A holistic exploration of risk factors and transmission pathways to enteric infections in infants. A case study in rural tribal Rajasthan, India

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Declaration

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

Abstract

Introduction

Globally, enteric infections are the third leading cause of child mortality, and they contribute to child malnutrition and stunting. Safe Water, Sanitation, and Hygiene (WASH) should interrupt infection transmission; however, recent WASH trials have shown little impact on child infections and growth outcomes. This thesis addresses the need to better understand the multiple and complex factors contributing to infants' enteric infections, adopting a holistic, interdisciplinary approach.

Methods

A mixed-methods case study was conducted in 9 tribal villages of Rajasthan, India. Qualitative data were collected from 9 transect walks, 63 hours of household observations, 12 interviews, and 4 group discussions with infant caregivers and were analysed thematically. Quantitative data were collected from 42 household surveys, 47 structured infant observations, and 316 environmental samples tested for faecal bacteria and analysed in a microbial risk assessment.

Results

Multiple cross-sectoral factors contributing to infants' enteric infections were observed: an arid climate, earthen households, domestic animals, no toilet facilities or handwashing with soap habits, weak governance systems, low emphasis on WASH promotion and infection risk awareness health services, limited livelihood opportunities, and tribal attitudes of limited self-efficacy. Faecal contamination was widespread, with 90% of environmental samples positive for faecal bacteria. Risk assessment results estimated that by their second birthday, infants had a median accumulated risk of enteric infection of over 71% from drinking and bathing in local waters and 100% infection risk from mouthing soil while crawling on the earthen floors. Tailored recommendations to enhance infant hygiene and infection prevention were co-developed with local stakeholders.

Conclusions

This thesis provides in-depth ground-level evidence from tribal communities in rural India. Given the multifaceted factors contributing to infants' enteric infections and the widespread faecal contamination, transformational changes across sectors will be required to improve child health and development. Enabling the tribal communities' self-efficacy may be crucial for future efforts towards the Sustainable Development Goals.

Impact statement

Learnings and findings from this PhD have a potential beneficial impact on the knowledge, policy, and practice concerning child health and development in rural India.

First, the empirical evidence gathered in this case study contributes to recognised knowledge gaps. As highlighted by the World Health Organisation, it is still unclear which approaches are feasible and effective at addressing the multiple infection risks to infants in rural farming environments[1]. The detailed descriptions of the ground-level realities in this thesis provide relevant insights about the context, practices, attitudes, and beliefs influencing infection risks in the study setting. The findings bear implications for future intervention design studies by informing them of important considerations when addressing infection risks to infants, particularly in domestic environments where faecal contamination is widespread. For these findings to be put to beneficial use, I wrote an article that is now published at the BMC Public Health Journal[2].

Second, the exposure risk assessment revealed that infants' exposures to soil and soiled hands from playing in the earthen rural environments, posed a higher risk of enteric infection than other exposures such as drinking contaminated water. This finding, alongside growing evidence in the literature, has implications for the WASH sector. While years of research have focused on improving water and sanitation facilities, this finding suggests that exposure to the broader domestic environments, particularly when these are contaminated with domestic animals' faeces, pose more important infection risks to infants, and urgently requires further evidence on how to best address them. I presented this argument at the Royal College of Paediatrics and Child Health International Conference[3] and I am preparing a scientific article to contribute to the evolving understanding on key infection risks.

Third, findings from this study have implications for policy and practice in rural India. Several barriers to how frontline WASH promotion and infection prevention health services are being delivered and taken up by the community were identified, and recommendations to enhance them were developed. The co-developed recommendations described direct implications for local programmatic action under national-level programmes such as the POSHAN Mission, to accelerate progress in child infections and stunting reduction. To realise the impact of these findings, I discussed them with several local stakeholders, NGO, and government officials through a series of expert consultations, I wrote an article published at the Indian Pediatrics Journal[4], and presented them at the 42nd WEDC International Conference[5].

Lastly, this study highlights the first 1000 days of life as a critical period for child development in which a holistic approach to care is needed. This is a topic of utmost importance given that almost half of children in low-and-middle-income countries are failing to reach their developmental potential. To raise the profile of this key issue and advocate for further investment into integrated care during the early years, I participated in several public engagement events, including a 3-Minute Thesis competition, an online YouTube dissemination event that gathered over 300 views from the general public[6], and a virtual art & science exhibition[7], where I showcased my research.

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7. PAHUS. The Early Years: A window of Opportunity. https://www.pahus.org/early-years-exhibition (2021)

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In India, I am forever indebted to the members of the study communities in Banswara and to all the India colleagues that welcomed me into this warm, vibrant, and caring culture that I will now always carry close to my heart. To the study participants, who gave their time and energy to the study. I feel very lucky to have been able to see and hear first-hand about a way of living and thinking very different to what I had known. Learning about different social realities reminded me of the diverse and fascinating cultural world that we live in. Those interactions were very enriching, for the study, but also for me. धन्यवाद.

In India, I am also especially grateful to Mr Hemant Chaturvedi and Mr Pramod Pandya, for their dedicated support in research matters as well as in all life matters during my stay. I feel truly lucky to have worked with you, learning about the intricacies of fieldwork research and tribal Indian culture, and having really fun times along the way. Thank you for your kindness, hospitality, and knowledge. Thank you also to the Save the Children Rajasthan Office, in particular Mr Sanjay Sharma, Mr Satya Pattanaik, and Mr Sandeep Soni, for their logistical support and for welcoming me into their office in Jaipur. I am also grateful to the Save the

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Abbreviations

ANM: Auxiliary Nurse Midwives

ASHA: Accredited Social Health Activists

AWW: Anganwadi workers

CFU: colony-forming units

CI: Confidence Interval

EED: Environmental Enteric Dysfunction

FGD: Focus Group Discussions

FIB: Faecal Indicator Bacteria

ICDS: Integrated Child Development Services

IIHMR: Indian Institute of Health Management Research

KII: Key Informant Interviews

MLE: Maximum Likelihood Estimation

NFHS: National Family Health Survey

NGO: Non-governmental organisation

NHM: National Health Mission

OBC: Other Backward Class

OR: Odds Ratio

ORS: Oral Rehydration Salts

PANChSHEEEL: Participatory Approach for Nutrition in Children: Strengthening Health-Education-Engineering-Environmental Linkages

POSHAN: PM's Overarching Scheme for Holistic Nourishment

QMRA: Quantitative Microbial Risk Assessment

RCT: Randomised Control Trials

SC: Scheduled Castes

SD: Standard Deviation

SDG: Sustainable Development Goals

ST: Scheduled Tribe

TNTC: Too numerous to count

U.S. EPA: United States Environmental Protection Agency

UCL: University College London

VHND: Village Health and Nutrition Days

VHSNC: Village Health, Sanitation and Nutrition Committees

WASH: Water, Sanitation and Hygiene

WHO: World Health Organisation

Preface

Let me start with some introductory remarks on how this research project came to be and how this thesis is organised. In 2017, the Medical Research Council funded the PANChSHEEEL project (MR/P024114/1), a study designed to bring together partners at University College London (UCL) and India (Save the Children India NGO, Indian Institute of Technology Delhi, Jawaharlal Nehru University) to develop a Participatory Approach for Nutrition in Children: Strengthening Health-Education-Engineering-Environmental Linkages (PANChSHEEEL) to optimise feeding practices in rural India[1]. The PANChSHEEEL project, led by Professor Monica Lakhanpaul, responded to the need to address the rates of child undernutrition and stunting in rural India, and it set out to explore the linkages between Health, Education, Engineering and the Environment on infant feeding practices, including feeding behaviours, dietary quality and diversity of infants aged 0 to 2 years. Selected rural villages in the Rajasthan state of India were used as a case study site. The research comprised a range of participatory methods that allowed the team to develop a deep community understanding and rapport building. While conducting fieldwork for the PANChSHEEEL project, the research team recognised a further knowledge gap to address the issues of child undernutrition and stunting: the need to explore the Health-Education-Engineering-Environment linkages and how they influenced enteric infections in infants. The realities observed at the field site revealed the need for interdisciplinary work to better acknowledge the broader environment in which infants grow up and develop a holistic understanding of the infant-specific infection risks that may have been overlooked insofar.

From this knowledge gap, an interdisciplinary project to develop an in-depth understanding of the multiple and complex drivers and pathways to infant enteric infections was conceptualised. The proposed PhD project was set to build on the PANChSHEEEL project and complement its findings towards the shared aim of developing a tailored intervention package to address child undernutrition and stunting in rural India, with the PhD project focusing on the infections side. As such, during this PhD project that was conducted between October 2018 and January 2022, I had access to several of the PANChSHEEEL resources. I was able to harness the already established relationships with the local partners (the Save the Children NGO Rajasthan Programme Office team), I was able to access their knowledge and experience, and the already trained fieldwork researchers to collect data and leverage the community rapport that had been built as a result of the previous research engagement. The Save the Children Rajasthan team were the local partners based in the study field site that provided key support in fieldwork logistics, links with the rural study communities, and crucial knowledge about the local realities.

Therefore, the longstanding relationship between the Save the Children team and the supervisory team from previous work was fundamental for the core fieldwork part of this PhD project to happen. Nonetheless, all the work presented in this thesis is entirely my own.

This thesis is organised into 9 different chapters. Chapter 1 presents a background to the research topic. It explores the literature on infant enteric infections, WASH interventions, the current policy situation in India, and it discusses previous findings. Based on the identified gaps in the literature, Chapter 2 presents the project rationale, the conceptual framework underpinning this research, and the overall project aim and objectives. Chapter 3 presents the case study setting: the geographical area, its population, and their historical roots and culture. Chapter 4 outlines the methods used to collect fieldwork data and provides personal reflections on conducting fieldwork-based research. Chapters 5 through 8 present the findings addressing each of the four thesis objectives, respectively. Chapter 9 presents an integrated discussion of the results, bringing together the implications of the findings for future work and concluding remarks. The appendices attached at the end of this thesis contain supplementary information, including the materials and tools used to conduct data collection and fieldwork research. A summary of the career development activities that I have conducted as part of the doctoral training is provided in Appendix A. Throughout the doctoral degree, I have participated in training courses and conferences, language courses, written ethics and risk assessment applications as well as fellowship applications, written and reviewed journal articles, conducted fieldwork abroad, participated in public engagement and outreach events, and others. As a result of the research carried out during this PhD, two peer-reviewed journal articles have been published, and a third one is in preparation for submission:

- Vila-Guilera, J., Parikh, P., Chaturvedi, H., Ciric, L., & Lakhanpaul, M. Towards transformative WASH: an integrated case study exploring environmental, sociocultural, economic and institutional risk factors contributing to infant enteric infections in rural tribal India. *BMC Public Health*, **21**(1), 1331 (2021)
- Vila-Guilera, J., Dasgupta, R., Parikh, P., Ciric, L., & Lakhanpaul, M. Barriers to the Delivery and Uptake of Water Sanitation and Hygiene (WASH) Promotion and Infant Diarrhea Prevention Services: A Case-Study in Rural Tribal Banswara, Rajasthan. Indian Pediatrics **59**(1), 38-42 (2022)
- Vila-Guilera, J., Ciric, L., Canales, M., Parikh, P., Dasgupta, R., Lakhanpaul, M. Assessing enteric infection risks in children from exposure to fecally contaminated water pathways in tribal villages in Banswara, India. (*In preparation*).

1 Chapter 1. Background

1.1 Chapter overview

In this first chapter, I begin the thesis by introducing the key issue at hand: the infant enteric infections and their consequences on child growth and development. I present a review of the evidence on the infection risks and transmission pathways for infants and the water, sanitation and hygiene interventions that have been tested to interrupt them. I follow by discussing the child health policies and programmes in India, particularly the hygiene promotion and infection prevention services that are currently in place. Finally, the background literature presented in this chapter highlights the knowledge gaps and provides justification for this study.

1.2 Overview of the problem at hand

1.2.1 Child diarrhoea, undernutrition, and stunting

In 2020, 5 million children worldwide died before reaching the age of 5[2]. Diarrhoeal diseases accounted for 1 in every 9 of these child deaths globally, making them the second leading cause of child mortality, despite being preventable and treatable[3]. Diarrhoea is a symptom defined as the passage of 3 or more loose stools per day[3]. While it may be caused by food allergies or intoxications, most diarrhoeal cases are the result of an enteric infection with gastrointestinal pathogens[4], particularly in low-and-middle income countries in the Sub-Saharan Africa and South Asian regions of the world, which see the highest diarrhoeal death rates[5]. The burden of diarrhoea and gastrointestinal infections is not evenly distributed across the globe, with India and Nigeria alone accounting for over a third of all the diarrhoeal deaths worldwide[5].

Diarrhoeal symptoms are not a comprehensive indicator of gastrointestinal infections[6], since subclinical enteric infections can often go unaccounted for and untreated. Enteric infections can be defined as “any documented infection of the gastrointestinal tract caused by a range of different bacteria, parasites and viral pathogens that disrupt intestinal functions”[6], regardless of the symptomatic manifestations. Therefore, in addition to the risk of diarrhoeal death, enteric infections are associated with several long-term morbidities related to its underlying effects on the gut. For instance, repeated enteric infections can disrupt several key functions of the gut, such as nutrient absorption, contributing to a worsening nutritional status (e.g. malnutrition) and increased susceptibility to infections[7].

Infants in their first 1000 days of life (from conception to age 2 years) are at a critical developmental phase when their brain is developing most rapidly, setting the foundation for health and wellbeing throughout life[8]. Health disruptions during this particularly sensitive period can entail longer-lasting or more severe consequences[9], so a continuous cycle of undernutrition, where an infant's dietary intake is insufficient, and persistent enteric infections during the early years of life is known to impair child development, including stunted physical growth and diminished cognitive development[10].

Stunting, or short height-for-age, is a prevalent and multifaceted condition that reflects a failure to reach growth potential[11]. Stunting by the age of 2 has been associated with increased mortality, increased risk of infections such as pneumonia and diarrhoea, and increased risk of chronic diseases such as high blood pressure or high glucose later in life[9], as well as reduced capacity of learning and processing new information, lower scores on attention tests, worse fluency, memory, and vocabulary, all of which translate into lower earnings and productivity loss for the societies' economies overall[12]. Overall, child stunting is a strong marker of suboptimal child development, with cumulative effects leading to productivity loss and overall decreased national economic performance[9].

