi@fco.gov.uk; Address: Shantipath, Chanakyapuri, New Delhi, Delhi 110021, India</p> <p>Formal PPE will be required for environmental sampling. Additionally, a sturdy pair of shoes (e.g. walking boots) to use as protective footwear if the need arises.</p>

Click or tap here to enter text.	<p>As India is a tropical country with dramatic weather changes, I will carry waterproofs as well as sun cream and sun hats to ensure that we are prepared for whatever the day may bring.</p> <p>The accommodation being sorted will be a guesthouse with secure entry. Upon arrival, the accommodation must be checked to ensure checks on fire safety, personal security, general safety, and emergency exits are complete before agreeing to stay - if accommodation fails these basic checks and an informed decision is made that identifies the accommodation as unsuitable, the fieldwork activity officer must change the booking.</p> <p>Covid-19 guidance in Delhi will be adhered to. Face masks will be worn where required and social distancing will be followed where it is recommended. The researcher will have Lateral Flow Tests with them to regularly test during their stay in India. The researcher is fully vaccinated against Covid-19 and has recovered from Covid-19 recently.</p>
----------------------------------	--

Residual Risk <i>Is the residual risk acceptable with the identified controls?</i>	Yes	The residual risks are acceptable given the given controls
	No	N/A

Assessment carried out by	Name:	Jemma Phillips
	Signature:	
	Date:	19/08/22
	Name:	
	Signature:	
	Date:	01.03.2022
Names of person(s) involved in Fieldwork <i>N.B: This can take the form of a signed class register when large group work</i>	Name:	Jemma Phillips
	Signature:	
	Date:	19/08/22

11.5 Appendix E: Microbial Sampling Protocols

Environmental Sampling Plans: Edited from SaniPath Protocols

Summary

These protocols provide instruction for sterile collection of drinking water, surface water, open drains, flooded areas, produce (vegetables) from markets that are eaten raw, street food from vendors, solid waste in the community, swabs of latrine surfaces, and soil. Methods are designed to collect samples for microbial analysis to detect possible faecal contamination in these environments.

Sample Collection of Drinking Water (Municipal Water, Other Drinking Water) or Bathing Water

The following materials and equipment are needed:

1. Gloves
2. Ice chest with frozen ice packs
3. Sterile 100ml Whirl-Pak bags with sodium thiosulfate for chlorinated water samples
4. Sterile 100ml Whirl-Pak bags for non-chlorinated water samples
5. Cotton swabs
6. 70 % ethanol solution
7. Android device
8. Extra paper forms
9. Pen
10. Permanent Marker

Preparation for collecting piped drinking water or bathing water sample

The day before fieldwork, make sure all sampling materials are clean, sterile, and of adequate quantity and quality. Generate unique sample identification codes (ID) that would be used for Whirl Pak bags of samples collected. Prepare one label for each unique sample ID using a permanent marker.

Sampling protocol for drinking water

1. Take a photo of the sampling location using the ONA Sample Picture form and log location.
2. Using a permanent marker, label clean, sterile 100mL Whirl-Pak bag with the Sample ID.
3. Put on gloves and spray your hands with alcohol.
4. Spray the cotton wool with 70% ethanol. First sanitize the interior of the mouth to the water source (this may be a tap, pump, or dispenser), rubbing the cotton wool in a circular motion around the interior about half a finger deep. Fold the cotton wool so that a new surface is available and

spray the cotton wool with more alcohol. Wipe the exterior of the drinking water source with the sprayed cotton wool making sure to clean both the tip and outside the tap, pump, or dispenser.

5. Make sure there are tablets of sodium thiosulfate in the 100ml Whirl-Pak bags for all municipal piped drinking water collection samples. Sodium thiosulfate tablets are not needed in the Whirl-Pak bags for non-chlorinated drinking water or bathing water samples.

6. Let the water run for 30 seconds. After the 30 seconds, open the labelled Whirl-Pak bag by pulling gently on the tabs on the side of the bag without touching the mouth or inside of the bag. Do not touch the mouth of tap with the bag or your hands. Fill the Whirl-Pak bag carefully through the central opening to above the 100mL mark. We will need more slightly more than 110 ml per sample (fill the sample to the second line).

7. Close the Whirl-Pak bag by carefully and quickly rotate the bag, without spilling the sampled water, and then twisting the wire tabs together. Make sure that the bag is completely closed and not leaking (turn it upside down to check).

8. Confirm that the ID is in place and carefully place the Whirl-Pak bag into the ice chest with frozen ice packs.

9. Transport samples to the lab within 6 hours of collection and deliver samples to one of the designated laboratory personnel.

10. Immediately transfer the sample(s) into a 4°C refrigerator until they are ready to be analysed. Samples should be stored no longer than 6 hours before analysis.

Sample Collection of Open Drain, Surface water and Flood Water

The materials and equipment needed to collect samples from open drains are as follows:

1. Gloves
2. Ice chest with frozen ice packs
3. Sterile 100ml Whirl-Pak bags
4. 70% ethanol
5. 90% ethanol
6. Android Device
7. Sterile ladle (soup spoon)/ bucket with rope
8. Pen
9. Permanent Marker
10. Extra Paper Forms
11. Lighter

Preparation for fieldwork

The day before fieldwork make sure all sampling materials are clean, sterile and of adequate quantity and quality. Generate unique sample identification codes (IDs) for labelling Whirl-Pak bags of samples collected.

Sampling protocol for open drain and flood water

1. Take a photo of the sampling location using the ONA Sample Picture form and log location.
2. Using a permanent marker, label clean, sterile 100mL Whirl-Pak bag with the Sample ID.
3. Put on clean gloves; spray them with 70% ethanol.
4. Sterilize the ladle/bucket on a rope by spraying with 70% ethanol and wiping with a clean paper towel.
5. Collect the water sample using the sterile ladle/bucket on a rope. If the source is shallow and the bailer cannot be submerged, turn the hand bailer/bucket horizontally to fill, but take care to not scoop up sediment or trash in the water.
6. Open the labelled Whirl Pak bag by pulling gently on the tabs on the side of the bag without touching the mouth or inside of the bag.
7. Carefully pour the drain water sample from the bailer into the 100mL labelled Whirl-Pak bag.
8. Close the Whirl-Pak bag by carefully and quickly rotating the bag, without spilling the sample, and then twisting the wire tabs together. Make sure that the bag is completely closed and not leaking (turn it upside down to check).
9. Confirm that the label is still affixed to the bag. Place the 100mL Whirl-Pak in the cooler with ice packs.
10. Clean the ladle/bucket by spraying it with 90% ethanol and then igniting the ethanol with a lighter. Take care to do this well away from any flammable liquids or dry environments that could catch on fire (like grass). Keep hands well away from the mouth of the ladle/bucket.
11. Transport samples to the lab within 6 hours of collection and deliver samples to one of the designated laboratory personnel.
12. Immediately transfer the sample(s) into a 4°C refrigerator until they are ready to be analysed. Samples should be stored no longer than 6 hours before analysis.

Sample Collection of Produce (Raw Vegetables)

The materials and equipment needed to collect produce samples are below:

1. Gloves
2. Ice chest with frozen ice packs
3. 70% ethanol
4. Sterile 2 litre Whirl-Pak bags
5. Android device.

6. Pen
7. Permanent Marker
8. Extra Paper Forms
9. Money for purchasing produce

Preparation for fieldwork

The day before fieldwork, make sure all sampling materials are clean, sterile and of adequate quantity and quality. Generate unique sample identification codes (IDs) for labelling Whirl-Pak bags of samples collected.