Globally, in 2020, 150 million children under-5 were stunted[13] and an estimated 1 billion children grew up with an impaired physical and cognitive developmental potential[14]. Of these 150 million children, 54 million lived in Southern Asia and 55 in Sub-Saharan Africa[13], showing how the issue of stunting is of concern particularly in low-and-middle income counties in these regions. Furthermore, it is likely that these numbers have been exacerbated due to difficulties in accessing nutritious diets and other basic services during the COVID-19 pandemic[13]. In India, stunting prevalence was estimated to be 35.5% for children under-5, according to the most recent national survey from 2019-2020[15]. Thus, there is strong economic and social justification for directing efforts towards improving developmental outcomes in low-and-middle income countries during this critical window for intervention, the first 1000 days.

1.2.2 Faecal contamination of the environment and WASH

Enteric pathogens are transmitted via faeces, which are passed on when someone ingests elements contaminated with faecal residue containing enteric pathogens, excreted by an infected individual (human or animal)[16]. Several environmental factors can contribute to the spread of faecal contamination and to people's exposures to faecal pathogens. Factors within the physical environment, such as the availability of improved drinking water and sanitation facilities, or factors within the socio-cultural environment, such as the customary hygiene habits and practices, they all play a role in determining the enteric infection risks that exist in every place[17].

Optimal Water, Sanitation and Hygiene (WASH) conditions are essential to maintain a safe environment and interrupt the pathways through which faecal pathogens are transmitted[18]. In 2020, however, over 2.3 billion people still lacked basic handwashing facilities at home, almost half a billion still defecated in open fields, and despite improvements in drinking water sources, only 37% of the population in the least developed countries used water sources that were free from faecal contamination[19]. Poor WASH remains a major global health risk. Conservative estimates suggest that up to 13% of all worldwide deaths among children under 5 are attributed to inadequate WASH, with 2 million deaths that could have been prevented in a year[20].

Furthermore, while WASH interventions should theoretically interrupt pathogen transmission pathways, the design of WASH interventions that improve the hygiene levels enough to see an effect on child health or growth has proved challenging[21]. Three recent large, pre-registered, multi-country trials attempted but failed to significantly reduce child stunting after implementing multiple strategies to improve nutrition and WASH conditions[22]. These results evidenced that addressing WASH factors, at least as currently defined, was not enough to have an impact on child stunting and that a broader view of the complex system of factors is needed, one that considers the physical and socio-cultural contexts, among others[23].

It was argued that the narrow focus of traditional WASH interventions on water quality, provision of toilets and handwashing with soap, may have been a rather reductionist approach at considering the multidimensional and complex pathways to faecal exposures for infants. The WASH sector was called to re-examine the WASH factors considered insofar and identify the broader environmental factors that are potentially being missed[21]. There was a call made by the WHO & UNICEF[24] for community-based interdisciplinary efforts by the WASH sectors to better understand the linkages between the broader environment and child infections and growth[24].

1.2.3 Current status of WASH, enteric infections and child stunting in India

Despite the steep decline in child diarrhoeal mortality over the last 4 decades (from 4.5 million in 1980 to only 0.5 million deaths per year in 2020)[25], and the worldwide WASH improvements since the turn of the century, such as access to improved water sources (from 61% in 2000 to 74% in 2020) and safely managed sanitation facilities (28% in 2000 to 54% in 2020)[26,27], important challenges remain for the global development agenda.

The progression from the Millennium Development Goals to the Sustainable Development Goals (SDG) in 2015 saw an expansion from reducing mortality to also improving healthy living and wellbeing. The SDG's comprise a more nuanced list of 17 goals and 169 targets, which include ending all forms of malnutrition and stunting in children under-5 (SDG 2), ending the epidemics of water-borne and communicable diseases such as diarrhoea (SDG 3), and achieving universal access to adequate and equitable access to safe drinking water, sanitation and hygiene for all (SDG 6)[28]. Parikh *et al.,* demonstrated the wide-spanning benefits of improving WASH, with synergistic links between WASH and all the rest of the 17 of the goals[29], however, it has been argued that "decades of underinvestment in sanitation and hygiene have made this sector the weakest link in the efforts to achieve the SDGs"[30].

Significant work remains to bring the WASH agenda forward and achieve the SDGs by 2030, especially for the country of India, where the challenges associated with WASH and enteric infections are particularly acute. India, being the second-most populous country worldwide with 1.4 billion inhabitants, has held almost one third of all stunted children worldwide[31], a significant proportion (13%) of the total child diarrhoea deaths[32], and a third of all the people defecating in the open (344 million people in 2017[19]). Thus, poor WASH, enteric infections and child stunting remain a paramount challenge for the country.

In India, exceptional efforts to improve water, sanitation and hygiene conditions and reduce child malnutrition and stunting have been seen under several government programmes and so-called flagship missions during this past decade. For instance, rural India was once home to 60% of all the people defecating in the open globally, but in 2014, the Government of India launched the *Swachh Bharat Abhiyaan* or Clean India Mission, which provided funds for the construction of toilets across all rural areas of India with the aim to end open defecation by 2019[33]. After remarkable efforts under the *Swachh Bharat* Mission, India achieved the largest drop in the proportion of people defecating in the open out of all the countries globally, with a decrease of more than 14 percentage points in just 5 years[19]. While challenges remain regarding the uptake of toilet use and open defecation, the *Swachh Bharat* Mission marked a nation-wide transformational shift of attention to the importance of WASH for overall health[33].

A few years after the *Swachh Bharat* Mission was launched, the Government of India revamped their efforts to tackle child malnutrition and stunting under a new scheme that recognised the need to integrate programmes and schemes across ministries to tackle them; the POSHAN Mission. In 2017, the NITI Aayog commission from the Government of India launched the PM's Overarching Scheme for Holistic Nourishment *Abhiyaan* (POSHAN Mission), a multi-ministerial mission designed to bring together different government ministries with the common goal of reducing child malnutrition and stunting[34]. The POSHAN mission laid out an ambitious goal to be achieved: a 2% reduction of undernutrition and stunting in children per year from 2017 to 2022[35], in track to achieve the SDGs by 2030. To do so, the Mission called for the convergence of resources, knowledge, and skills from a wide range of departments and programmes, including the *Swachh Bharat* Mission, the National Health Mission (NHM), the Integrated Child Development Services (ICDS) Scheme, the National Rural Drinking Water Program, and others, to harmonise and integrate policies tackling child stunting[34]. Unfortunately, despite these efforts, progress in WASH and child stunting, both in India and worldwide, are off-track to meet the goals set.

According to the National Family Health Survey (NFHS) in India, the prevalence of stunting in children under-5 has only decreased 3 percentage points from 38.4% in 2016/2017 to 35.5% in 2019/2020[15]. Data from 2019/2020 suggests that child stunting rates have stagnated and even increased in several states of the country[15,36]. Therefore, practically all districts in India need to accelerate their progress in order to reach the POSHAN goals[37], and the COVID-19 pandemic has only introduced additional setbacks. It has been suggested by the WHO that the stunting prevalence estimates for 2020 could be up to 15% higher than what has been predicted, due to the COVID-19 pandemic[13]. In parallel to the stunting trends, half a decade after the SDGs were set, progress towards achieving SDG 6 is also off-track, with almost half of the world's population still lacking access to safely managed sanitation[38]. The COVID-19 pandemic has stressed how crucial WASH services are to undermine public health efforts, and in response to this, a new Lancet Commission on Water, Sanitation, Hygiene and Health was launched in September 2021, to reimagine WASH as a crucial aspect of health, as well as an aspect of social and environmental justice[38].

This first few pages of the thesis have provided an overview of the problem at hand. In summary, the public health problem that this thesis deals with is the issue of enteric infections in infants in rural India, a problem triggered by the lack of basic water, sanitation, hygiene and broader living conditions in low-resource settings, and associated with long-term and severe consequences for child growth and development. This thesis focuses on developing a holistic understanding of the multifaceted factors contributing to enteric infections in infants in rural India, a recognised key underlying cause of child undernutrition and stunting, and with important trickle-down effects for the overall health and development of India. Given the range of complex factors contributing to enteric infection transmission, at the core of this thesis is an interdisciplinary approach that allows to look at the problem from different lenses and draw integrated interpretations of findings. Therefore, this thesis is timely in supporting revamped efforts under the POSHAN Mission, by providing evidence from the grass-root level and recommendations for cross-sectoral interventions tackling child health and stunting. It is also timely in informing the new Lancet Commission by providing critical insights on the current WASH and childhood infection concerns and priorities at the grass-root level. Following this overview of the problem at hand, a more detailed background to the literature on the causes and consequences of enteric infections in infants is presented, followed by a summary of the current health programmes, research trials and identified knowledge gaps to address them.

1.3 Enteric infections and their associated consequences

1.3.1 Pathogenesis of enteric infections

Enteric infections can be caused by an array of pathogenic organisms, but recent studies from children under-5 years in South Asia and Sub-Saharan Africa concluded that the top 6 enteric pathogens attributable to moderate-to-severe diarrhoea cases included *Shigella*, rotavirus, and adenovirus, followed by enterotoxigenic *Escherichia coli*, *Cryptosporidium*, and *Campylobacter*. These 6 pathogens of highest concern accounted for over 77% of all attributable diarrhoea[39]. Rotavirus alone was estimated to be responsible for over 30% of child diarrhoeal deaths globally[40]. *Vibrio Cholerae* bacteria, although only responsible for about 1% of severe diarrhoea globally, are endemic in South Asia[40] and *Campylobacter* infection is also increasingly recognised of high concern for young children, given it is a key zoonotic pathogen that can be transmitted via domestic animals' faeces to the infants' environment[41]. In addition to enteric viruses and bacteria, other enteric pathogens can also include soil-transmitted helminths (intestinal worms), such as *Ascaris lumbricoides* and *Trichuris trichuria*, which infect 2 billion people worldwide each year, a morbidity burden equivalent to that of malaria or tuberculosis[42].

Determining the incidence of each specific pathogen requires exhaustive microbiological techniques, particularly since co-infection with multiple pathogens is very frequent[25], therefore, a commonly used strategy to estimate the presence of enteric pathogens in the environment that is less resource-intensive, is the analysis of *Escherichia coli,* a bacterium that is ubiquitously present in the faeces of humans and animals. *E. coli* is used as a Faecal Indicator Bacteria (FIB), for which the presence of associated enteric pathogens can be estimated[43].

1.3.2 The mechanisms linking enteric infections, undernutrition, and stunting

The specific biological mechanisms linking persistent infections with enteric pathogens to child stunting involve an overall impoverished gut[7]. The continuous ingestion of enteric pathogens disrupts several functions of the intestinal walls. Typically, the epithelial cells in the intestinal walls act as a protective barrier against enteric pathogens, but in an impoverished gut, one perhaps constantly exposed to enteric pathogens, this barrier is broken down[44]. The intestinal wall has a particular shape with finger-like projections (villi) and downward pockets (crypts) (as seen in Image 1-1, left) that have a key role in nutrient absorption and immune functions[44]. In an impoverished gut, the villi are atrophied and shortened (Image 1-1, right), reducing the surface area used for nutrient absorption, the crypts secrete less antimicrobial proteins, and the epithelial cells are less tightly packed, increasing their permeability and allowing for microbial translocation[44]. Moreover, in addition to the loss of nutrients in an impoverished gut, the inflammatory response to infections has been seen to directly affect the bone development required for linear growth[45]. These are some of the key mechanisms that link enteric infections to undernutrition and stunting.

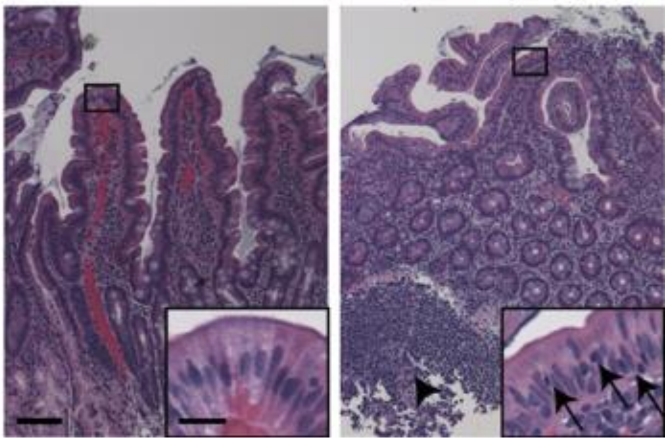


Image 1-1 Duodenal histology of a healthy intestinal wall with normal villi and crypts (left), and a disrupted intestinal wall with atrophied and shortened villi and crypts (right). Source: Histology image extracted from Syed et al., 2018[46].

In parallel, undernutrition, or not eating enough of the necessary nutrients, also damages gut functions and contributes to increased susceptibility to infections. For instance, nutrient deficiencies alter the gut mucosa, flattening the villi and reducing antibody secretion, thus compromising the immune defence functions of the epithelial barrier and greatly increasing the susceptibility to infectious diseases[45]. Severe undernutrition in early infancy leads to ill-developed lymphoid organs, causing long-lasting immune defects and reduced antibody responses. In addition to promoting infections, nutrient deficiencies such as protein-energy deficiencies lead to impaired linear growth, with a further reduction in food intake, nutrient absorption, and increased metabolic requirements[45]. It has been estimated that undernutrition contributes to over 50% of child deaths due to infections[47].

Overall, the interplay of undernutrition and frequent infections leads to a vicious cycle of worsening nutritional status and increasing susceptibility to infection[48]. Undernutrition increases the susceptibility to infections, and infections contribute to undernutrition by diminishing absorption of nutrients and diverting nutrients away from growth towards the immune response[47]. Thus, undernutrition and recurrent enteric infections, and most importantly the interaction of both, are the main causes of child stunting[12]. Based on the literature reviewed[7,44,45,47,48], Figure 1-1 was put together to depict a summary of the key factors in the vicious cycle to stunted growth.