Sampling protocol for produce (fruits and vegetables)

1. Take a photo of the sampling location using the ONA Sample Picture form and log location.
2. Using a permanent marker, label clean, sterile 2L Whirl-Pak bag with the Sample ID.
3. Put on gloves and spray your hands with 70% ethanol.
4. Open the labelled Whirl-Pak bag by gently pulling out the tabs of the side of the bag without touching the mouth or inside of the bag.
5. If you are selecting produce at a market vendor's stall, carefully open the Whirl-Pak bags without touching the mouth of the bag. Ask the vendor to place the produce in the bag. Only collect as much produce as you think one person may consume during a single meal (i.e. one serving). Quickly close bag.
6. Confirm that the label is still affixed to the bag. Place the Whirl-Pak bag in the ice chest with ice packs.
7. Transport samples to the lab within 6 hours of collection and deliver samples to one of the designated laboratory personnel.
8. Immediately transfer the sample(s) into a 4°C refrigerator until they are ready to be analysed. Samples should be stored no longer than 6 hours before analysis.

Sample Collection of Solid Waste

The materials and equipment needed to collect produce samples are below:

1. Gloves
2. Ice chest with frozen ice packs
3. 70% ethanol
4. Sterile 2 litre Whirl-Pak bags
5. Android device
6. Pen

7. Permanent Marker

8. Extra Paper Forms

Preparation for fieldwork

The day before fieldwork, make sure all sampling materials are clean, sterile and of adequate quantity and quality. Generate unique sample identification codes (IDs) for labelling Whirl-Pak bags of samples collected.

Sampling protocol for Solid Waste

1. Take a photo of the sampling location using the ONA Sample Picture form and log location.
2. Using a permanent marker, label clean, sterile 2L Whirl-Pak bag with the Sample ID.
3. Put on gloves and spray your hands with 70% ethanol.
4. Open the labelled Whirl-Pak bag by gently pulling out the tabs of the side of the bag without touching the mouth or inside of the bag.
5. If you are selecting produce at a market vendor's stall, carefully open the Whirl-Pak bags without touching the mouth of the bag. Place the solid waste in the bag. Quickly close bag.
6. Confirm that the label is still affixed to the bag. Place the Whirl-Pak bag in the ice chest with ice packs.
7. Transport samples to the lab within 6 hours of collection and deliver samples to one of the designated laboratory personnel.
8. Immediately transfer the sample(s) into a 4°C refrigerator until they are ready to be analysed. Samples should be stored no longer than 6 hours before analysis.

11.6 Appendix F: Household Survey Questions

28/09/2025, 10:35

Household Survey

Household Survey

* Indicates required question

1. Do you consent to participate in this study? *

क्या आप सर्वे के लिए हमें भरते हैं?

Mark only one oval.

Yes

No

General Questions

2. Name of the surveyor *

⌵ Dropdown

Mark only one oval.

Kamla Sharma

Manju Upreti

Deepak Joshi

3. Name of the settlement *

⌵ Dropdown

Mark only one oval.

Jagdamba Camp

Madrasi Camp

Andrews Ganj

Sanjay Colony, Okhla

4. Distance of the house from the main drain *

नाले से घर की दूरी

⌵ Dropdown

Mark only one oval.

- <50m
- 50-100m
- 100-150m
- 150-200m
- 200-250m
- >250m

5. Gender of respondent *

उत्तरदाता का लिंग

Mark only one oval.

- Male
- Female

6. Age of respondent *

7. Household type *

Mark only one oval.

- Single family home
- Joint family

8. How many people live in your home? *

आपके घर में कितने लोग रहते हैं?

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Household Survey

9. Do you have children between the ages of 0-5? *

आपके घर 0-5 साल के बच्चे हैं?

Mark only one oval.

Yes

No

10. Do you have children between the ages of 5-12? *

आपके घर 5-12 साल के बच्चे हैं?

Mark only one oval.

Yes

No

11. How many times in the past month did you go into the rivers, ponds, or lakes *
for any of these reasons?

पिछले एक महीने में आप किसी नदी, तालाब, या किसी नहर में गये हैं? (तेरने, डुबकी लगाने, कपडे धोने, फिशिंग, सोच आदि)

Mark only one oval.

More than 10 times

6 to 10 times

1 to 5 times

Never

Do not know

12. How many times in the past month did you go or come in close contact with the main drains? *

पिछले एक महीने में आप किसी गंदे नाले के संपर्क में आये हैं? (रोड पार करने के वक्त नाले के पानी में निकलना पड़ा हो, नाले में गिर गए हों, या सोच के लिए गए हों)

Mark only one oval.

- More than 10 times
- 6 to 10 times
- 1 to 5 times
- Never
- Do not know

13. How many times do you come into contact with floodwater during times of flooding? *

फ्लडिंग के समय में आप कितनी बार गंदे पानी के संपर्क में आये हैं? (घर में घुस गया हो, बरसात के दौरान गंदे पानी में निकले हों, कुछ उठाना पड़ा हो, घर के आगे की रोड की सफाई करनी पड़ी हो)

Mark only one oval.

- More than 10 times
- 6 to 10 times
- 1 to 5 times
- Never
- Do not know

14. How many days within the past week did you drink municipal water? *

आप हफ्ते में कितने दिन डीजेबी द्वारा प्राप्त पानी पीते हैं?

Mark only one oval.

- Every day
- 4 to 6 days
- 3 days or less
- Never
- Do not know

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Household Survey

15. Does your household regularly treat your household's water? *

क्या आप पानी को इस्तमाल करने से पहले उपचार करते हैं?

Mark only one oval.

- Yes
- No
- Do not know
- Not applicable / unable to collect information

16. How do you treat the water for drinking purpose? *

आप पीने के पानी का उपचार कैसे करते हैं?

Mark only one oval.

- boiling
- adding chlorine
- using a normal filter
- using a RO filter
- no treatment

17. How many times within the past week did you eat raw (uncooked) produce (Vegetables or Fruits)? *

पिछले हफ्ते आपने कितने बार कच्ची सब्जी या कच्चे फल खाये होंगे?

Mark only one oval.

- with every meal?
- at least 1 meal a day?
- Few days a week
- Never
- Do not know

21. How many times within the past week did you eat street food? *
- पिछले हफ्ते में आपने कितनी बार बहार ढाबे या ठेले से खाना मंगवाके या जाके खाया है?

Mark only one oval.

- every meal?
- at least 1 meal a day
- Few days a week
- Never
- Do not know

22. Do you have a personal toilet? *
- आपके घर शौचालय है?

Mark only one oval.

- Yes
- No Skip to question 24

Solid Waste

23. How many times total every week do you come into contact with solid waste? *
- आप हफ्ते में कितनी बार कूड़े के संपर्क में आये होंगे? (कूड़ा उठाया हो, कूड़े के बीच से निकलना पड़ा हो, घर की सफाई करते हुए कूड़े के संपर्क में आये हों, या बहार से कूड़ा आया हो जो आपने उठके डाला हो)

Mark only one oval.

- More than 10 times
- 6 to 10 times
- 1 to 5 times
- Never
- Do not know

Toilet Use

28/09/2025, 10:35

Household Survey

24. If no toilet at home, where do you go for defecation? *

अगर आपके घर शौचालय नहीं है तोह सोच के लिए कहाँ जाते हैं?

Mark only one oval.

- Public Toilet Skip to question 25
- Shared Toilet Skip to question 23
- Open field Skip to question 23

Public Toilet Use

25. How many times within the past week did you use public latrines in your neighborhood? *

पिछले हफ्ते में आप कितनी बार सुलभ शौचालय गए हैं?

Mark only one oval.

- More than 10 times Skip to question 23
- 6 to 10 times Skip to question 23
- 1 to 5 times Skip to question 23
- Never Skip to question 23
- Do not know Skip to question 23

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Google Forms

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11.7 Appendix G: Raw Foods Survey

28/09/2025, 10:38

Household Survey

18. Which of the following vegetables do you eat raw (uncooked)? *

आप इनमें से कौनसी सब्जिया कच्ची खाते हैं?

Check all that apply.

	Daily	Few times a week	Occasionally	Never
onion	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
garlic	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
tomato	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
carrot	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
beetroot (chukundar)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
radish (mooli)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
spinach (palak)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
corn	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
cabbage	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
cucumber	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
sprouts	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
collard greens (saag)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
chilies	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
coriander (dhania)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
cauliflower (foolgobhi)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
mint (pudina)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

<https://docs.google.com/forms/d/143p6qH0cgZ59vsa5JT1OEzrNsWK046wMn1-1g5FYyjk/edit?ts=636f30cc>

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28/09/2025, 10:38

Household Survey

19. Which of the following fruits do you eat raw (uncooked)? *

आप इनमें से कौनसे फल कच्चा खाते हैं?

Check all that apply.

	Daily	Few times a week	Occasionally	Never
apple	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
papaya	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
grapes	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
berries (jamun)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
singara (water chestnut)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
baer	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
kiwi	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
banana	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
guava (amrud)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

20. Does anyone in your household wash the produce that your household eats before eating it? *

आपके घर में सब्जिया खाने से पहले धोयी जाती हैं?

Mark only one oval.

- Yes
- No
- Do not know

<https://docs.google.com/forms/d/143p6qH0cgZ59vsa5JT1OEzrNsWK046wMn1-1g5fYygg/edit?ts=636f3ccc>

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11.8 Appendix H: R Script for Fresh Produce Dose Modelling

```
require(truncdist)

# Create an empty vector with 10,000 elements
cfu_vector <- numeric(10000)

# Parameters for log-normal distribution
mean_portion <- 1.6
sd_portion <- 0.6

# Set the random seed for reproducibility (optional)
# set.seed(858)

# Loop to fill the vector
for (i in 1:10000) {

  # Generate a random CFU value (samples without farm or farm market included which
  # are 24125, 36375, 128000, 134150 )
  cfu_value <- sample(c(0, 5, 25, 2025, 3617, 3843, 4183, 4300, 7833, 8050, 17700,
  40333, 41667, 46500, 62375, 73125, 75000, 109000), size = 1, replace = TRUE)

  # Generate a random portion eaten from log-normal distribution
  #portion_eaten <- rlnorm(n = 1, meanlog = log(mean_portion), sdlog = log(sd_portion))
  #check conversion for mean and sd is correct. Lpook for the formula.
  portion_eaten <- rtrunc(1, spec = "norm", a = 0, b =
  2.9, mean = (mean_portion), sd = (sd_portion))

  # Calculate Cn = n * S1
  cn <- cfu_value * portion_eaten

  # Store Cn in the vector
  cfu_vector[i] <- cn
}
```

11.9 Appendix I: Fieldwork Plan for sampling, observation and Focus Group Discussions for Solid Waste

Field work plan

When?	Field visit October 2023.
Where?	Settlements: <ol style="list-style-type: none"> 1. Madrasi Camp– Juggi Jhopri Colony, established 1982; 483 households. 2. Andrews Ganj – Juggi Jhopri Colony, established 1978; 904 Households 3. Jagdamba Camp – Juggi Jhopri Colony, established 1975; 1099 Households.
Samples to be taken	Solid waste from around communities
Sampling	Samples to be collected from the waste collection sites/bins, corners/streetside piles or SW, beside the open drain, and any other key areas. Approximately 20 samples in total. <ul style="list-style-type: none"> - Plating for Faecal coliforms
	Observing community members behaviour regarding how they interact with solid waste around the communities. <ol style="list-style-type: none"> a) Number of people depositing waste onto trash piles and grading as to how much they touch what is already there in the process. (Do they step on SW in the process, do they touch with their hands eg to push their SW onto the pile?) b) Number of people touching the trash with notes of why if obvious (ie dropped something they had to retrieve, not sure why) c) Number of people removing something from the trash that they did not just deposit (notes about if they seem to behave as if the item is dirty or not). d) Instances of children playing near/with/on solid waste (and do adults tell them to come away from the SW).
Focus Groups	Three communities divided by area/main street: <ol style="list-style-type: none"> 1. Asking what they put on the solid waste piles (ie does it include flying toilets (poo in a bag), diapers, children's faeces, animal faeces, faeces on clothes or bedding, incontinence products, menstrual products, etc) 2. How often to they take waste from their home to the bins/piles? 3. Is it one person's responsibility or everyone in the household? 4. Do they pay something towards the removal of their waste? 5. Finding out how much the communities perceive that they interact with the communal solid waste piles 6. If they perceive it to be dirty 7. If they are careful not to touch it when they put their own waste on the piles 8. How often the piles are collected 9. What happens to solid waste dredged out of the Open Drains 10. If they would collect something they saw that could be of value or use to them from the SW. Would it be considered dirty or would they wash it. 11. Do you allow your children to play with or near the SW

11.10 Appendix J: Pilot and Final Hourly Observation Tally Sheets

Pilot Hourly Observations Tally Sheet for Solid Waste Interactions

Jemma Phillips, University of Leeds

Observer name				
Community name				
Photo number				
Location				
Date of observations				
Time of observations (1 hour)				
Any other notes about conditions				
	Adult		Child	
Behaviour	Man	Woman	Boy	Girl
Depositing something onto SW pile/bins without touching what is already there				
Depositing something onto SW pile/bins touching what is already there or the bin side				
Removing something from SW				
Playing / recreation involving touching SW (no adult)				
Playing / recreation involving touching SW (adult present)				
Child being told off / prevented from touching SW by adult				
Stepping on or kicking SW				
Sanitation Worker present (Y/N)				
Waste segregating present (Y/N)				
Rag picking present (Y/N)				

Finalised Hourly Observations Tally Sheet for Solid Waste Interactions

Jemma Phillips, University of Leeds

Observer name				
Community name				
Photo number				
Location				
Date of observations				
Time of observations (1 hour)				
Any other notes about conditions				
	Adult		Child	
Behaviour	Man	Woman	Boy	Girl
Depositing something onto SW bins without touching what is already there				
Depositing something onto SW bins using hand to scoop from own container				
Depositing something onto SW pile, touching what is already there or the bin side				

11.11 Appendix K: Solid Waste Content Comparisons

Mean CFU/ml powder	leaves	raw food	cooked	mud/sc	packag	foil	paper
1.12E+05							
1.63E+05							
1.66E+05							
2.16E+05							
6.90E+05							
1.56E+06				sandy			
1.94E+06							
2.01E+06							
2.08E+06							
2.11E+06							
2.54E+06				ashy			
3.05E+06							
5.92E+06							
7.08E+06							
7.80E+06							
8.72E+06							
9.80E+06							
1.01E+07							

11.12 Appendix L: R Script for Solid Waste Exposure Modelling

```
# Create an empty vector to store doses
dose_vector <- numeric(10000)

#For 10,000 loops
for (i in 1:10000) {

#CFU data from sampling in Delhi
cfu_values <- c(33100, 80000, 103000, 112000, 163000, 166000, 216000,
               690000, 1560000, 1940000, 2010000, 2080000, 2110000,
               2540000, 3050000, 5920000, 7080000, 7800000, 8720000,
               9800000, 10080000)

selected_cfu <- sample(cfu_values, 1)

#number of contacts seen in observations in Delhi

contact_value <- runif(1, 0, 1)
if (contact_value < 0.9) {
  contact_frequency <- 0
} else if (contact_value < 0.93) {
  contact_frequency <- 1
} else if (contact_value < 0.95) {
  contact_frequency <- 2
} else if (contact_value < 0.97) {
  contact_frequency <- 3
} else if (contact_value < 0.99) {
  contact_frequency <- 4
} else {
```

```
contact_frequency <- 5 }

#Transfer efficiency range taken from Lopez et al (2013).

transfer_efficiency <- runif(1, 0.0001, 1.00)

#dose calculation

dose <- contact_frequency * selected_cfu * transfer_efficiency

#end of the looping instruction
dose_vector[i] <- dose
}

#Show first few data points
head(dose_vector)

#Histogram
hist(dose_vector, breaks = 10, main = "Dose Distribution",
     xlab = "Dose", ylab = "Frequency", col = "skyblue")

#Summary stats
mean_dose <- mean(dose_vector)
median_dose <- median(dose_vector)
sd_dose <- sd(dose_vector)
highest_dose <- max(dose_vector)
lowest_dose <- min(dose_vector)
```