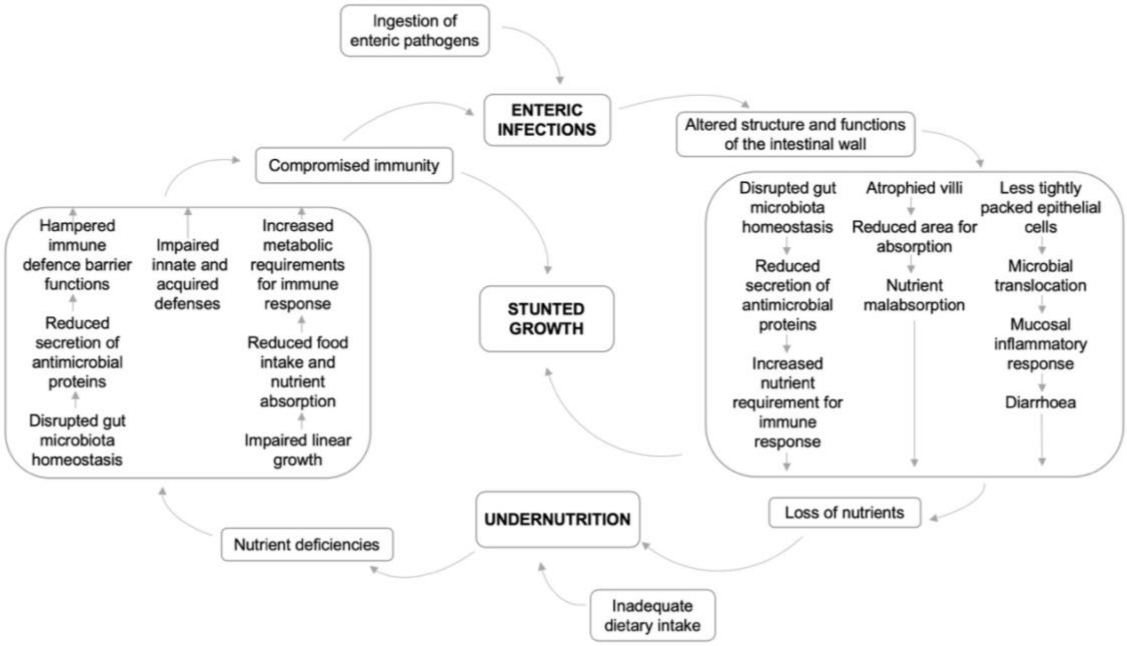


Figure 1-1 Vicious cycle of undernutrition and enteric infections.

It is clear that both the infants' diets and feeding practices, as well as the infants' infection risks and hygiene habits, contribute to the vicious cycle that leads to child stunting. While this thesis focuses on the factors contributing to enteric infections rather than the factors shaping infants' diets and feeding practices, it is important to remember how the nutrition and infection pathways to stunting are both deeply intertwined.

As it has been explained in the preface of this thesis, this study builds onto the work done during the PANChSHEEEL project[49,50] that identified the need to explore the infection pathways to develop a more comprehensive understanding of the undernutrition and stunting burden. Furthermore, stunting prevention programmes have traditionally placed a larger emphasis on feeding practices and nutrient intake, relative to the attention placed to the role of enteric infections and diarrhoea. As aptly pointed by Professor Chambers, *"the mouth remains visible and attractive, and the anus hidden, as in daily life*", and despite many nutrition interventions, WASH has remained "undernutrition's blind spot" in India, where stunting has been persistent[51].

1.3.3 Environmental Enteric Dysfunction (EED)

As it has been previously mentioned, enteric infections can manifest as identifiable clinical symptoms such as diarrhoea episodes but can also remain silent and asymptomatic. Recent evidence has drawn attention to the impact of these subclinical enteric infections and the role they play in the causal pathways to child stunting.

Under the assumption that children's growth is impaired by a poor dietary intake and diarrhoea episodes, numerous studies in the past tested the impact of nutrition and WASH interventions on child stunting[52]. While many of these studies achieved relative improvements in linear growth, few managed to achieve normal linear growth outcomes[53]. Nutrition education interventions, nutrient-dense foods and supplements, and sanitation and hygiene interventions were helping, but it appeared that child stunting could not be fully explained simply by poor diets and diarrhoeal episodes[52]. Thus, a new hypothesis was put forward: that a subclinical disorder of the small intestine could be a primary causal pathway to stunting[52], in addition to clinical diarrhoea and poor diets.

This disorder has now been defined as Environmental Enteric Dysfunction (EED), an asymptomatic syndrome associated with the continuous exposure to enteric pathogens and characterised by overall impaired intestinal functions, including atrophied villous and crypts, increased permeability, reduced nutrient absorption capacity and inflammation of the gut mucosal lining[17]. Rather than a clinical syndrome, EED is considered a longer-lasting condition that involves overall impaired gut functions, leading to linear growth faltering. EED has remained a blind spot in the past due to its unclear clinical manifestation[51]. Studies in Sub-Saharan Africa and South Asia hinted to the ubiquity of EED, as up to 72% of children under-5 were found to be infected with multiple enteric pathogens even when they did not have any diarrhoeal symptoms[54], showing the extent of the widespread burden of unrecognised, silent and subclinical enteric infections.

The hypothesis that EED is caused by the repeated ingestion of enteric pathogens has been validated by studies that have found an association between environmental factors that would introduce enteric pathogen exposures and EED. Several environmental factors within the domestic settings have been seen to be strongly linked to increased odds of EED. For instance, households with poor water quality (*E. coli* ≥ 10 colony-forming units (CFU)/100 mL), inadequate sanitation facilities or unhygienic washing conditions were associated with elevated levels of immunoglobulin G in children, a marker for chronic infection and therefore a proxy for EED[55]. The role that domestic animals play in bringing contamination into the household environments has also been recently highlighted, as EED markers have been associated with having an animal corral in the child's bedroom[56], and children that lived in houses owning cattle or that kept animals indoors had higher odds of an infection-positive stool sample[41].

The role that factors within the domestic environment and living conditions play on infant enteric infections is a complex one that will be further discussed later on, since it is still unclear exactly which environmental factors, and to what extent they would need to be tackled to prevent EED and reduce child stunting. Every factor that contributes to the faecal contamination of the infants' environments increases the risk of enteric infections and stunting, but the threshold of "how clean is clean enough" to keep children safe is still unknown. What is clear is that to address child stunting, integrated interventions need to tackle not only the drivers of dietary intake and acute enteric infections (i.e., diarrhoea episodes) but also the environmental factors that contribute to asymptomatic and underlying enteric disruptions such as EED[10].

1.3.4 The early years of life

From the evidence presented thus far, it appears that repeated enteric infections during the first years of life impair child growth, but what are the specific mechanisms that make the early years of life so crucial? The period between the third trimester of pregnancy through to the first 2 years of life is a well-recognised critical period for brain development, where the brain grows most rapidly and has the highest plasticity, and when much of the brain's final structure is defined[8].

It has been seen that in just four months (from the 5th to the 9th month of life), the structure of the brain matures drastically from a smooth structure to a rough surface indicative of significant complexity[57]. During the first year of life, there is a rapid growth of the hippocampus (crucial for recognition and spatial memory), the visual and auditory cortices, and the prefrontal cortex (responsible for cognitive attention and flexibility), as well as a rapid proliferation of neurones, differentiation (where cells develop complexity), and synaptogenesis (cells develop connectivity)[57]. Failure to provide the optimal environment for brain development during this critical period can therefore entail life-long consequences.

Enteric infections and undernutrition during the early years are relevant to the critical period for brain development because it is the time where the brain is most vulnerable to nutrient deficiencies[8]. For instance, iron, which is the most common nutritional deficiency among pregnant women and young children worldwide[58], has been seen to be essential during the neonatal period as well as from ages 6 months to 3 years. During these periods, the brain requires iron to synthesize proteins that regulate neuronal energy production and other processes that are responsible for motor, socio-emotional or neurophysiologic functioning[59]. In a series of tests in a longitudinal study, zinc deficiencies were linked to lower muscle tone at the new-born stage, lessened reflexes at 1 and 3 months of age, delayed response performance at

7 months, reduced open field exploration at 12 months, to impaired learning outcomes at 3 years of age[60].

These results highlight the long-term effects of early life nutrient deficiencies, spanning across cognitive, behavioural, emotional, physical and motor outcomes. Grain-based diets are insufficient to meet the nutrient requirements, and enteric infections and inflammation significantly affect the absorption and distribution of nutrients such as iron, zinc and proteins[8]. Given this evidence, the need to provide an optimal environment for brain development during the early years of life is clear, including the provision of optimal dietary intake of key nutrients as well as an environment free of enteric pathogens that impair nutrient absorption.

In summary, a range of enteric pathogens can colonise and infect the gut, leading to a series of disruptions on the gut functions. These infections may be acute with clinical symptoms like diarrhoea, or longer-term subclinical conditions leading to undernutrition and impairing growth and development, particularly when they affect infants in their first years of life.

1.4 Faecal contamination of the environment and pathogen transmission pathways

Thus far, the consequences of enteric infections for child health have been presented. Now, the transmission pathways that lead up to enteric infections are discussed in detail.

1.4.1 Faecal-oral routes of transmission and the F-diagram

As previously mentioned, enteric pathogens are transmitted via faeces when they are ingested by a new host. These are otherwise known as the faecal-oral routes of transmission. The seminal F-diagram proposed by Wagner and Lanoix in 1958 was one of the first attempts to describe the main faecal-oral transmission routes from contaminated faeces to a new host[61]. The F-diagram showed how individuals can become exposed to faecal pathogens via mouthing or ingesting contaminated food, fluids (water), fingers (hands), fomites (objects), fields (floors and dirt), and flies (Figure 1-2). The F-diagram also depicted how WASH interventions such as improved sanitation, water supply and handwashing can act as barriers to faecal pathogen transmission.

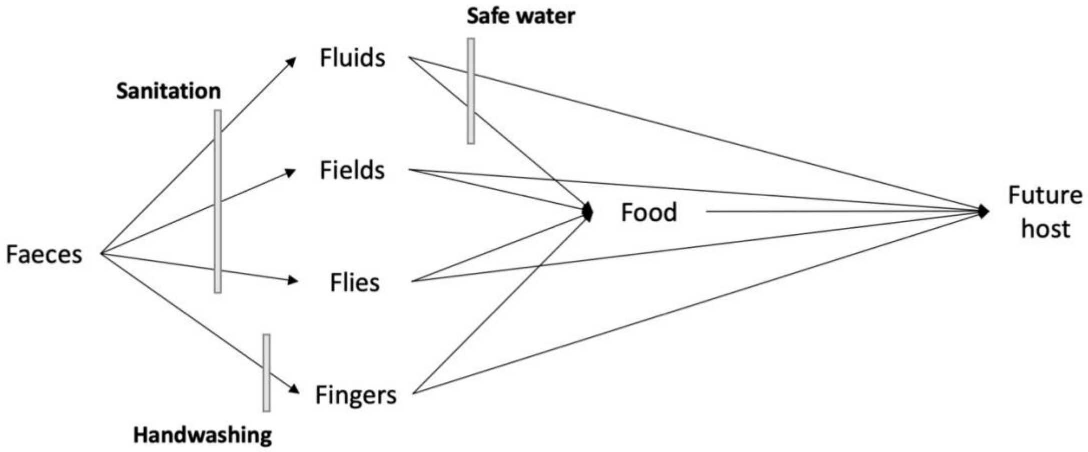


Figure 1-2 Seminal F-diagram of faecal-oral transmission routes. Source: Adapted from Wagner and Lanoix, 1958[61].

Based on the seminal F-diagram, the WASH sector initially placed its focus on improving water, toilets, and handwashing facilities as the key intervention strategies to interrupt some of the faecal-oral routes. However, it is now known that this approach overlooked other transmission pathways, particularly neglecting several infant-specific nuances and the fact that the primary faecal-oral transmission pathways differ significantly for infants[62]. For instance, infants during their first months of life mostly breastfeed, and interventions that focus on interrupting faecal exposure from drinking water or food become trivial for them. Instead, infants constantly perform exploratory and mouthing behaviours, continuously touching and mouthing the elements in their surroundings, which can introduce additional pathways to faecal exposures from the floors as they crawl and mouth the objects they find[10]. While the classic F-diagram did include “Fields” as a potential exposure pathway, this mainly referred to the transmission of pathogens through agricultural produce irrigated or fertilised with contaminated water and soil, neglecting the fact that infants can also be directly exposed to contaminated soil through crawling on earthen floors.

Furthermore, the classic F-diagram (Figure 1-2) focused on human faeces as a source of contamination, but in rural settings where domestic animals are kept in the household vicinities and open defecation is practised, faecal pathogens from both human and animal faeces may spread around the domestic environment and the household floors where infants crawl and play[63]. Other infant-specific considerations may include food hygiene practices particular to weaning foods[24], or infants’ faeces disposal practices.

These infant-specific faecal exposure pathways have been largely overlooked in the past, and therefore remain relatively under researched[62]. This knowledge gap has been increasingly recognised, and it has led to a recent growing body of evidence concerned with investigating WASH factors and enteric infection risk factors particularly relevant to infants in their early years, a field of research that has been coined by the term "BabyWASH"[64]. BabyWASH was coined to highlight the need for infant-targeted WASH studies to prevent EED and child stunting, given the strong economic and health rationale for focusing on this critical period[65], and the fact that it requires age-specific considerations. Hence, while the original F-diagram (Figure 1-2) set the foundation in the field of WASH, an extended version of the F-diagram that illustrates the additional infant-specific faecal exposure pathways highlighted by recent literature was drawn (Figure 1-3). Following, findings from the emerging BabyWASH literature exploring additional and different faecal exposure pathways and risk factors particular to infants are presented. This evidence arises primarily from rural, low-resource settings with poor WASH facilities where faecal contamination is widespread and thus faecal exposure may occur through several different pathways.

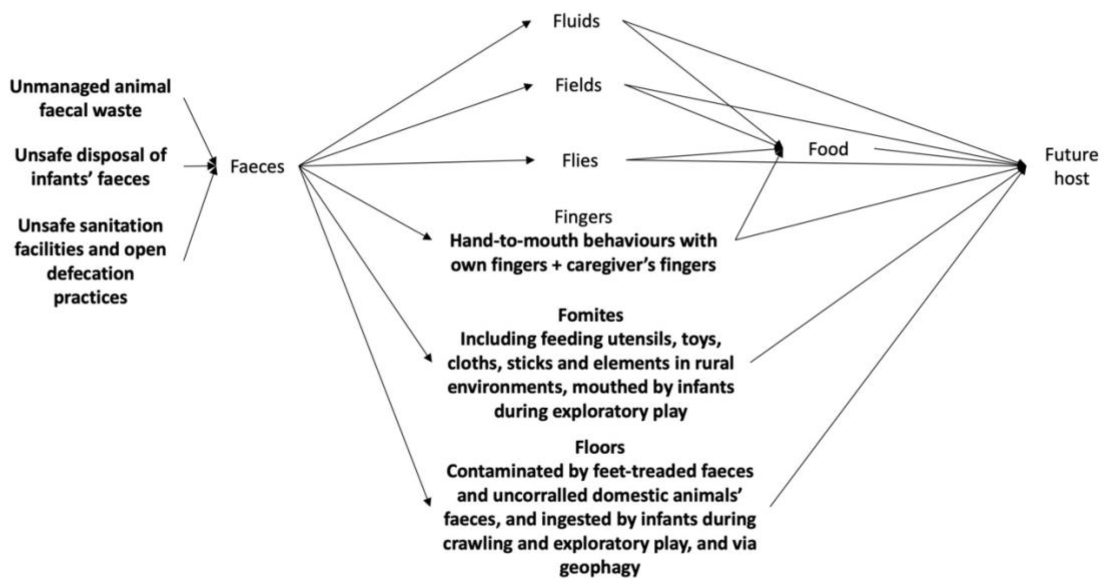


*Figure 1-3 Extended F-diagram of faecal-oral transmission pathways. In **bold**, the additional infant-specific factors are indicated.*

1.4.2 Infant-specific faecal-oral routes: Floors

One of the faecal exposure pathways that is significantly more relevant to infants than it is to adults is the exposure via contact with contaminated household floors. In many rural low-resource settings, household courtyards and household floors are made of dirt, mud, and dung. Such earthen floors collect dust, spills and puddles and may become a breeding ground for mosquitoes and parasites (such as soil-transmitted helminths)[66]. Human and animal feet that tread in faeces outdoors can bring pathogens into the domestic environment, spreading them across the earthen floors[67], which cannot be washed or easily disinfected.

Extensive evidence has been collected on the high levels of faecal contamination that are present on household earthen floors, which appear to be ubiquitous across rural settings[67–72] ranging from 1 log_{10} *E. coli* CFU/ gram of soil in Zimbabwe[67] to 5 log_{10} in Bangladesh[70]. Despite the widespread high levels of contamination on floors, it appears that within households, the floor areas that are shaded, wet or treaded in high frequency tend to be more highly contaminated than areas exposed to the sun[70], even if next to the latrines. In two separate studies in rural Tanzania[69] and rural Zimbabwe[67], the highest bacterial concentrations were found in soil samples collected from the household indoor floors, kitchen areas, and water activities area, rather than those collected from the latrine floor, as would have been expected.

Given the infants' exploratory behaviours while crawling and playing on the floor, they are much more intensely exposed to faecal pathogens that lay on the floor than adults. As such, several studies have found an association between household floor contamination and child health outcomes like diarrhoea and stunting.

In Burkina Faso, for example, children living in highly contaminated domestic environments had a 30% higher probability of being stunted in comparison to those in the least contaminated environments[73], and in Bangladesh, *E. coli* counts in soil were significantly associated with higher prevalence rates of child diarrhoea[74]. In Zimbabwe, households with improved flooring (i.e., cement) were less likely to report child diarrhoea than those households with earthen floors[75]. Upgrading household floor materials may help decrease contamination levels in the house. For instance, improving floor materials from earthen floors to cemented floors was seen to significantly reduce the faecal contamination loads of household floors in Peru by 27% in the Log_{10} *E. coli* CFU per 900 cm^2 of floor[76]. Pooled results from 5 surveillance studies including the large MAL-ED Study in India indicated that floors covered with wood, tiles, or cement rather than earthen floors were associated with a 9% reduction in diarrhoea risk in children[77], although the risk reduction was more highly statistically significant for some pathogens such as Campylobacter spp. and Giardia spp., rather than for enteric viral infections.

Further studies are needed to elucidate the true impact of improved flooring on child health, as children often also play outdoors and around the household surroundings, not only indoors. Despite this, given the high levels of faecal contamination on domestic floors, particularly where domestic animals are present, it is clear that exposures to contaminated household earthen floors need to be considered as a potential faecal exposure pathway for infants.

1.4.3 Infant-specific faecal-oral routes: Animal faeces

As household floors are recognised as a key faecal exposure pathway for infants, the impact of animal husbandry on the domestic contamination levels also needs to be considered. The presence of domestic animals such as chickens, goats, and cows has been associated with higher levels of faecal contamination in household soil samples[71,78]. A study in rural Bangladesh estimated that animal presence increased the soil contamination levels by an additional 0.5 $\log_{10}$ *E. coli* CFU/g (95% Confidence Interval (CI) 0.18-0.91), around an 11% increase[70]. Microbial source tracking techniques have also been used to find out the origin of faecal contamination in domestic soil. In Odisha (India) human faecal markers were detected more often in the domestic domain than in the public domain, but animal faecal markers were widely detected in both domains indicating the ubiquitous presence of zoonotic pathogens in the domestic and wider settings[43].

There are now quite a few studies that have seen a link between animal ownership and the levels of enteric pathogens detected on child stools, thus indicating a link between animal ownership and child enteric infections. A review revealed that domestic animal exposure, particularly to poultry, was substantially associated with an almost 3-fold increase in the odds of *Campylobacter* bacteria in stools (Odds Ratio (OR) 2.73, 95% CI 1.90-3.93)[79] . In addition to *Campylobacter,* other enteric pathogens including enteropathogenic *Escherichia coli* 0157:H7, *Cryptosporidium* spp., *Giardia* spp. have also been found in child stools and associated to domestic animal ownership[63,80]. *Campylobacter* bacteria have been isolated from almost 70% of domestic chicken stools in rural Ethiopia[41] and multiple zoonotic enteropathogens have been commonly found in child stools in rural contexts in Peru and Ecuador[81,82]. While ruminants (i.e., cows, goats) have been identified as the main reservoir of *E. coli* O157:H7 causing human enteric infections[83], poultry (i.e., chickens, ducks) has remained a primary concern for child health, since they are more often left free roaming around the households in contrast to larger animals, increasing the opportunities for faecal exposure to children[84].

Several observational studies have also looked at the associations between domestic animal ownership and diarrhoeal disease or child growth, but with some heterogeneity in the results when looking at different animals and health outcomes. For instance, a meta-analysis found consistent evidence of a positive association between ownership of domestic animals and diarrhoea illness across a range of animals, but a particularly strong association was found for poultry exposure[79]. Instead, exposure to cows in rural India was not associated with child diarrhoea[85], and in Madagascar, cow ownership was even found to be protective against severe diarrhoea[86]. Not only the type of animal but also the number of animals has been seen to impact the effects on child diarrhoea. A recent cross-sectional analysis in Uganda found that having a larger than average number of chickens was associated with an 83% higher diarrhoea prevalence than those with fewer than average number of chickens[84]. By contrast, studies that looked at the association between animal ownership and child growth in Kenya[87], India[85] and 30 sub-Saharan African countries[88] reported not seeing an association between livestock ownership and poorer child growth rates.

While this inconsistent results between ownership of livestock and child diarrhoea and growth may seem confusing, there is a plausible explanation for the heterogeneity in the results. It has been argued that while domestic animals may increase household contamination levels through animal faeces and contribute to enteric infections and impaired child growth, at the same time, animal ownership also increases access to animal-source foods like eggs and milk, improving child nutritional status and consequently growth outcomes[62,89]. This may explain why the presence of domestic animals seems to be more consistently associated with enteropathogen stool infection and diarrhoea, but not so consistently with impaired child growth.

A study that found that when livestock was kept corralled outside the home, children had significantly better height-for-age compared to those that did not keep livestock outside the home[90] may further support the argument that livestock ownership is beneficial for child growth, as long as they are well separated. Nevertheless, as argued by Penakalapati in the most comprehensive meta-analysis (from 2017) summarising the impact of animals and animal faeces on child health[63], there is still scarce information on the health impacts of exposure to animal faeces in rural settings where people live in close contact with animals.

This has led to the concept of One Health gaining momentum in the recent years, One Health is a multisectoral approach recognising and seeking to harmonise the interactions between people, animals and their shared environment has been[91,92]. While the literature indicates that domestic animals and their faeces contribute to the problem of faecal contamination and the enteric health burden[63], further studies with a One Health approach, and a better understanding of the trade-offs between the nutritional benefits and the infections risks posed by domestic animals to infants, are urgently needed to address child health and growth.

From the outset, this thesis was conceptualised to seek a comprehensive understanding of the factors within the infant's environment contributing to enteric infections, including the role of domestic animals, but this evidence further emphasised the need to study the interaction between animals and infants, as potentially important risk factors for enteric infections.

1.4.4 Infant-specific faecal-oral routes: Mouthing and geophagy

As it has been previously discussed, the risk of exposure to contaminated earthen floors or animal faeces around the household domains is much more relevant to infants at the onset of mouthing behaviours, than it is to adults and older children. Infants in their early years frequently perform hand-to-mouth behaviours, which involve constantly mouthing the objects and elements in their surroundings. In environments where infants are exposed to soil, they have also been observed to directly ingest soil, a behaviour known as geophagy[67]. Despite the additional infection risks they pose, mouthing behaviours during the first years of life are part of a normal exploratory stage that is key for child development, in which infants need to acquire information about the visual and tactile properties of objects around them[93].

While the mouthing and exploratory behaviours in infants are necessary and beneficial for their development, they can introduce faecal exposure pathways to infants that live in environments where faecal contamination is widespread. To better understand the infection risks posed by mouthing and geophagy behaviours, several studies have been concerned with quantifying the frequency and volumes of residue ingested by infants via those pathways. By means of extensive structured observations of infants, a study in rural Bangladesh estimated that infants mouthed their hands between 43-72 times per hour they are awake[94], with infants at the stage of crawling having the highest exposure frequencies[95,96]. Through detailed measurements of the soil volumes on children's hands, infants that lived in rural earthen households were estimated to ingest a total of 162-234 mg of soil/day, via mouthing their own soiled hands, via directly ingesting soil or by mouthing soiled objects[94]. Mouthing of objects (or fomites) may happen in high frequencies and they have been found to be highly contaminated, so they need to not be forgotten as important potential faecal exposure pathways[74]. For example, 45% of children were seen mouthing a dirty fomite during a 5-hour observation[97], with object-mouthing frequencies found to be slightly lower but comparable to hand mouthing frequencies[94]. In Tanzanian households, over three-quarters of all the fomite samples tested were positive for *E. coli*. Kitchen utensils, cups, and plates were found to have the highest contamination levels, even in comparison to brooms and latrine walls[69], which may be partly explained by the fact that non-porous surfaces such as steel cups and plates have a higher soil transfer efficiency (up to 57%) than porous surfaces (<7%)[98]. Given that infants can mouth a variety of fomites, surfaces, hands, soils, etc, around a house, the complexity when trying to minimise the infection contact points is not minor.

In addition to the faecal exposures through direct ingestion of soil and mouthing of contaminated objects or hands, direct ingestion of animal faeces, mainly from poultry, has also been recorded. In Peru, toddlers touched poultry faeces and subsequently put their hands in their mouth a mean of 4 times/day[80]. In Zimbabwe, 1-year olds were observed to mouth chicken faeces 2 times (Standard Deviation (SD) 1.4) in a 6-hour period[67]. However, other studies noted that no direct contact with faeces were observed among infants in their first 6 months[67,95,99], and only 2-3% of the infants aged 6-24 months were observed to have direct faeces exposures[95,99]. Ingestion of faeces, even if very sporadic, poses substantial enteric infection risks, as the concentration of pathogens in chicken faeces has been found to be up to 5000 times higher than soil samples[67].

Assessments of exposure frequencies have allowed epidemiological studies to analyse the association between geophagy and mouthing behaviours and child enteric disease. Ingestion of soil (as reported by caregivers) was associated with 2-fold higher odds of stunting (OR 2.27, 95% CI: 1.14-4.51) in Bangladesh[100] and higher odds of diarrhoea (OR 3.13, 95%CI 2.76-3.55)[101]. Mouthing of objects that were visibly dirty was also associated with environmental enteropathy markers in stool samples[74]. Soil, hand, faeces and fomite exposure assessments for U.S infants are available in periodically updated Exposure Handbooks[102], but exposure estimates are much scarcer for infants in low-resource settings. Context-specific exposure studies are needed since estimates from the U.S differ significantly from those in rural low-resource contexts, reporting lower hand-to-mouth and object-mouthing frequencies[103,104], as well as lower soil ingestion volumes[94], likely driven by the physical context differences.

1.4.5 Infant-specific faecal-oral routes: Weaning food

Weaning food can also act as a faecal exposure pathway to infants. Weaning food may become contaminated with faecal pathogens during preparation, storage, and feeding, or due to contact with contaminated kitchen utensils. Weaning food may be prepared separately, using specific utensils (i.e., feeding bottles), or stored, re-heated, and fed at different times from that of adults' meals, so there are several infant-specific risk factors that need to be considered when thinking of faecal exposure pathways to infants.

Weaning foods have been found to be contaminated with faecal bacteria. In Bangladesh, contamination ranged from 0.86-1.84 Log_{10} CFU faecal coliforms/g of food[105]. In Democratic Republic of Congo, *E. coli* levels in food were found to be even higher (0-3.40 Log10 CFU/g of food)[106]. Not heating food to high temperatures and the duration of food storage have been shown to be key factors impacting contamination levels[105]. Epidemiological studies corroborated that poorer weaning food hygiene practices (related to handwashing, food preparation, cleanliness of utensils, water sources, and child bottle-feeding hygiene) were associated with higher odds of diarrhoea among children in their first 2 years of life (OR 4.55, 95% CI 1.08-19.1)[107].

Overall, while traditional WASH studies were focused on improving safe water supply, sanitation infrastructures, and handwashing facilities driven by the seminal F-diagram (Figure 1-2), several other infant-specific pathways to faecal exposure and infection risks have been largely neglected. Evidence compiled mainly during this last decade under a common effort to address BabyWASH has shed light on the importance of addressing domestic contamination factors such as earthen floors, domestic animal faeces, soiled fomites and surfaces, and weaning foods as additional pathways to microbial ingestion for infants (Figure 1-3).

1.5 Progress in WASH intervention design

While evidence from observational studies has gradually uncovered additional important transmission pathways and infection risks to infants, intervention studies have also progressed and seen a shift. Traditionally, WASH interventions were designed following an engineer-led and supply-driven approach that largely focused on providing latrine and clean water infrastructures[108,109], but it was quickly made apparent that such an approach was limited, with engineers realising that "their" facilities (i.e., toilets, water taps) were not being implemented, maintained or used "properly"[108]. It appeared that a more interdisciplinary approach, including professionals from the fields of engineering, as well as anthropology, psychology, health, education, microbiology and others, was needed to address the infrastructural, behavioural, socio-cultural and institutional factors influencing WASH and health[110]. Since the turn of the century, a paradigm shift within the WASH sector was brought about to better understand and acknowledge the role of behaviours and socio-cultural influences to the burden of enteric infections, and to encourage integrative thinking across sectors to address the multifaceted pathways to infection[111].