11.13 Appendix M: Iterations of the Amplified F-diagram

Containment Solved:

```
// SankoyMATIC diagram inputs - Saved:
21/07/2025, 21:40:52
// https://sankoymatic.com/build/

// === Nodes and Flows ===
// Source to Exposure Faecal flows - ALL

// colours of nodes and flows
// sources
:Open defecation #FFFFFF
:Broken containment #FFFFFF
:Direct discharge #FFFFFF

:Spillage during emptying #FFA500
:Direct discharge from pipes #FFA500
:Leaking from pipes #FFA500
:Dumped faecal sludge #FFA500

:Insufficiently treated WW #FF1493
:Insufficiently treated FS #FF1493

:Sources #FFFFFF
:Exposures #FFFFFF

// mid nodes
:Soil #8B4513
:Groundwater #008080
:Agriculture #006400
:Open drain #2F4F4F

// exposures
:Ocean #00008B
:Fresh produce #00FF00
```

```
:Fomites #FF0000
:Surface water #0096FF
:Piped water #FFFFFF
:Well water #D19C57

// Flow values
Sources [10] Exposures

// flows from failed containment
Open defecation [20] Exposures

Direct discharge [20] Exposures
Direct discharge [20] Exposures
Direct discharge [20] Exposures
Direct discharge [20] Exposures
Direct discharge [20] Exposures
Direct discharge [20] Exposures

Broken containment [20] Exposures
Broken containment [20] Exposures
Broken containment [20] Exposures
Broken containment [20] Exposures
Broken containment [20] Exposures

// flows from failed transport
Spillage during emptying [20] Surface water
Spillage during emptying [20] Open drain
```

```
Spillage during emptying [20] Soil
Spillage during emptying [20] Fomites

Dumped faecal sludge [20] Surface water
Dumped faecal sludge [20] Open drain
Dumped faecal sludge [20] Ocean
Dumped faecal sludge [20] Soil
Dumped faecal sludge [20] Fresh produce
Dumped faecal sludge [20] Fomites
Dumped faecal sludge [20] Agriculture

Direct discharge from pipes [20] Surface water
Direct discharge from pipes [20] Open drain
Direct discharge from pipes [20] Ocean
Direct discharge from pipes [20] Soil
Direct discharge from pipes [20] Groundwater
Direct discharge from pipes [20] Fomites

Leaking from pipes [20] Surface water
Leaking from pipes [20] Open drain
Leaking from pipes [20] Groundwater
Leaking from pipes [20] Piped water

// flows from failed treatment
Insufficiently treated WW [20] Surface water
Insufficiently treated WW [20] Open drain
Insufficiently treated WW [20] Ocean
Insufficiently treated WW [20] Soil
Insufficiently treated WW [20] Agriculture

// flows between exposures
Well water [10] Fresh produce
Piped water [10] Fresh produce
Fomites [10] Fresh produce
Ocean [10] Fomites

Insufficiently treated FS [20] Soil
Insufficiently treated FS [20] Agriculture

// flows from mid nodes
Open drain [25] Surface water
Open drain [25] Ocean
Open drain [25] Soil
Open drain [25] Groundwater
Open drain [25] Agriculture
Open drain [25] Fomites

Groundwater [37] Surface water
Groundwater [37] Piped water
Groundwater [37] Well water
Groundwater [37] Ocean

Soil [40] Agriculture
Soil [40] Fresh produce
Soil [40] Fomites
Soil [40] Groundwater

Agriculture [23] Surface water
Agriculture [23] Open drain
Agriculture [23] Soil
Agriculture [23] Groundwater
Agriculture [23] Fresh produce
Agriculture [23] Fomites
```

```
Surface water [10] Ocean
Surface water [10] Soil
Surface water [10] Groundwater
Surface water [10] Fresh produce
Surface water [10] Agriculture
Surface water [10] Fomites
Surface water [10] Groundwater

// === Settings ===
size w 600
h 600
margin l 12
r 12
t 18
b 20
bg color #ffffff
transparent N
node w 12
h 50
spacing 75
border 0
theme a
color #888888
opacity 1
flow curvature 0.5
inherit from source
color #999999
opacity 0.45
layout order automatic
justify origins Y
justify ends Y
reverse graph N
```

```
attach incomplete to nearest
labels color #000000
hide N
highlight 0.3
font face sans-serif
line spacing 0.2
relative size 128
magnify 100
label name appears Y
size 18
weight 400
label value appears N
full precision Y
position below
weight 400
label position auto align 0
scheme per_stage
first before
breakpoint 2
value format !'
prefix *
suffix *
theme offset a 9
b 0
c 0
d 0
meta mentions sankoymatic N
list imbalance Y

// === Moved Nodes ===
move Open defecation -0.02059, -0.05479
move Broken containment -0.01176, -0.06885
move Direct discharge -0.00588, -0.068
```

```
move Leaking from pipes -0.01765, -0.08987
move Direct discharge from pipes -0.00294, -0.06706
move Dumped faecal sludge -0.02059, 0.25209
move Surface water 0.01765, -0.15031
move Spillage during emptying -0.00294, 0.11045
move Open drain -0.57451, -0.09293
move Soil -0.33627, -0.0121
move Well water 0.01176, 0.264
move Piped water 0.00882, -0.11771
move Fresh produce 0.02647, -0.24089
move Groundwater -0.24398, 0.5012
move Ocean 0.00588, 0.18942
move Fomites 0.01471, -0.32637
move Sources -0.04813, -0.25115
move Exposures 0.01765, -0.04825
move Insufficiently treated WW -0.05, 0.0546
move Insufficiently treated FS -0.00294, 0.04247
move Agriculture -0.43236, 0.00599
```