For instance, it is now recognised that in addition to the infrastructural constraints to safe water access, behavioural factors such as the handling and water storage habits can be important barriers to clean water[112], as well as socio-cultural factors like the community's perception of the water colour, taste, or smell, which may prevent its use regardless of its actual quality[113]. Similarly, toilet infrastructure is crucial for achieving safe sanitation practices, but complex cultural beliefs related to contact with waste, and traditional habits varying with social caste, gender, marital status and age may also prevent toilet uptake[114,115], regardless of the infrastructure. In the case of hygiene, it is understood that the availability of handwashing facilities and soap is only the first step towards the adoption of handwashing practices, and that elaborate hygiene behaviour-change strategies need to be incorporated as key components of WASH interventions for communities to adopt and sustain safer hygiene practices[116]. It has become extremely clear that WASH interventions need to integrate the engineering/infrastructural component with other components, including education and training components, incentives and reminders, and others.

1.5.1 The effect of WASH interventions on child diarrhoea and growth

The progress in the WASH evidence base and intervention design has led to improvements in the intervention effectiveness for some child health outcomes. For instance, according to one of the most recent meta-analyses that included 135 studies, different single WASH interventions were overall associated with lower risk of childhood diarrhoea: improving point-of-use water access, water treatment, and storage reduced diarrhoea risk by up to 75%, sanitation interventions reduced diarrhoea risk by 25%, and handwashing with soap reduced diarrhoea morbidity risk by 30%[117]. Despite these positive results for child diarrhoea, evidence on the effectiveness of WASH interventions on the subclinical or longer-term child health outcomes such as EED and stunted growth is weaker[21]. Even in recent WASH interventions that were more comprehensive with infrastructural and educational components, the effect in reducing subclinical enteric infections and child stunting is unclear, with the literature showing mixed results[10].

For example, two handwashing randomised control trials (RCT) succeeded at finding a significant effect on reducing child diarrhoeal morbidity (41% reduction in Kathmandu and 51% reduction in Karachi) but not on reducing stunting rates (7% in Kathmandu and 3% in Karachi)[118–120]. Similarly, a demographic health survey from 59 countries found that sanitation alone had no effect on stunting but did reduce diarrhoea rates[121]. Then, a meta-analysis that looked at combined WASH trials found only borderline statistically significant effects between WASH interventions and improved child linear growth (Height-for-age z-scores' mean difference 95% CI: 0.00-0.16)[122], making matters more unclear. For this reason, in 2018, three large, high-quality and pre-registered WASH trials were set to bring some clarity on the impact of combined WASH interventions on children's enteric infections and growth[123–125]. These trials were designed to deliver improved latrines, handwashing stations with soap, water chlorination tablets, extensive hygiene education modules, and some other complementary intervention activities. However, the WASH Benefits trials in Bangladesh[123] and Kenya[124], and the SHINE trial in Zimbabwe[125] all failed to find an effect on child growth outcomes and only found mixed effects on diarrhoea (Table 1-1). None of the WASH arms (water, sanitation, and hygiene, respectively) in combination or alone significantly reduced stunting by the age of 2 in children, and they also failed to significantly reduce the prevalence of enteric pathogens in the environment and in child stool samples[126,127].

Table 1-1 SHINE and WASH Benefits trials results

	Diarrhoea prevalence (95% CI of adjusted prevalence difference between control vs trial)	**Stunting prevalence (95% CI of adjusted prevalence difference between control vs trial)**
WASH Benefits-Bangladesh	Water arm: -2.2 to 0.6 Sanitation arm: −3.5 to −1.1* Handwashing arm: −3.6 to −1.3* WASH combined arm: −3.1 to −0.4*	Water arm: -2.6 to 7.3 Sanitation arm: −5.3 to 4.6 Handwashing arm: 0.2 to 10.3 WASH combined arm: −5.5 to 4.4
WASH Benefits-Kenya	Water arm: –3.2 to 4.0 Sanitation arm: –3.2 to 2.6 Handwashing arm: –4.0 to 1.8 WASH combined arm: - 4.3 to 2.0	Water arm: –4.2 to 4.3 Sanitation arm: –2.0 to 6.6 Handwashing arm: –3.5 to 5.1 WASH combined arm: –3.0 to 5.6
WASH SHINE-Zimbabwe	WASH combined arm: - 0.93 to 1.41	WASH combined arm: -0.01 to 12

*Significant difference.

These results were of great significance because they showed that unless truly comprehensive and tailored WASH packages are developed to address the multiple and complex local exposures to enteric disease, stunting will remain[22]. These results emphasised the need to consider a broader range of factors within the infants' environment to ensure the complexity of drivers contributing to child stunting are addressed, for interventions to be effective[128]. Furthermore, these results have prompted researchers in the field to question the role that the RCT methodology in itself played.

RCTs have always been regarded as the gold-standard for rigour and accuracy to determine cause-effect relationships, but Professor Robert Chambers noted that RCTs often fail to address timeliness, as well as failing to recreate real life contexts with multiple factors, and thus the realistic implementation of recommendations that are grounded in an understanding of the local-level realities[129]. It has been suggested that RCTs may not be the most optimal methodology for the WASH sector, since it can be unethical to randomise communities to WASH interventions when they are in urgent need of these basic services, and furthermore, single evaluative methods like RCTs are not well equipped to capture the complexity of WASH interventions and the multisectoral outcomes they entail[30]. Chambers argues that participatory research presents the opportunity to focus on real engagement, dialogue and reflexivity on the complex topics that really matter on the ground, enhancing the rigour of research in this manner[129]. It has been argued that the current "gold standard" definition of research is failing the WASH sector and that perhaps a mixed-methods toolkit centred on participatory design may be the new gold standard for designing and testing WASH interventions[30].

Overall, despite advancements in WASH evidence and interventions, it appears that improving the hygiene levels in the children's surroundings enough to block the multiple enteric infection risks and prevent child growth faltering continuous to be a challenge. The complexity and multiplicity of factors contributing to enteric infections demands for more comprehensive and integrated approaches.

1.5.2 Newly tested BabyWASH intervention strategies

Since the SHINE and WASH Benefits results highlighted the need for more comprehensive interventions, some renewed efforts have been directed towards designing and evaluating new potential solutions to tackle some of the recently recognised infection risks to infants. However, only a few very recent trials have been documented so far testing potential solutions to minimise infants' microbial exposures from soil, earthen floors, animal faeces, soiled hands and fomites, or weaning food, with many of the studies having been published during the course of this PhD.

1.5.2.1 Separating infants from domestic animal faeces

One of the potential solutions that has been explored to reduce infants' exposures to contaminated domestic environments from animal faeces has been corralling and caging of domestic animals. As it has been explained in Section 1.4.3, there are clear trade-offs between the risks and benefits to child health of livestock ownership, given that children can benefit from the nutritious aspects of animal-sourced food while on the other hand there is the risk of them being exposed to animal faeces. Therefore, owning but corralling livestock would appear to be an optimal balance.

Nevertheless, investigative studies have revealed that animal husbandry practices are difficult to intervene on, as they are intertwined with social norms and cultural behaviours, and caging solutions are often cost-prohibitive in subsistence farming contexts[130]. For instance, people have reported being worried about predators and thieves if they left livestock caged outdoors[130], or not wanting to cage them because chickens are perceived to be happier, healthier and produce better eggs when roaming free[131]. The costs of the required materials and labour for constructing the animal sheds pose additional financial constraints[89,131]. In Zimbabwe, the SHINE trial found that none of their participating families wanted to try corralling chickens even after negotiation with the field researchers. Families argued that corralling chicken augmented the costs of feeding them, as well as the potential costs of treating them for parasites, a risk that was perceived to arise from corralling the poultry. Therefore, no animal corralling solutions were trialled in SHINE[132]. Other studies testing the acceptability and effect of different animal corral designs have been presented at recent scientific conferences (UNC Water and Health 2021), with results underway, but different methods to assist caregivers in the separation of infants from animal faeces in rural settings are still needed[16].

1.5.2.2 Separating infants from earthen floors and soil

In many low-resource settings, households are made from rudimentary materials, with earthen floors and walls that are made of soil, mud, or dung. A potential solution that has been explored in recent trials to separate infants from the soil and dirt environments in earthen households has been the provision of infant play yards (protective enclosures) or safe play spaces.

Three different studies in rural Ethiopia and rural Zambia[62,133,134] have recently tested the acceptability and effectiveness of different playpen designs, ranging from locally made designs to brand-made imported designs. All studies found several non-hygiene related benefits associated with playpens, as caregivers commonly reported that playpens aided in caregiving and infant supervision. In particular, mothers felt relieved that infants could be kept safe while they carried out other domestic tasks such as cooking or cleaning[62], protecting infants from fire hazards, from drowning, and from eating soil[134]. Another study in Bangladesh however, found that families reported that children did not want to stay inside the playpen which led to the seldom use of playpens[135]. Despite all these remarks about the acceptability of playpens, the impact in reducing the levels of faecal contamination around the infants and in improving child health outcomes was less clear across the studies. In Ethiopia, *E. coli* was found in the majority of the playpens after a few weeks of use[62], and there were no significant differences in the *Campylobacter* prevalence in child stool samples between the control and the intervention group (with vs without playpens). It was concluded that playpens alone, while they may be helpful as part of a comprehensive approach, they were not able to protect infants from environmental contamination[62].

Another potential strategy that has been explored to reduce the infant's chances of mouthing soil or other soiled fomites has been the use of pacifiers[136]. Rather than separating the infant from the soil and dirt environment it would "occupy" the infants' mouth and prevent mouthing with other objects. However, no trials have tested the impact of pacifier use on the infants' exposure to faecal pathogens, and it is likely that pacifiers would quickly become contaminated from contact with earthen floors and they would potentially introduce new pathways of faecal transmission from the environment to infants[99].

Finally, another potential option for making infant play spaces safe is improving the household flooring type, since earthen floors have been associated with higher risks of diarrhoea in comparison to cement floors [75]. In Mexico, a study showed that replacing earthen floors with concrete floors could potentially reduce child diarrhoea prevalence by 49%, leading to potential improvements in child cognitive development of 36-96%, while also improving the adults' perceived quality of life[137]. In Bangladesh and Kenya, living in households with finished floors for over 2 years was associated with a lower prevalence of enteropathogens and helminths[138]. EarthEnable, an initiative that is set to eliminate earthen floors across Rwanda and Uganda, also reports several benefits from improving household flooring, with their beneficiaries reporting being able to wash and clean the floors, as well as being able to keep children clean and healthy[66]. Thus, improving household flooring has the potential of being a useful intervention to improve child hygiene, but so far evidence is lacking in terms of the impact of improving household flooring on reducing child enteric infections and stunting, and it remains a cost-prohibitive solution for many households.

1.5.2.3 Improving infants' weaning food hygiene

Interventions to improve food hygiene have been more widely evaluated than those for soil exposure, as they are also relevant to adults, but scarce research is available on specific considerations that apply to weaning and complementary foods for infants. In Kenya, researchers realised that the behaviours associated with infant complementary food contamination, such as hand-feeding, and unsafe food storage were largely influenced by broader social and domestic realities of the caregivers. For instance, mothers reported preparing infant food in the morning and storing it for other caregivers to feed it to the child later while they were at work, which inevitably required storing the food throughout the day[139].

Food preparation and storage practices often differ for infant food than for adult food, so weaning food hygiene practices need specific attention. Particularly as many different behaviours can influence food hygiene: contamination can be introduced due to contaminated irrigation water, unhygienic food preparation, water source use, hand feeding, cleanliness of utensils and handwashing, food storage and re-heating practices, etc. In Indonesia, 36 separate food-hygiene practices were identified[107]. In rural Nepal, a creative intervention used a behaviour change approach to design "kitchen makeover parties", which involved local rallies, games, storytelling, competitions, and rewards to tackle several food hygiene practices all at once. This intervention was able to significantly improve and sustain food hygiene behaviours including handwashing with soap, proper storage and reheating of food, as well as cleaning utensils[140], however, the impact on the infants' microbial exposures via food was not measured.

Overall, several food hygiene behaviour change interventions have been successful at improving food hygiene habits, but more evidence on weaning food and infant-specific food hygiene practices and their impact on child enteric infections and stunting rates is needed[105,140–142].

1.5.3 Recognising the knowledge gaps in the BabyWASH literature

The BabyWASH evidence presented above posits that infant-specific considerations need to be acknowledged when assessing infection risks and designing WASH interventions. As presented above, these include the role of domestic animals, child play spaces, geophagy and mouthing behaviours, and weaning food hygiene, among others. Despite the strong economic and health rationale to focus on infants' under-2 years of age given the critical period for development[143], WASH RCTs have traditionally neglected infant-specific factors and have obtained only mixed results in improving child health outcomes[22]. Studies that have evaluated the feasibility and acceptability of measures to reduce infant-specific domestic faecal exposures have only started to be documented[62], and stronger evidence is needed on what the key pathogen exposure pathways for infants in their early years are and how can they be tackled to improve child health and developmental outcomes[10].

The evidence presented so far suggests that no one single solution on its own will be enough to reduce the faecal contamination of the infant's environment enough to see a change in their health and developmental outcomes, so a comprehensive package of interventions is needed to account for the multiple and multifaceted drivers of infant enteric infections.

1.5.4 Towards transformative WASH interventions

After the results from the SHINE and Benefits WASH trials[123–125] which did not succeed at reducing child diarrhoeal and stunting rates, several commentary papers debating the implications of such results were published[22,144]. Why did these WASH interventions fail to improve key child health outcomes, and what should future WASH interventions look like? - the researchers enquired. Concluding remarks from the reflective publications and a position paper published by the WHO/UNICEF[21] reached a consensus statement to guide future work: the need to work towards transformative WASH interventions[145]. And while there is agreement in the need for transformative WASH interventions, what this means remains unclear. Some argue that "transformative" describes an aspirational level rather than a level of services to be achieved, some others that transformative interventions refer to achieving substantial changes in the health outcomes, and others in the exposures (the services and the physical and social environment)[146]. However, a list of consensus characteristics that future transformative WASH programming will require has been put together[21]:

- To be context-specific, responding to local social, institutional, and environmental factors.
- To be risk-based, responding to the local disease burden and transmission patterns. It is suggested that if context-specific risks and exposures are identified, interventions can be tailored to prioritise tackling the most dominant pathways of faecal pathogen transmission in each setting, since these may differ across contexts. For instance, the SaniPath team found that while in Accra, Ghana, the role of raw produce was key for transmitting faecal pathogens, contaminated water from shallow wells was the key contributor to faecal exposures in Lusaka, Zambia[147].
- To re-examine and address traditionally neglected faecal exposure risks[21], such as several infant-specific factors that have been presented in this chapter. The need to separate infants from soiled environments has been particularly emphasised[144]. Reducing exposure to animal faeces will be central to future WASH programming, which will require One Health approaches, where the human-animal interactions are considered in an integrated manner[148].
- To achieve high community coverage for sanitation, and continuous and sustainable access to water[144,149]. Recent analyses on the community levels of faecal contamination have revealed high widespread levels of faecal contamination globally, suggesting that community-level shifts will be required before interventions lead to reductions of diarrhoea[150]. Estimates suggested that currently, less than 50% of the global population lives in communities where at least 75% have access to basic sanitation services[150], which means that community-level coverage is still majorly lacking throughout the globe.
- To strengthen systems of WASH governance. It is argued that an important "transformation" needs to happen at the implementation level, where "greater investment in the systems of governance for leadership, policy, planning, financing, market development, capacity development and monitoring" will be needed. Strengthened WASH governance systems will require interdisciplinary efforts, where different ministries including the ones responsible for water, health, built infrastructure, education, and others, plan convergent action.
- To be equitable, efficient, affordable, and sustainable, in addition to being effective at improving health outcomes. WASH economists have pointed out that interventions that are highly effective in their target health outcome may not be cost-

beneficial, and *transformative* WASH interventions must not be only evaluated on the magnitude of the effect they achieve but also on their scalability and opportunity cost[146].

1.6 Child health and WASH programmes in rural India

Given the evidence that has been accumulating on the relevance of early childhood development during the first 1000 days of life and the BabyWASH risk factors, some countries have developed specific BabyWASH guidelines to optimise WASH and infant enteric infection prevention practices, and ultimately improve child health and development. For instance, the Federal Ministry of Health in Ethiopia developed an implementation guideline for frontline health workers and organisations working in the WASH, health and nutrition sectors to integrate BabyWASH interventions into their programmes[151]. The guide defines a set of interventions that focus on pregnant women and infants in their first 3 years of life, with the overall aim to reduce the microbial burden and promote child health. India, being such a large country and divided into states, does not have an equivalent nationwide guide for implementing BabyWASH interventions. Instead, several government schemes are in place to address several relevant aspects of WASH, child health and infections, and child malnutrition, growth, and development, in a more fragmented manner. To be able to understand the challenges in implementing potential BabyWASH recommendations, it is important to understand the current government schemes in place that are relevant to WASH, infections, and child health.

There are three cadres of frontline health workers that are in charge of delivering child health services in rural India: the Auxiliary Nurse Midwives (ANM), the Anganwadi workers (AWW), and the Accredited Social Health Activists (ASHA). The first ones to be introduced were the ANMs, implemented in 1950 to be based at the grass-root level healthcare facilities, which are available across rural areas and are known as health sub-centres[152]. ANMs were envisioned to be in charge of providing basic health care at the sub-centres to serve rural communities, in addition to performing visits to the villages in specific occasions such as for vaccination schemes. The second cadre of frontline health workers to be introduced was the AWW. AWW were introduced in 1975 when Anganwadi centres were implemented across rural villages in India. Anganwadi centres are public rural childcare centres that serve as platforms to deliver child health, nutrition, and early learning activities, like pre-schools or kindergartens[152]. AWW are the government workers in charge of the Anganwadi centres and delivering the activities in it[152]. Lastly, in 2005, the ASHA scheme was launched to provide a third cadre of frontline health workers to aid AWW and ANMs across rural areas, and to act as a link between the rural communities and the public health system.

Under the current Government of India and delivered by the three cadres of frontline health workers, two main flagship programmes are in place to deliver child health services in rural areas: The Integrated Child Development Services (ICDS) Scheme and the National Rural Health Mission (recently re-named National Health Mission-NHM).

Since its inception in 1975, the ICDS Scheme's focus was to address early childhood development, with the specific objectives to improve the health, nutrition and education of children aged 0-6 years in rural areas[153]. To achieve these objectives, the scheme offers a package of services delivered at the Anganwadi centres, which includes the delivery of complementary nutrition packets for children under 6 years, the provision of pre-school non-formal education for children aged 3-6 years, nutrition and health education to mothers of children under-6, provision of child immunisations, as well as health check-ups and referrals for pregnant and lactating mothers[153]. This package of services are delivered by AWW, aided by the other frontline health workers. The package of services are envisioned to be delivered at the Anganwadi centres on a daily basis, and also during organised village events such as the PUKKAR meetings, which are meetings with pregnant and lactating mothers, or Village Health and Nutrition Day (VHND) events, which are fixed monthly village meetings with new mothers and young children.

Among the ICDS package of services, the provision of nutrition and health education component provides a platform with huge potential for the delivery of WASH promotion and raising awareness on child infection risks[154]. However, while the ICDS scheme seeks to improve the infants' health and nutritional status, ICDS guidelines do not place an emphasis on WASH promotion and infection prevention education, despite being critical factors contributing to improved nutritional status[154]. Prior studies have found that only a minority of AWW were providing nutrition and health education in Bengaluru[155,156], with the majority (80%) of AWW reporting a lack of guidance on how to do so in another study[157].

The other key national flagship programme delivering child health services is the NHM, which was launched in 2005 to revamp healthcare in underserved rural areas. Under the NHM, ASHAs were introduced as the key components of the Mission[158]. ASHAs are women that reside in the village they serve and who are trained primarily to act as "social health activists", providing health education and community mobilisation services, and as "link-workers", facilitating access to higher healthcare services[159]. Based on the ASHA's government guidelines[159], Figure 1-4 was drawn to summarise her key responsibilities.

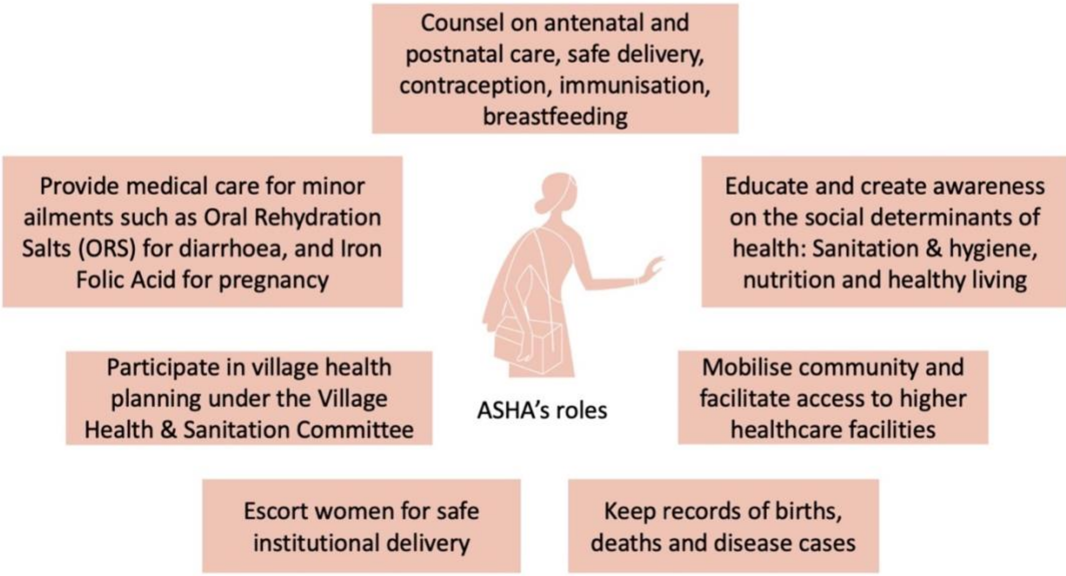


Figure 1-4 ASHA's main roles and responsibilities

ASHAs' responsibilities under their link-worker role (i.e. linking rural communities to health services) range from maintaining data on births and disease cases, mobilising parents to make sure all eligible children are immunised, providing first-aid treatments like Oral Rehydration Salts (ORS), providing referrals to higher healthcare services in case of severe diarrhoea or malnutrition cases, escorting pregnant women to hospitals for institutional delivery, etc[159]. Their health activist role involves activities to create awareness and provide information on the determinants of health such as safe WASH practices, nutrition and healthy living, including infection prevention advice[159].

In addition, ASHAs and the other frontline health workers (AWW, ANM) also have the responsibility of contributing to the improvement of the village-level sanitation and hygiene by being part of the Village Health, Sanitation & Nutrition Committees (VHSNC), committees to which the government provides funds to take collective action for village health planning and infrastructural needs[160,161]. While ASHAs are "honorary volunteers", some of their responsibilities such as escorting pregnant women for institutional delivery or ensuring child immunisation are further incentivised via monetary compensation[159].

Therefore, the services provided by frontline health workers, and in particular by ASHAs, such as their social health activist role, the VHND, VHSNC, etc, are valuable programmes and platforms that are already in place to raise awareness on WASH factors and infant infection risks across rural villages. However, integrated guidelines to address BabyWASH factors are missing, as current government schemes to improve WASH, child health and infections and nutrition are scattered across ministries, programmes, and frontline health workers' responsibilities. Thus, while the platforms for delivering these key services (WASH promotion and infection risk awareness for child health) are already in place, there may be gaps in how they are being implemented, delivered, or taken up.

It is precisely for this reason that the POSHAN Mission was launched. The POSHAN Mission was launched to foster convergent action across different ministries (i.e., Water, Sanitation, Child Development, Health, etc) to accelerate progress with the problem of child malnutrition and stunting. However, challenges remain to enhance the programme implementation and reach[162]. Several states remain without having used any of the funds under the POSHAN Mission, and it is argued that the Mission warrants further evidence-based research to inform recommendations for implementation at the grass-root level[162]. Evidence from the grass-root level generated during this PhD project will timely support the POSHAN mission and its impending goals by informing its guidelines for convergent action on child malnutrition and stunting.

2 Chapter 2. Theoretical approach, rationale, and objectives

2.1 Chapter overview

Having presented the background literature in chapter 1, this second chapter explores the theoretical approaches and conceptual frameworks to understanding the multifaceted drivers to enteric infections and child health. Based on the evidence presented, I provide the rationale that justifies this thesis' work and define the overall aim and specific objectives of this thesis.

2.2 A holistic conceptual framework

2.2.1 Recognising complexity in WASH

It is understood from the literature presented in the background chapter that WASH factors and infection drivers are influenced by complex and interlinked factors within the physical and socio-cultural environments in each specific community, and that a reductionist approach that undermines the complexity of the systems proves insufficient to impact health. There is a need to recognise the complexity of systems to develop successful BabyWASH programmes, but what is exactly meant by recognising and addressing complex systems? Efforts to better understand this have been described by the complexity theory[163].

Under the complexity theory, "complexity" has been defined as a state where there are patterns that are not immediately obvious because the patterns do not repeat themselves in an exact manner at every instance[163]. Human societies are one of the most relatable examples of a complex system because unexpected dynamics can arise from the interactions among its "parts" (i.e., the people), but underlying patterns shape how societies behave.

For example, in a rural community with poor WASH conditions, it is not possible to accurately predict when each infant is becoming exposed to faecal pathogens. However, patterns of how and when that happens are identifiable. For instance, understanding the behavioural patterns that define the common defecation practices in a specific community would enable the prediction (to a certain degree of certainty) of how and when infants may become exposed to faecal pathogens in this community. Patterns on hygiene and caregiving practices are formed through the physical, social, and policy environments in the system. Hence, complex systems such as poor WASH communities require an integrated approach, to be able to identify the underlying patterns. Complexity is therefore the foundation that triggered the need for Systems Thinking[163], a stream of thought described below.

2.2.2 Systems thinking

Systems can be understood as a "*set of elements (i.e., people, cells, molecules) that are interconnected in such a way that produce their own pattern of behaviour over time*"[164]. Systems Thinking was first coined as a term by psychologist Barry Richmond, who defined it as "*the art and science of making reliable inferences about behaviour by developing an increasingly deep understanding of underlying structure*"[165]. Under the Systems Thinking approach, systems need to be viewed as an integrated whole, rather than the sum of its parts taken in isolation[166]. That is because the interactions between the "parts" of a system (i.e., the people and the environment) lead to a set of emergent behaviours and patterns that cannot be identified unless the system is observed as a whole[163].

Systems Thinking not only served as a new approach to science, but it also reinforced a paradigm shift that moved away from linear reductionist principles, towards integrative modes of thinking[166]. Traditionally, science has succeeded at understanding several phenomena in this world by breaking them down into smaller parts and simplifying living systems into linear models. Such an approach is useful in many cases, but it loses sight of the context and the interactions between the parts of a system[163]. A Systems Thinking approach emphasised the need to shift the focus from the measurement of the systems' component properties to their interconnectedness and observation of patterns in a system[166]. The shift towards integrative thinking highlighted the value of holistic syntheses of complex systems, rather than reductionist analyses with linear models. Integrative Thinking valued the understanding of qualitative properties, rather than focusing on quantitative properties only[110]. Overall, a Systems approach understands knowledge as a network[166].

A particular strand of Systems Thinking that considers the dynamics between the social and ecological parts in a system are Social-Ecological Systems. Social-Ecological Systems focus on understanding the links between the natural systems (the natural and physical environment) and the social systems (socio-cultural, economic and policy environments) at the different hierarchal levels[163]. Socio-Ecological Systems can also be understood as Complex Adaptative Systems since they describe a dynamic network of interactions between individual and collective components[163]. These ideas of Systems Thinking are relevant to understanding the problem of poor WASH and enteric infections in infants. Viewing the issue of community WASH and enteric infections as a Social-Ecological System can prove useful to think of the range of factors across the different dimensions that can drive WASH-related infections. Physical and environmental factors (e.g., natural resources, technologies and infrastructure), socio-cultural (e.g., habits, behaviours, knowledge, attitudes), and economic and institutional factors (e.g., financial opportunities, public services) all interact in complex environments (i.e., communities) populated by complex agents (i.e., people), leading up to the transmission of enteric infections. Thus, it appeared that adopting a Socio-Ecological Systems Thinking approach would compel me to consider the network of relations between WASH factors across natures and levels, helping me work towards a more integrated understanding of the enteric infection drivers to infants in the study setting.