Transport Solved:

```
// SankeyMATIC diagram inputs - Saved:
21/07/2025, 21:53:24
// https://sankeymatic.com/build/

// === Nodes and Flows ===

// Source to Exposure Faecal flows - ALL

// colours of nodes and flows
// sources
:Open defecation #800080
:Broken containment #800080
:Direct discharge #800080

:Spillage during emptying #FFFFFF
:Direct discharge from pipes #FFFFFF
:Leaking from pipes #FFFFFF
:Dumped faecal sludge #FFFFFF

:Insufficiently treated WW #FF1493
:Insufficiently treated FS #FF1493

:Sources #FFFFFF
:Exposures #FFFFFF

// mid nodes
:Soil #8B4513
:Groundwater #008080
:Agriculture #008400
:Open drain #2F4F4F

// exposures
:Ocean #00008B
:Fresh produce #00FF00
```

```
:Fomites #FF0000
:Surface water #0096FF
:Piped water #FFFF00
:Well water #D19C57

// Flow values
Sources [10] Exposures

// flows from failed containment
Open defecation [20] Surface water
Open defecation [20] Open drain
Open defecation [20] Ocean
Open defecation [20] Soil
Open defecation [20] Fresh produce
Open defecation [20] Fomites
Open defecation [20] Agriculture

Direct discharge [20] Surface water
Direct discharge [20] Open drain
Direct discharge [20] Ocean
Direct discharge [20] Fresh produce
Direct discharge [20] Soil
Direct discharge [20] Fomites

Broken containment [20] Surface water
Broken containment [20] Open drain
Broken containment [20] Ocean
Broken containment [20] Soil
Broken containment [20] Groundwater

// flows from failed transport
Spillage during emptying [20] Exposures
Spillage during emptying [20] Exposures
```

```
Spillage during emptying [20] Exposures
Spillage during emptying [20] Exposures

Dumped faecal sludge [20] Exposures
Dumped faecal sludge [20] Exposures
Dumped faecal sludge [20] Exposures
Dumped faecal sludge [20] Exposures
Dumped faecal sludge [20] Exposures
Dumped faecal sludge [20] Exposures

Direct discharge from pipes [20] Exposures
Direct discharge from pipes [20] Exposures
Direct discharge from pipes [20] Exposures
Direct discharge from pipes [20] Exposures
Direct discharge from pipes [20] Exposures
Direct discharge from pipes [20] Exposures

Leaking from pipes [20] Exposures
Leaking from pipes [20] Exposures
Leaking from pipes [20] Exposures
Leaking from pipes [20] Exposures

// flows from failed treatment

Insufficiently treated WW [20] Surface water
Insufficiently treated WW [20] Open drain
Insufficiently treated WW [20] Ocean
Insufficiently treated WW [20] Soil
Insufficiently treated WW [20] Agriculture

Insufficiently treated FS [20] Surface water
Insufficiently treated FS [20] Open drain
```

```
Insufficiently treated FS [20] Ocean
Insufficiently treated FS [20] Soil
Insufficiently treated FS [20] Agriculture

// flows from mid nodes
Open drain [21] Surface water
Open drain [21] Ocean
Open drain [21] Soil
Open drain [21] Groundwater
Open drain [21] Agriculture
Open drain [21] Fomites

Groundwater [30] Surface water
Groundwater [30] Piped water
Groundwater [30] Well water
Groundwater [30] Ocean

Soil [39] Agriculture
Soil [39] Fresh produce
Soil [39] Fomites
Soil [39] Groundwater

Agriculture [22] Surface water
Agriculture [22] Open drain
Agriculture [22] Soil
Agriculture [22] Groundwater
Agriculture [22] Fresh produce
Agriculture [22] Fomites

// flows between exposures
Well water [10] Fresh produce
Piped water [10] Fresh produce
Fomites [10] Fresh produce
```

```
Ocean [10] Fomites

Surface water [10] Ocean
Surface water [10] Soil
Surface water [10] Groundwater
Surface water [10] Fresh produce
Surface water [10] Agriculture
Surface water [10] Fomites
Surface water [10] Groundwater

// === Settings ===
size w 600
h 600
margin l 12
r 12
t 18
b 20
bg color #ffffff
transparent N
node w 12
h 50
spacing 75
border 0
theme a
color #888888
opacity 1
flow curvature 0.5
inherit from source
color #999999
opacity 0.45
layout order automatic
justify origins Y
justify ends Y
```

```
reversegraph N
attachincompletesto nearest
labels color #000000
hide N
highlight 0.3
fontface sans-serif
linespacing 0.2
relativesize 128
magnify 100
labelname appears Y
size 16
weight 400
labelvalue appears N
fullprecision Y
position below
weight 400
labelposition autoalign 0
scheme per_stage
first before
breakpoint 2
value format ':'
prefix "
suffix "
themeoffset a 9
b 0
c 0
d 0
meta mentionsankeymatic N
listbalances Y

// === Moved Nodes ===
move Open defecation -0.04118, -0.23132
move Broken containment -0.02941, -0.37201
```

```
move Direct discharge -0.03525, -0.34884
move Leaking from pipes -0.04118, -0.41469
move Direct discharge from pipes 0, -0.28895
move Dumped faecal sludge 0.00294, -0.17368
move Surface water 0.01176, -0.04868
move Spillage during emptying -0.01765, -0.14931
move Open drain -0.56568, -0.10549
move Soil -0.33921, -0.04119
move Well water 0.00568, 0.07253
move Piped water 0.01471, -0.13666
move Fresh produce 0.01765, 0.02605
move Groundwater -0.24397, 0.28634
move Ocean 0.01176, 0.05708
move Fomites 0.00882, -0.44343
move Sources 0, -0.07717
move Exposures 0, -0.06704
move Insufficiently treated WW -0.00294, 0.05466
move Insufficiently treated FS -0.01471, 0.03392
move Agriculture -0.43236, -0.01307
```



Treatment Solved:

```
// SankayMATIC diagram inputs - Saved:
21/07/2025, 22:02:41
// https://sankeymatic.com/build/

// === Nodes and Flows ===
// Source to Exposure Faecal flows - ALL
// colours of nodes and flows
// sources

:Open defecation #800080
:Broken containment #800080
:Direct discharge #800080

:Spillage during emptying #FFA500
:Direct discharge from pipes #FFA500
:Leaking from pipes #FFA500
:Dumped faecal sludge #FFA500

:Insufficiently treated WW #FFFFFF
:Insufficiently treated FS #FFFFFF

:Sources #FFFFFF
:Exposures #FFFFFF

// mid nodes
:Soil #8B4513
:Groundwater #008080
:Agriculture #006400
:Open drain #2F4F4F

// exposures
:Ocean #00008B
:Fresh produce #00FF00

:Fomites #FF0000
:Surface water #0098FF
:Piped water #FFFF00
:Well water #D19C57

// Flow values
Sources [10] Exposures

// flows from failed containment
Open defecation [20] Surface water
Open defecation [20] Open drain
Open defecation [20] Ocean
Open defecation [20] Soil
Open defecation [20] Fresh produce
Open defecation [20] Fomites
Open defecation [20] Agriculture

Direct discharge [20] Surface water
Direct discharge [20] Open drain
Direct discharge [20] Ocean
Direct discharge [20] Fresh produce
Direct discharge [20] Soil
Direct discharge [20] Fomites

Broken containment [20] Surface water
Broken containment [20] Open drain
Broken containment [20] Ocean
Broken containment [20] Soil
Broken containment [20] Groundwater

// flows from failed transport
Spillage during emptying [20] Surface water
Spillage during emptying [20] Open drain
```

```
Spillage during emptying [20] Soil
Spillage during emptying [20] Fomites

Dumped faecal sludge [20] Surface water
Dumped faecal sludge [20] Open drain
Dumped faecal sludge [20] Ocean
Dumped faecal sludge [20] Soil
Dumped faecal sludge [20] Fresh produce
Dumped faecal sludge [20] Fomites
Dumped faecal sludge [20] Agriculture

Direct discharge from pipes [20] Surface water
Direct discharge from pipes [20] Open drain
Direct discharge from pipes [20] Ocean
Direct discharge from pipes [20] Soil
Direct discharge from pipes [20] Groundwater
Direct discharge from pipes [20] Fomites

Leaking from pipes [20] Surface water
Leaking from pipes [20] Open drain
Leaking from pipes [20] Groundwater
Leaking from pipes [20] Piped water

// flows from failed treatment

Insufficiently treated WW [20] Exposures

Insufficiently treated FS [20] Exposures
Insufficiently treated FS [20] Exposures

Insufficiently treated FS [20] Exposures
Insufficiently treated FS [20] Exposures

// flows from mid nodes
Open drain [27] Surface water
Open drain [27] Ocean
Open drain [27] Soil
Open drain [27] Groundwater
Open drain [27] Agriculture
Open drain [27] Fomites

Groundwater [45] Surface water
Groundwater [45] Piped water
Groundwater [45] Well water
Groundwater [45] Ocean

Soil [46] Agriculture
Soil [46] Fresh produce
Soil [46] Fomites
Soil [46] Groundwater

Agriculture [21] Surface water
Agriculture [21] Open drain
Agriculture [21] Soil
Agriculture [21] Groundwater
Agriculture [21] Fresh produce
Agriculture [21] Fomites

// flows between exposures
Well water [10] Fresh produce
Piped water [10] Fresh produce
Fomites [10] Fresh produce
```

```
Ocean [10] Fomites
Surface water [10] Ocean
Surface water [10] Soil
Surface water [10] Groundwater
Surface water [10] Fresh produce
Surface water [10] Agriculture
Surface water [10] Fomites
Surface water [10] Groundwater

// === Settings ===
size w 600
h 600
margin l 12
r 12
t 18
b 20
bg color #ffffff
transparent N
node w 12
h 50
spacing 75
border 0
theme a
color #888888
opacity 1
flow curvature 0.5
inheritfrom source
color #999999
opacity 0.45
layout order automatic
justifyorigins Y
justifyends Y

reversegraph N
attachincompleteto nearest
labels color #000000
hide N
highlight 0.3
fontface sans-serif
linespacing 0.2
relativsize 128
magnify 100
labelname appears Y
size 16
weight 400
labelvalue appears N
fullprecision Y
position below
weight 400
labelposition autoalign 0
scheme per_stage
first before
breakpoint 2
value format ','
prefix "
suffix "
themoffset a 9
b 0
c 0
d 0
meta mentionsankaymatic N
listimbalances Y

// === Moved Nodes ===
move Open defecation -0.03235, -0.02417
move Broken containment -0.00588, -0.06048
```

```
move Direct discharge -0.00588, -0.04907
move Leaking from pipes -0.00294, -0.29565
move Direct discharge from pipes -0.00588, -0.29619
move Dumped faecal sludge -0.01176, 0.12957
move Surface water 0.04412, -0.14222
move Spillage during emptying -0.00294, -0.01194
move Open drain -0.57744, 0.47607
move Soil -0.35097, 0.20296
move Well water 0.00294, 0.2784
move Piped water 0.01176, -0.072
move Fresh produce 0.03529, -0.04626
move Groundwater -0.24986, 0.54109
move Ocean 0.00588, 0.19619
move Fomites 0.03529, -0.35652
move Sources -0.04813, -0.25115
move Exposures 0.00588, -0.7588
move Insufficiently treated WW -0.00882, -0.65916
move Insufficiently treated FS -0.01471, -0.77572
move Agriculture -0.44412, 0.32726
```



11.14 Appendix N: Applied Amplified F-diagram

```
// SankeyMATIC diagram inputs - Saved:
03/09/2025, 21:38:51

// https://sankeymatic.com/build/
// === Nodes and Flows ===
// Source to Exposure Faecal flows - ALL
// colours of nodes and flows
// sources
:Open defecation #800080
:Broken containment #800080
:Direct discharge #800080

:Spillage during emptying #FFA500
:Direct discharge from pipes #FFA500
:Leaking from pipes #FFA500
:Dumped faecal sludge #FFA500

:insufficiently treated WW #FF1493
:insufficiently treated FS #FF1493

:Sources #FFFFFF
:Exposures #FFFFFF

// mid nodes
:Soil #8B4513
:Groundwater #008080
:Agriculture #006400
:Open drain #2F4F4F

// exposures
:Fresh produce #00FF00
:Fomites #FF0000
:Surface water #0096FF
:Piped water #FFFF00
```

```
:Well water #D19C57

// Flow values
Sources [10] Exposures
// flows from failed containment
Open defecation [20] Surface water
Open defecation [20] Open drain
Open defecation [20] Soil

Open defecation [20] Fomites
Open defecation [50] Agriculture

Direct discharge [20] Surface water
Direct discharge [50] Open drain
Direct discharge [20] Soil
Direct discharge [20] Fomites

Broken containment [20] Surface water
Broken containment [20] Open drain
Broken containment [20] Soil
Broken containment [20] Groundwater

// flows from failed transport
Spillage during emptying [20] Surface water
Spillage during emptying [20] Open drain
Spillage during emptying [20] Soil
Spillage during emptying [20] Fomites

Dumped faecal sludge [20] Surface water
Dumped faecal sludge [20] Open drain
Dumped faecal sludge [20] Soil
Dumped faecal sludge [20] Fomites
```

```
Direct discharge from pipes [20] Surface water
Direct discharge from pipes [50] Open drain
Direct discharge from pipes [20] Soil
Direct discharge from pipes [20] Groundwater
Direct discharge from pipes [20] Fomites

Leaking from pipes [20] Surface water
Leaking from pipes [20] Open drain
Leaking from pipes [20] Groundwater
Leaking from pipes [20] Piped water

// flows from failed treatment
Insufficiently treated WW [20] Surface water
Insufficiently treated WW [20] Open drain
Insufficiently treated WW [20] Soil

Insufficiently treated FS [20] Surface water
Insufficiently treated FS [20] Open drain
Insufficiently treated FS [20] Soil

// flows from mid nodes
Open drain [70] Surface water
Open drain [50] Soil
Open drain [50] Groundwater
Open drain [70] Agriculture
Open drain [50] Fomites

Groundwater [60] Surface water
Groundwater [60] Piped water
Groundwater [80] Well water

Soil [57] Agriculture
Soil [57] Fresh produce
Soil [57] Fomites
Soil [57] Groundwater

Agriculture [30] Surface water
Agriculture [30] Open drain

Agriculture [30] Groundwater
Agriculture [100] Fresh produce
Agriculture [30] Fomites

// flows between exposures
Well water [40] Fresh produce
Well water [40] Agriculture
Piped water [60] Fresh produce
Fomites [70] Fresh produce

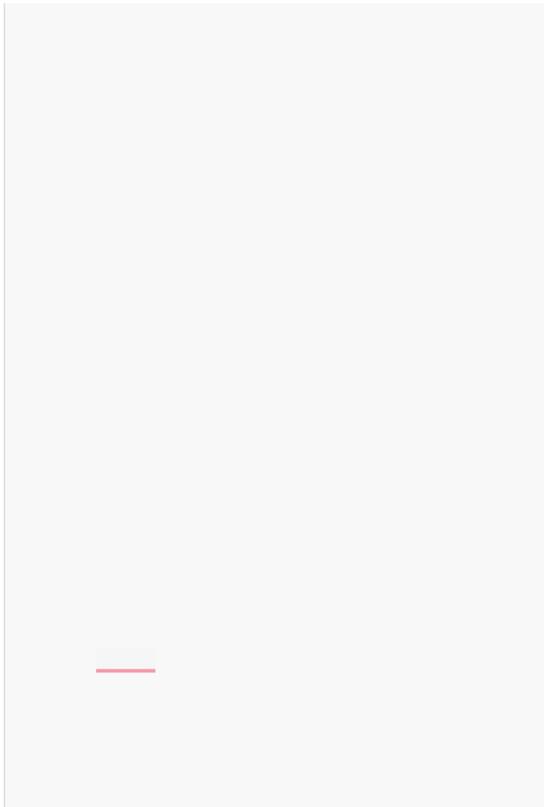
Surface water [10] Soil
Surface water [10] Groundwater
Surface water [10] Open drain
Surface water [10] Fomites
Surface water [10] Groundwater

// === Settings ===
size w 600
h 600
margin l 12
r 12
t 18
b 20
bg color #ffff
transparent N
```

```
node w 12
h 50
spacing 75
border 0
theme a
color #888888
opacity 1
flow curvature 0.5
inherit from source
color #999999
opacity 0.45
layout order automatic
justify origins Y
justify ends Y
reverse graph N
attach incomplete to nearest
labels color #000000
hide N
highlight 0.3
fontface sans-serif
linespacing 0.2
relativesize 128
magnify 100
labelname appears Y
size 16
weight 400
labelvalue appears N
fullprecision Y
position below
weight 400
labelposition autoalign 0
scheme per_stage
first before
```

```
breakpoint 2
value format :
prefix ""
suffix ""
themecoloffset a 9
b 0
c 0
d 0
meta mentionsankeymatic N
listimbalance Y

// === Moved Nodes ===
move Open defecation -0.32135, -0.0575
move Broken containment -0.01224, -0.09014
move Direct discharge -0.00306, -0.07359
move Leaking from pipes -0.00918, -0.14364
move Direct discharge from pipes -0.00918, -0.12773
move Dumped faecal sludge -0.01224, 0.11019
move Surface water -0.41316, -0.11383
move Spillage during emptying -0.00306, -0.03044
move Open drain -0.21667, -0.02887
move Soil -0.73989, 0.43693
move Piped water -0.1163, -0.14047
move Fresh produce 0, -0.04199
move Groundwater -0.59628, 0.19248
move Fomites -0.07957, 0.07262
move Sources -0.04813, -0.25115
move Exposures 0.03209, -0.06813
move Insufficiently treated WW 0, -0.03045
move Insufficiently treated FS 0, -0.0305
move Agriculture -0.41094, 0.07702
move Well water -0.15302, -0.14297
```