2.2.3 The socio-ecological model

To synthesise and visually represent the Social-Ecological Systems Thinking approach, several frameworks have been developed. In 1991, Dahlgren and Whitehead developed the socio-ecological model[167]. Since then, the socio-ecological model has been used to understand the complex and interrelated factors influencing health outcomes across a series of hierarchical layers (or agency levels) (Figure 2-1)[167]. The model maps factors across the multiple levels of agency (individual, family, community, and wider societal environments), and considers the physical and socio-cultural dimensions. The socio-ecological model recognises the multi-level and multi-dimensional complexity of health determinants, but it also recognises their interrelationships, and it illustrates how factors at one level influence factors at another level. For instance, structural factors at the societal level (such as education, housing, and health care systems), operate through intermediary factors at the community and family level (e.g., habits, lifestyle behaviours) to impact individual health (e.g., enteric disease).

The socio-ecological model has been used to guide studies and public health strategies across many different fields. Because it is broad in scope, several adaptations of the model are used, with UNICEF employing a 5-level hierarchical model[168] and the CDC employing a four-level model, for example[169]. In the field of WASH, several studies have employed adapted versions of the socio-ecological model to comprehensively understand the multiple influences to different WASH behaviours such as handwashing and latrine use[170,171]. For instance, a study in Ethiopia used an adaptation of the socio-ecological model to understand the determinants of latrine use, categorising them into individual-level psychosocial factors (i.e., beliefs & perceptions on sanitation), household-level factors (i.e., family dynamics, living circumstances, and financial barriers to sanitation), community-level factors (i.e., social norms, cultural beliefs) and societal-level factors (i.e., geographical and political climate), which were all explored[172]. Since the socio-ecological model has proved useful in other WASH studies that looked at and categorised the range of factors contributing to a health outcome of interest, it was also considered to guide and underpin this study.

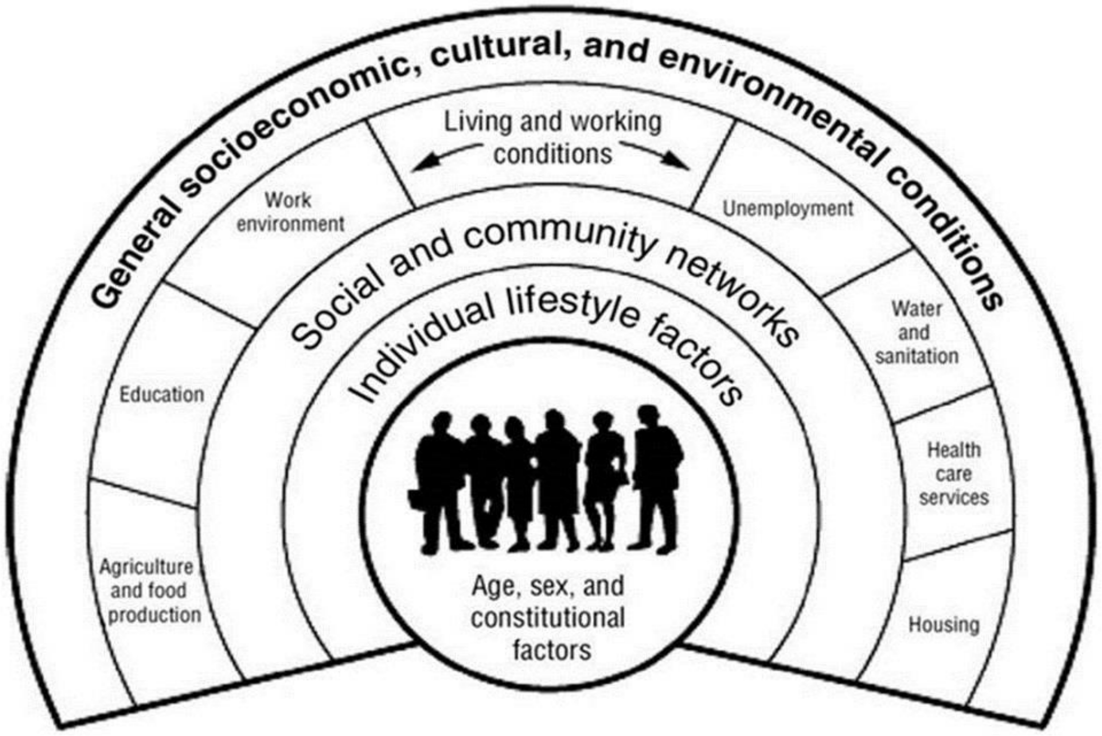


Figure 2-1 Socio-Ecological Model. Source: Extracted from Dahlgreen and Whitehead, 1991[167]*.*

2.2.4 The need for interdisciplinary and participatory approaches

Interdisciplinary teams are essential to work with complex Socio-Ecological Systems that are concerned with factors across disciplines, and also need to consider the interactions between them[163]. However, traditionally, academia and other institutions have struggled to work across disciplines and move from their disciplinary silos[110], with the fragmentation of knowledge also translating into governmental divisions by disciplines (i.e., Ministry of Water, separate from the Ministry of Maternal and Child Health, separate from the Ministry of Housing and Urban Affairs).

Interdisciplinary teams need to include not only experts from different disciplines but also experts from different forms of expertise, including the local community and study participants. Thus, a key aspect of interdisciplinarity is adopting a participatory approach. As engineers, sociologists, or health professionals can bring more theoretical and formal knowledge, the community members and their local perspectives are essential for the experiential and grounded knowledge of the context[163].

As Professor Chambers argues in his report "*Whose Reality Counts?"*[173]*,* the participants are undoubtedly the experts of the study context, and their realities should not only be included as tokenism in participatory research, but they should be given the decision power to be central to the design of development programmes that need to be tailored to their contexts. Engineer Roland Clift describes this shift towards participatory research by suggesting that professional experts should take the role of "honest brokers", where, rather than deciding, designing and delivering technological solutions, the experts' job should be to describe a range of technical options that provide locally suitable solutions to the participants, who are then the key decision-makers[174], just as a broker-client relationship. Figure 2-2 clearly illustrates the different necessary questions that may be asked in an interdisciplinary team that includes local stakeholders[163], which would ensure that agents across expertise and communities are given the voice and the power to highlight WASH development considerations that each considers essential from their own perspective.

The water tap is broken…

Engineer: Was the tap quality poor?
Educator: Do you know how to fix the tap?
Sociologist: Do the community all agree that the tap should be fixed?
Health worker: Who is affected by the lack of water?
Politician: Whose responsibility is it to fix the tap?
Local man: Do you know the shopkeeper so that you can get spare parts?
Local woman: I am so busy, I am going to the river to collect water while you work it out.

Figure 2-2 Example of possible questions asked by an interdisciplinary team. Source: Excerpt from Neely's book "Systems thinking in WASH", 2019[163].

2.2.5 A call for applied Systems Thinking

Theoretical evidence on systems thinking and the value of integrative, interdisciplinary and participatory research is not new and was first published several decades ago[165]. However, applying the theoretical knowledge to real-world scenarios has remained a challenge for many years. To transform approaches and theory into programmes and policies that can be delivered has been the main difficulty faced by practitioners. The difficulty in the applicability of these ideas has contributed to a persistent tendency to reductionist WASH development programmes despite the recognised value of holistic approaches[163]. Nevertheless, the staggering evidence on how essential such holistic approaches have started to shape applied research and policy frameworks. For instance, since the concept of One Health was coined, further integrated research into how humans, animals and the environment interact is being produced[91,92]. Accumulating evidence on the importance of the early years has also triggered studies and initiatives that look at child health holistically during this critical period.

Notably, the BabyWASH Coalition was founded in the recent years, a multi-stakeholder platform with the purpose to bring together stakeholders from different fields and promote integrated action between sectors, namely the fields of WASH, nutrition, early child development, and maternal and child health, with the common aim of improving infant's wellbeing in the first 1000 days of life[65]. Furthermore, examples of governmental efforts to work across sectors and develop integrated solutions to child health have also been seen. Such is the case of the POSHAN Mission in India, a public programme with the pivotal purpose to converge actions across different government ministries and integrating efforts to tackle child malnutrition[35].

The need for holistic approaches is no longer limited to theoretical studies, and it is now an active call from governments, public institutions, and initiatives to apply it to look at problems and provide solutions in a comprehensive and holistic manner.

2.2.6 Theoretical framework guiding this study

Bearing in mind the theoretical evidence presented, it was decided that in view of the complexity of factors influencing WASH and infant enteric infection drivers in rural communities, the socio-ecological model was going to be used as a guiding theoretical framework underpinning the study design, aims, and methods, so they could be explored using an integrated and holistic approach. In this manner, the study communities in this project were viewed as Socio-Ecological Systems. The purpose of the systems approach was to better understand the multiple and complex factors contributing to enteric infections in infants in selected study villages of rural India. The local community members were viewed as the system's agents, the system boundaries were inherently defined by the limits of the case study villages, and the elements of the system were the different factors contributing to infant enteric infections across a range of natures (physical-environmental, socio-cultural, and institutional dimensions) and their interdependencies across individual, family, and community-levels, as structured in the Socio-Ecological model. Adopting the socio-ecological model as the theoretical underpinning of the study served to compel me to consistently adopt an interdisciplinary, holistic approach along the different research stages of the study.

2.3 Rationale

Based on the prior research during PANChSHEEEL[49,50], the background literature reviewed, and the current knowledge gaps towards improving BabyWASH, the key arguments motivating this research study can be summarised as:

- Prior research conducted during the PANChSHEEEL project in rural India identified the need to better understand the drivers of enteric infections for infants in their early years, paying attention to the broader physical and socio-cultural environment to gain a comprehensive understanding of the multifaceted factors contributing to child undernutrition and stunting, a cornerstone for the development of India.

- Enteric infections in infants, particularly during the first 2 years of life, are still responsible for a significant morbidity and mortality burden worldwide, especially when considering their associated consequences for child undernutrition and impaired linear growth and development.
- Basic and safe water, sanitation and hygiene conditions are essential to interrupt exposures to environmental faecal pathogens and enteric disease, yet they are still lacking across most low-resource settings such as several rural Indian contexts. Rural India is of particular concern given that it is amongst the most populous countries and large numbers of children are exposed to poor WASH and enteric infection risks.
- There are national and international goals in place to improve WASH (SDG6) and reduce child enteric disease morbidity and stunting rates (POSHAN Mission & SDG2), but knowledge gaps on how to best achieve them remain.
- Different measures to improve WASH conditions and interrupt faecal exposure pathways have been tested, but the results obtained have been rather unsuccessful at reducing enteric disease and stunting rates.
- There is a knowledge gap regarding the nature and magnitude of infant-specific infection risks and transmission pathways, which have been largely neglected, and very limited evidence is available on potential strategies to address them.
- Current thinking suggests that to achieve successful WASH programming, the sector needs to move towards *transformative* WASH interventions: These will probably need to be tailored to each context, responding to the local risks and transmission patterns, considering infant-specific risk factors such as domestic contamination by animal faeces, and strengthening WASH governance and delivery systems.
- The sector of WASH needs to better understand the broader risk factors across sectors contributing to infant enteric infections in an integrated holistic manner.

Given these arguments, it was considered that conducting a holistic in-depth exploration of the environment surrounding infants would enable an understanding of the communities' inner workings, and their physical, socio-cultural, economic, and institutional realities. It was thought that developing this in-depth holistic understanding could lead to the identification of underlying factors contributing to infants' enteric infections that are being overlooked in current interventions, potentially leading to findings that inform future research towards *transformative* WASH.

2.4 Aim and objectives

The overall ***aim*** of this study was to develop a holistic understanding of the multiple risk factors and transmission pathways to enteric infections in infants in rural tribal India and develop tailored recommendations for local programming. Four individual objectives were defined to address the overall study aim:

> **Objective 1.** To holistically explore the multiple and multifaceted risk factors at the individual, household and village-level contributing to infant enteric infections.
>
> **Objective 2.** To assess the faecal contamination levels in the infants' environment and evaluate the risks of enteric infection from multiple transmission pathways.
>
> **Objective 3.** To identify key barriers for the delivery and uptake of rural child healthcare services, particularly WASH promotion and infant enteric infection prevention services.
>
> **Objective 4.** To co-develop a set of tailored recommendations to inform local policy and programming for enhancing infant hygiene and enteric infection prevention practices.

To achieve the study objectives, I planned to carry out extensive data collection in a case study field site. The following chapters present the case study site and the methodology used for data collection during the fieldwork period.

3 Chapter 3. Case study in Banswara district

3.1 Chapter overview

In this third chapter I introduce the case study area where the fieldwork and data collection for this project took place. I provide a detailed contextualisation of the case study by describing the geographical, historical, and socio-cultural background of the study setting and its population.

3.2 Study design

3.2.1 Case study

To address the study objectives, a case study design was adopted. A case study design is characterised by the generation of new knowledge grounded in a specific research environment[175]. Case study research allows linking the micro-level actions observed at the individual level to larger-scale social structures and processes[110]. A case study design responded to the aim of the project that required an in-depth, comprehensive examination of the complex day-to-day realities of the study communities, by focusing on a specific research setting to generate new knowledge regarding what *transformative* WASH entails and what key infection drivers may be being missed insofar. A case study approach is not tied to a specific method or tool for data collection and analysis, instead, it usually involves different types of observation and data gathering methods[175]. The interpretation of the data from a case study differs from other study designs where generalisation forms the foundation of the study. Instead, the cornerstone of case study research is ensuring access and engagement with the selected case site and the use of various methods enabling an integrated interpretation of results and increased reliability and validity of the data collected[175]. Thus, while yielding context-specific results limited in their generalisability, a case study design allowed me to capture a nuanced and holistic picture of enteric infection drivers in the study setting, which could potentially serve as an exemplary case representative of other similar settings, laying the groundwork for future epidemiological, microbiological, or trial studies that test and tackle newly recognised key factors.

3.2.2 Building up upon previous work

As described in Chapter 1, this PhD was conceptualised to build upon the findings uncovered during the PANChSHEEEL Project[49] which looked at the health, education, engineering and environment linkages influencing infant feeding practices, and ultimately child malnutrition in rural tribal India. Given that poor diet and enteric diseases are the two main underlying factors contributing to child malnutrition and stunting[176], this PhD was set to bring the PANChSHEEEL work forward by exploring the multifaceted drivers to infant's enteric infections. To expand on the PANChSHEEEL research and leverage the relations with local partners and study communities, this research was carried out in the same study setting: in 9 selected rural tribal villages of the Banswara district in the state of Rajasthan, India.

3.3 Study setting: Banswara district, Rajasthan

3.3.1 Location and geography

The district of Banswara is located at the southern tip of the Rajasthan state in north-west India, bordering the states of Madhya Pradesh and Gujarat (Figure 3-1). With a surface of over 5000 km^2, it has an undulating topography with high hills and narrow valleys, making rural areas less easily accessible[177]. The region sees a semi-arid climate with highly variable rainfall mainly concentrated during the monsoon season, and frequent droughts. The river Mahi crosses the district from east to south, and it is the source of irrigation for most crops of the area via the Mahi district canal[177].