11.15 Appendix O: Iterations of the applied Amplified F-diagram

Containment Solved:

```
// SankayMATIC diagram inputs - Saved:
04/09/2025, 09:33:27
// https://sankaymatic.com/build/

// === Nodes and Flows ===
// Source to Exposure Faecal flows - Delhi
// colours of nodes and flows
// sources
:Open defecation #FFFFFF
:Broken containment #FFFFFF
:Direct discharge #FFFFFF

:Spillage during emptying #FFA500
:Direct discharge from pipes #FFA500
:Leaking from pipes #FFA500
:Dumped faecal sludge #FFA500

:Insufficiently treated WW #FF1493
:Insufficiently treated FS #FF1493

:Sources #FFFFFF
:Exposures #FFFFFF

// mid nodes
:Soil #8B4513
:Groundwater #008080
:Agriculture #006400
:Open drain #2F4F4F

// exposures
:Fresh produce #00FF00
:Fomites #FF0000
:Surface water #0096FF

:Piped water #FFFFFF
:Well water #D19C57

// Flow values
Sources [10] Exposures

// flows from failed containment
Open defecation [20] Exposures
Open defecation [20] Exposures
Open defecation [20] Exposures

Open defecation [20] Exposures
Open defecation [50] Exposures

Direct discharge [20] Exposures
Direct discharge [50] Exposures
Direct discharge [20] Exposures
Direct discharge [20] Exposures

Broken containment [20] Exposures
Broken containment [20] Exposures
Broken containment [20] Exposures
Broken containment [20] Exposures

// flows from failed transport
Spillage during emptying [20] Surface water
Spillage during emptying [20] Open drain
Spillage during emptying [20] Soil
Spillage during emptying [20] Fomites

Dumped faecal sludge [20] Surface water
Dumped faecal sludge [20] Open drain
Dumped faecal sludge [20] Soil

Dumped faecal sludge [20] Fomites
Soil [40] Agriculture
Soil [40] Fresh produce
Soil [40] Fomites
Soil [40] Groundwater

Direct discharge from pipes [20] Surface water
Direct discharge from pipes [50] Open drain
Direct discharge from pipes [20] Soil
Direct discharge from pipes [20] Groundwater
Direct discharge from pipes [20] Fomites

Leaking from pipes [20] Surface water
Leaking from pipes [20] Open drain
Leaking from pipes [20] Groundwater
Leaking from pipes [20] Piped water

// flows from failed treatment
Insufficiently treated WW [20] Surface water
Insufficiently treated WW [20] Open drain
Insufficiently treated WW [20] Soil

Insufficiently treated FS [20] Surface water
Insufficiently treated FS [20] Open drain
Insufficiently treated FS [20] Soil

// flows from mid nodes
Open drain [50] Surface water
Open drain [30] Soil
Open drain [30] Groundwater
Open drain [50] Agriculture
Open drain [30] Fomites

Groundwater [45] Surface water
Groundwater [45] Piped water
Groundwater [65] Well water

// flows between exposures
Well water [30] Fresh produce
Well water [30] Agriculture
Piped water [80] Fresh produce
Fomites [80] Fresh produce

Surface water [10] Soil
Surface water [10] Groundwater
Surface water [10] Open drain
Surface water [10] Fomites
Surface water [10] Groundwater

// === Settings ===
size w 600
h 600
margin l 12
r 12
t 18
b 20
bg color #ffffff
transparent N

node w 12
h 50
spacing 75
border 0
theme a
color #888888
opacity 1
flow curvature 0.5
inheritfrom source
color #999999
opacity 0.45
layout order automatic
justifyorigins Y
justifyends Y
reversigraph N
attachincompletesto nearest
labels color #000000
hide N
highlight 0.3
fontface sans-serif
linespacing 0.2
relativesize 128
magnify 100
labelname appears Y
size 16
weight 400
labelvalue appears N
fullprecision Y
position below
weight 400
labelposition autoalign 0
scheme per_stage
first before

breakpoint 2
value format !'
prefix ""
suffix ""
themeoffset a 9
b 0
c 0
d 0
meta mentionsankaymatic N
listbalances Y

// === Moved Nodes ===
move Open defecation -0.32135, -0.0575
move Broken containment -0.01224, -0.09014
move Direct discharge -0.00306, -0.07359
move Leaking from pipes -0.05509, -0.23672
move Direct discharge from pipes -0.05815, -0.21234
move Dumped faecal sludge -0.06427, 0.07797
move Surface water -0.32441, -0.11182
move Spillage during emptying -0.05509, -0.08495
move Open drain -0.1983, -0.11683
move Soil -0.73989, 0.14411
move Piped water -0.10712, -0.52059
move Fresh produce 0.00306, -0.4308
move Groundwater -0.57486, 0.06758
move Fomites -0.07957, 0.21169
move Sources -0.04813, -0.25115
move Exposures 0.03209, -0.06813
move Insufficiently treated WW -0.11018, -0.10445
move Insufficiently treated FS -0.04897, -0.12393
move Agriculture -0.43848, -0.17723
move Well water -0.14384, -0.14114
```

Transport Solved:

```
// SankeyMATIC diagram inputs - Saved:
04/09/2025, 09:51:24
// https://sankeymatic.com/build/

// === Nodes and Flows ===

// Source to Exposure Faecal flows - ALL
// colours of nodes and flows
// sources

:Open defecation #800080
:Broken containment #800080
:Direct discharge #800080

:Spillage during emptying #FFFFFF
:Direct discharge from pipes #FFFFFF
:Leaking from pipes #FFFFFF
:Dumped faecal sludge #FFFFFF

:Insufficiently treated WW #FF1493
:Insufficiently treated FS #FF1493

:Sources #FFFFFF
:Exposures #FFFFFF

// mid nodes
:Soil #8B4513
:Groundwater #008080
:Agriculture #006400
:Open drain #2F4F4F

// exposures
:Fresh produce #00FF00
```

```
:Fomites #FF0000
:Surface water #0096FF
:Piped water #FFFF00
:Well water #D19C57

// Flow values
Sources [10] Exposures

// flows from failed containment
Open defecation [20] Surface water
Open defecation [20] Open drain
Open defecation [20] Soil
Open defecation [20] Fomites
Open defecation [50] Agriculture

Direct discharge [20] Surface water
Direct discharge [50] Open drain
Direct discharge [20] Soil
Direct discharge [20] Fomites

Broken containment [20] Surface water
Broken containment [20] Open drain
Broken containment [20] Soil
Broken containment [20] Groundwater

// flows from failed transport
Spillage during emptying [20] Exposures

Dumped faecal sludge [20] Exposures
Dumped faecal sludge [20] Exposures
```

```
Dumped faecal sludge [20] Exposures
Dumped faecal sludge [20] Exposures

Direct discharge from pipes [20] Exposures
Direct discharge from pipes [50] Exposures
Direct discharge from pipes [20] Exposures
Direct discharge from pipes [20] Exposures
Direct discharge from pipes [20] Exposures

Leaking from pipes [20] Exposures
Leaking from pipes [20] Exposures
Leaking from pipes [20] Exposures

// flows from failed treatment
Insufficiently treated WW [20] Surface water
Insufficiently treated WW [20] Open drain
Insufficiently treated WW [20] Soil

Insufficiently treated FS [20] Surface water
Insufficiently treated FS [20] Open drain
Insufficiently treated FS [20] Soil

// flows from mid nodes
Open drain [40] Surface water
Open drain [30] Soil
Open drain [30] Groundwater
Open drain [40] Agriculture
Open drain [30] Fomites

Groundwater [40] Surface water
Groundwater [40] Piped water
Groundwater [60] Well water

Soil [35] Agriculture
Soil [35] Fresh produce
Soil [35] Fomites
Soil [35] Groundwater

Agriculture [25] Surface water
Agriculture [25] Open drain
Agriculture [25] Groundwater
Agriculture [50] Fresh produce
Agriculture [25] Fomites

// flows between exposures
Well water [30] Fresh produce
Well water [30] Agriculture
Piped water [40] Fresh produce
Fomites [50] Fresh produce

Surface water [10] Soil
Surface water [10] Groundwater
Surface water [10] Open drain
Surface water [10] Fomites
Surface water [10] Groundwater

// === Settings ===
size w 600
h 600
margin l 12
r 12
t 18
b 20
bg color #fffff
transparent N
node w 12
```

```
h 50
spacing 75
border 0
theme a
color #888888
opacity 1
flow curvature 0.5
inheritfrom source
color #999999
opacity 0.45
layout order automatic
justifyorigins Y
justifiends Y
reversegraph N
attachincompletesto nearest
labels color #000000
hide N
highlight 0.3
fontface sans-serif
linespacing 0.2
relativsize 128
magnify 100
labelname appears Y
size 16
weight 400
labelvalue appears N
fullprecision Y
position below
weight 400
labelposition autoalign 0
scheme per_stage
first before
breakpoint 2
```

```
value format !,
prefix "
suffix "
themeoffset a 9
b 0
c 0
d 0
meta mentionsankeymatic N
listbalances Y

// === Moved Nodes ===
move Open defecation 0, 0.06805
move Broken containment -0.00918, -0.19572
move Direct discharge -0.00306, -0.15449
move Leaking from pipes -0.03979, -0.62036
move Direct discharge from pipes -0.0153, -0.37529
move Dumped faecal sludge -0.01224, -0.23249
move Surface water -0.4254, -0.19914
move Spillage during emptying -0.00612, -0.27125
move Open drain -0.25952, -0.1474
move Soil -0.7001, 0.106
move Piped water -0.12854, -0.33467
move Fresh produce 0.07039, -0.28015
move Groundwater -0.52589, -0.12301
move Fomites -0.101, -0.03829
move Sources -0.04813, -0.25115
move Exposures 0.03209, -0.06813
move Insufficiently treated WW -0.00306, 0.03556
move Insufficiently treated FS -0.0153, 0.01999
move Agriculture -0.41094, -0.07751
move Well water -0.14996, -0.28971
```



Treatment Solved:

```
// SankeyMATIC diagram inputs - Saved:
04/09/2025, 11:41:15
// https://sankeymatic.com/build/
// === Nodes and Flows ===
// Source to Exposure Faecal flows - ALL
// colours of nodes and flows
// sources
:Open defecation #800080
:Broken containment #800080
:Direct discharge #800080

:Spillage during emptying #FFA500
:Direct discharge from pipes #FFA500
:Leaking from pipes #FFA500
:Dumped faecal sludge #FFA500

:Insufficiently treated WW #FFFFFF
:Insufficiently treated FS #FFFFFF

:Sources #FFFFFF
:Exposures #FFFFFF

// mid nodes
:Soil #8B4513
:Groundwater #008080
:Agriculture #006400
:Open drain #2F4F4F

// exposures
:Fresh produce #00FF00
:Fomites #FF0000
:Surface water #0096FF
```

```
:Piped water #FFFF00
:Well water #D19C57

// Flow values
Sources [10] Exposures

// flows from failed containment
Open defecation [20] Surface water
Open defecation [20] Open drain
Open defecation [20] Soil
Open defecation [20] Fomites
Open defecation [50] Agriculture

Direct discharge [20] Surface water
Direct discharge [50] Open drain
Direct discharge [20] Soil
Direct discharge [20] Fomites

Broken containment [20] Surface water
Broken containment [20] Open drain
Broken containment [20] Soil
Broken containment [20] Groundwater

// flows from failed transport
Spillage during emptying [20] Surface water
Spillage during emptying [20] Open drain
Spillage during emptying [20] Soil
Spillage during emptying [20] Fomites

Dumped faecal sludge [20] Surface water
Dumped faecal sludge [20] Open drain
Dumped faecal sludge [20] Soil
Dumped faecal sludge [20] Fomites
```

```
Direct discharge from pipes [20] Surface water
Direct discharge from pipes [50] Open drain
Direct discharge from pipes [20] Soil
Direct discharge from pipes [20] Groundwater
Direct discharge from pipes [20] Fomites

Leaking from pipes [20] Surface water
Leaking from pipes [20] Open drain
Leaking from pipes [20] Groundwater
Leaking from pipes [20] Piped water

// flows from failed treatment
Insufficiently treated WW [20] Exposures
Insufficiently treated WW [20] Exposures
Insufficiently treated WW [20] Exposures

Insufficiently treated FS [20] Exposures
Insufficiently treated FS [20] Exposures
Insufficiently treated FS [20] Exposures

Soil [45] Agriculture
Soil [45] Fresh produce
Soil [45] Fomites
Soil [45] Groundwater

Agriculture [30] Surface water
Agriculture [30] Open drain
Agriculture [30] Groundwater
Agriculture [100] Fresh produce
Agriculture [30] Fomites

// flows between exposures
Well water [40] Fresh produce
Well water [40] Agriculture
Piped water [80] Fresh produce
Fomites [70] Fresh produce

Surface water [10] Soil
Surface water [10] Groundwater
Surface water [10] Open drain
Surface water [10] Fomites
Surface water [10] Groundwater

// flows from mid nodes
Open drain [60] Surface water
Open drain [40] Soil
Open drain [40] Groundwater
Open drain [60] Agriculture
Open drain [40] Fomites

Groundwater [60] Surface water
Groundwater [60] Piped water
Groundwater [80] Well water

// === Settings ===
size w 600
h 600
margin l 12
r 12
t 18
b 20
bg color #ffff
transparent N
```

```
node w 12
h 50
spacing 75
border 0
theme a
color #888888
opacity 1
flow curvature 0.5
inherit from source
color #999999
opacity 0.45
layout order automatic
justify origins Y
justify ends Y
reverse graph N
attach incomplete to nearest
labels color #000000
hide N
highlight 0.3
fontface sans-serif
linespacing 0.2
relativesize 128
magnify 100
labelname appears Y
size 16
weight 400
labelvalue appears N
fullprecision Y
position below
weight 400
labelposition autoalign 0
scheme per_stage
first before
```

```
breakpoint 2
value format !'
prefix ''
suffix ''
themeoffset a 9
b 0
c 0
d 0
meta mentionsankeymatic N
listimbalance Y

// === Moved Nodes ===
move Open defecation -0.00918, -0.19335
move Broken containment -0.04591, -0.23582
move Direct discharge 0, -0.2138
move Leaking from pipes -0.01224, -0.27825
move Direct discharge from pipes -0.00612, -0.25226
move Dumped faecal sludge 0, -0.01705
move Surface water -0.40092, -0.03841
move Spillage during emptying -0.00918, -0.19324
move Open drain -0.20137, 0.11231
move Soil -0.70622, 0.33455
move Piped water -0.11936, -0.45026
move Fresh produce 0.00306, -0.23594
move Groundwater -0.59016, 0.37581
move Fomites -0.07957, -0.1761
move Sources -0.00306, -0.30655
move Exposures 0.1622, -1.00971
move Insufficiently treated WW -0.00306, -0.91904
move Insufficiently treated FS -0.01836, -0.53557
move Agriculture -0.50888, 0.15973
move Well water -0.14384, 0.09122
```