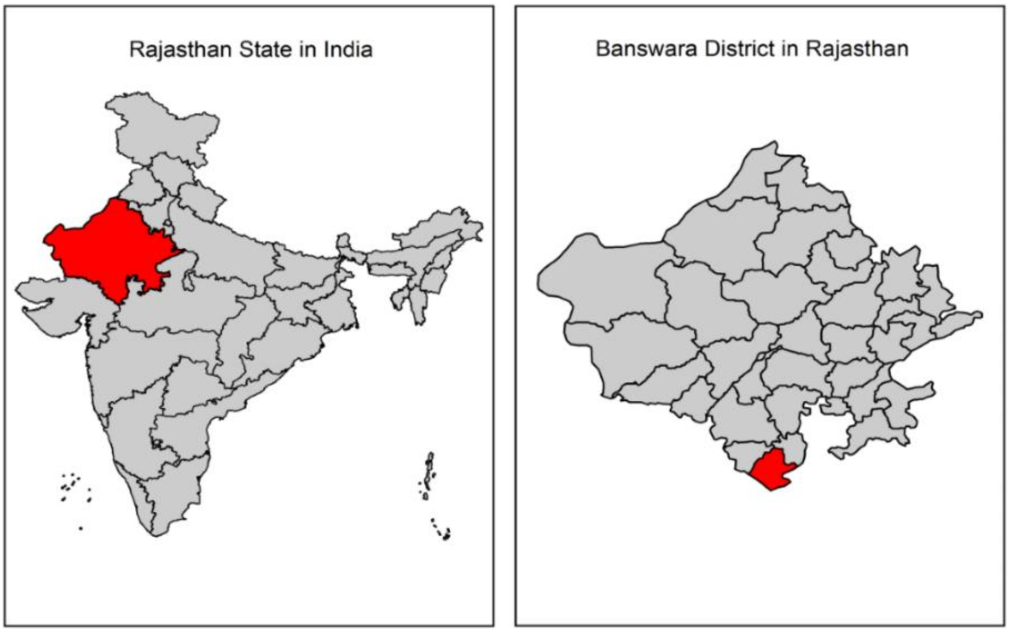


Figure 3-1 Location of Banswara district. Source: Banswara District Census Handbook (2011)

3.3.2 People and culture: the Bhils

Banswara is characterised by being mainly a rural district. With a population of 1.8 million (2011, last census)[178], over 93% of them live in rural areas[179]. Banswara is one of the few predominantly tribal districts remaining in India, in which over 75% of its population pertains to Scheduled Tribes (explained below)[178].

The tribal population of Banswara mainly belongs to the *Bhil* ethnic group, a group of communities that have inhabited the forests of southern Rajasthan since as far back as 1400 BC, and it is considered one of the oldest tribal groups of the country[180]. In 1949, *Bhils* were designated by the Indian Constitution as a Scheduled Tribe (ST), a term used to categorise tribal communities into social classes for the purposes of official statistics. ST's were classified as a disadvantaged group due to their poverty, illiteracy and health levels[180].

Prior to the Indian Constitution, the *Bhils* lived mostly isolated from the rest of society and retreated to the interior of the hilly forests that they inhabited during the time of colonial invasions in the past, therefore managing to maintain many of their tribal customs. *Bhils* were traditionally an agrarian society that, for many years, lived off cultivation, hunting and gathering in the forests, independently of other civilisations. *Bhils* traditionally strived for self-subsistence, and consequently, they highly regarded the protection of nature and their crops[180]. Therefore, *Bhil* settlements were characterised by their scattered households, which were generally constructed around their agriculture fields. Households were built next to the agricultural land, as land ownership was the main source of livelihood and an indicator of one's social position[180].

Traditionally, *Bhils* followed a pattern of patrilineal nuclear families. This meant that once sons got married, they would be given a share of agricultural land from the father and would be expected to lead mainly a separate life with their wife and children and care for their crops independently[181]. This pattern contrasts with non-tribal families and that more common in other parts of India, where the cultural norm is of joint families, where parents co-live with their sons and married wives and share the agricultural land and work. The recent decades have brought about a shift in the family organisation patterns of *Bhils*. Now, scattered houses from *Bhil* families have become more condensed, often forming hamlet settlements – or *phalas* – where a few family units have grouped together, representing a common clan[181] (Image 3-1).

Image 3-1 *Example of Bhil phalas surrounded by crops. Source: Google Maps satellite*

The increasing pressures on land availability and the influences from neighbouring non-tribal communities have led to the replacement of nuclear families for joint families organisation[181], which may have influenced *Bhil* live aspects such as those of social cohesion and joint management of childcare practices. These modernisation shifts may have potential implications on domestic hygiene and childcare, which will be further discussed later.

*Bhil*s' traditional beliefs were rooted in the power of supernatural forces of nature, including omens, charms, witchcraft and sorcery, and they recognised various deities of the forest[180]. While nowadays the *Bhils'* religious beliefs have been increasingly influenced by Hinduism, several traditional tribal beliefs and figures such as the *Bhopas* are still present in contemporary tribal communities[180]. *Bhopas* were the shamans or healers in charge of performing rituals for the protection from spiritual beings and health afflictions, and as such, they had a prominent leadership role amongst tribal communities, which, to some extent, may have persisted to the present day.

In addition, *Bhil* communities' decision-making power traditionally fell on an appointed headman that had authority over a small community of one or a few *phalas*[181]. Nowadays, Sarpanchs, the village-level government heads in India, have emerged as new authority figures, but the historical lack of recognised large-scale village management mechanisms and the superstitious beliefs and spiritual perspectives on health[181] may have important implications on the structure of leadership and how public healthcare services are uptaken in the current times which will be further discussed.

3.3.3 Livelihoods: Agriculture and Migration

Agriculture was and still is the backbone of the district. According to the last census, over 80% of the working population in Banswara are cultivators and agricultural workers[178]. Therefore, the lives of the rural population are heavily marked by the seasonality in Banswara. The climate sees a mild dry winter from December to February, followed by a hot and dry period until June, with temperatures hovering over 40ºC. Then, the monsoon season lasts from June to September, with heavy rainfalls that enable rain-fed crop cultivation[177]. During the dry period, however, from November to May, people strongly rely on the supply of irrigation water by the district canal to cultivate crops. Unfortunately, the district canal does not reach all areas of the Banswara district[177], which creates a marked division of the district in canal-fed and non-canal-fed areas that shapes people's agricultural practices as well as their social status. Irrigation facilities have been seen to enhance people's livelihoods but also create a social divide[181].

Traditionally, *Bhils* practised shifting agriculture with rotating crops suited to the dry or monsoon season accordingly, but the availability of irrigation by the district canal led to the homogenisation and specialisation into more remunerative and irrigated crops such as maize, wheat, and cotton[182]. Although this increased financial remuneration, it also contributed to increased dependency and water pressures for irrigation and less drought resilient crops[182]. Moreover, since the turn of the century, rainfall variation has been an increasing concern, with years of serious drought becoming more and more frequent. Overall, the increasing droughts, the rise in population, industrialization and agricultural growth has led to a decrease in the water available per capita[177].

The increasing pressures for subsistence agriculture have gradually led to tribal communities seeking job opportunities and other forms of stable income[181]. These opportunities are mostly sought from self-employed ventures (i.e., local shops, provision of services…) or from the limited local industry opportunities available, which in Banswara notably include textile factories. However, temporary migration remains one of the most common alternative livelihood strategies among the rural tribal communities in Banswara when the crops are not sufficient. According to the 2011 census, over 40% of the working population in Banswara describe themselves as being involved in marginal activity, providing a livelihood for less than 6 months per year, which often means temporary jobs away from the hometown village[178]. Migration is an increasing trend, yet two very distinct patterns of migration can be observed in rural Banswara[183].

- Long-term migration: Typically involving male adults migrating to distant cities or countries for a long period (6 months+) and sending remittances for the wives, children and their grandparents that stay behind and care for the house, livestock, and crops. This type of migration is frequent among households that wish to complement their earnings to meet increased social expenditures and move up the social ladder.
- Seasonal migration: This typically involves the whole nuclear family, including fathers, mothers, and children, to migrate for a few months (1-4 months) to nearby cities or states, often for agriculture labour work or construction work, while the elders stay back caring for the house and the land. This type of migration is more common across villages that are not canal-fed and cannot cultivate crops during the dry summer months, and therefore require an alternative source of subsistence.

For a minority of the households in tribal Banswara, migration offers additional financial opportunities and a surplus economy, but for the poorer majority, migration remains a coping mechanism to cover extreme economic vulnerability[183]. Migration flows, particularly in the case of seasonal migration where infants and young children migrate as well, may have important implications for childcare and domestic practices that will be further discussed.

The recent COVID-19 outbreak is likely to have further shifted the livelihoods of seasonal migrators in Banswara. The national lockdown declared in March 2020 led to the immediate closure of all economic activities and the loss of livelihood for many migrant workers, who were mostly on short-term contracts or in the informal sector. A survey carried out at the time (April 2020), revealed that over a third of the migrants, who were surviving on daily subsistence wages (186-335 INR or 2-3 GBP/day) were left without access to food, water or money overnight[184]. As the job market is still significantly affected by substantially reduced job opportunities for migrant workers, the impact on the future livelihoods of tribal migrant families and ultimately the impact on the children's health and nutrition remains to be seen. Some studies have already started to document the impact of lockdown and its inevitable economic backlash for the children of India's poorest and rural households[185]. Interruptions in the mid-day school meals, which cater to about 144 million school children, or the supplementary nutrition program from the ICDS scheme, that caters to over 100 million lactating women and pre-school infants, are likely to have exacerbated family's food insecurity and the nutritional status of infants and children[185].

3.3.4 Health and development indicators

The rural population in Banswara has been steadily growing over the last decades. From 2001-2011 (data from the latest census) it saw a 27% increase in the district population, far higher than the state average (19%), with fertility rates of around 5 children per women[179]. At the same time, Banswara is one of the high priority districts selected by the National Health Mission, as it was ranked 2nd lowest in terms of the Human Development Index within Rajasthan[186].

According to the latest development indicators from the demographic health survey NFHS-5 (2019-2020), literacy levels in Banswara currently stand at 53% for women[187]. In terms of housing and WASH infrastructure development, the 2011 census reported that 77% of the rural households in Banswara were made of semi-permanent or temporary rudimentary materials[188], although 93% of households are reported to have access to electricity nowadays, 96% have access to an improved water source, but only 20% have access to an improved sanitation facility, with the majority still defecating in the open[187]. While these indicators are used as a proxy for rural development, they have important limitations in conveying the current lived realities in rural Banswara. For instance, according to the nation-wide flagship programme *Swachh Bharat* Mission that aimed to end open defecation by 2019, the Banswara district has now been declared open-defecation free, where coverage of sanitation facilities is reported to be over 95%[189]. However, this remains to be confirmed by independent surveys, as there have been claims that figures of coverage could be much lower[190]. Furthermore, regardless of the figures for toilet facilities coverage, figures for the uptake of toilet use could show a very different picture of the remaining challenge to end open defecation[114]. Also, despite 96% of rural households using an "improved" water source as described by the World Health Organisation (WHO) (i.e., piped water into yard, including public tap, tube well, borehole, dug well, protected spring or rainwater), the vast majority (88%) of households in rural Banswara use shallow dug-wells or uncovered wells as a source of drinking water[178], which do not ensure that water is microbiologically safe, particularly in an environment where open defecation is still prevalent and groundwater contamination is therefore likely.

In terms of health indicators, Banswara has recorded persistently high infant and under-5 mortality rates (infant mortality rate=62, under-5 mortality rate=99) in comparison to the Rajasthan State and National indicators[179]. As per the 2019-2020 data, 47% of children under-5 in Banswara were reported to be stunted, 39% were reported to be underweight and over 82% of children under-5 were anaemic[187]. Even more concerning is the fact that these figures have not yet captured the potential impact of the COVID-19 pandemic and the disruptions in accessing basic health services and nutritious meals that families have endured[13].

Overall, the rural tribal communities in Banswara district remain socially and economically disadvantaged communities despite development efforts from the Government of India[191]. Although traditional *Bhil* communities may have attained a self-sustained socio-economic balance in the past, modern-day pressures are straining the socio-economic problems *Bhils* face today. The rapidly growing population, increasingly fragmented land, unproductive landholdings, paired with the increasing droughts and rainfall variations and cultivation of less resilient crops are leading to a decrease in the water and land available per capita[177] and threatening the backbone of the tribal families in Banswara: their agricultural livelihoods. The COVID-19 pandemic has only introduced additional challenges such as hindering the practice of short-term migration and temporary job contracts in the informal sector, which was the other source of livelihood for the tribal families in Banswara, or limiting the access to school meals due to school closures. New studies that account for these contemporary stressors faced by tribal communities are required to develop policy recommendations that are appropriate and respond to today's lived realities in rural tribal India.

3.4 Study villages in Ghatol and Kushalgarh blocks

3.4.1 Selection of study villages

The district of Banswara is sub-divided into 5 administrative blocks (Ghatol, Garhi, Banswara, Bagidora and Kushalgarh, Figure 3-2). Of these, the PANChSHEEL study focused on two blocks: Ghatol and Kushalgarh. These two blocks were selected under the criteria of maximising variations in social and ecological characteristics. The Ghatol block is close to the district capital, with good road connections and it is canal-fed. By contrast, the Kushalgarh block is geographically more isolated, further away from the district capital, and non-canal-fed, therefore dependant on rain and groundwater sources only[177]. Differences in key demographic characteristics between both blocks as per the latest census are summarised in Table 3-1.

Table 3-1 Key demographics of Banswara study Blocks

Demographics (Census 2011)	Ghatol	Kushalgarh
Populated villages	239	213
Total rural population	287,101	187,136
Population in the age group 0-6	52,416	40,564
ST/SC Population	85.35%	96.35%
Literacy rate	49.71%	41.11%
Area (km2)	777	649

Within each of the blocks, the PANChSHEEEL Project team developed a list of selection criteria to identify the study villages. Villages were considered if they had at least 1000 inhabitants, one elementary school, and one Anganwadi centre, and they were excluded if they were already involved in other interventions by the local NGOs. After an initial process of village profiling and building of rapport with the communities, a final of 9 villages, 5 in Ghatol and 4 in Kushalgarh were purposively selected by the PANChSHEEEL team (Figure 3-2).

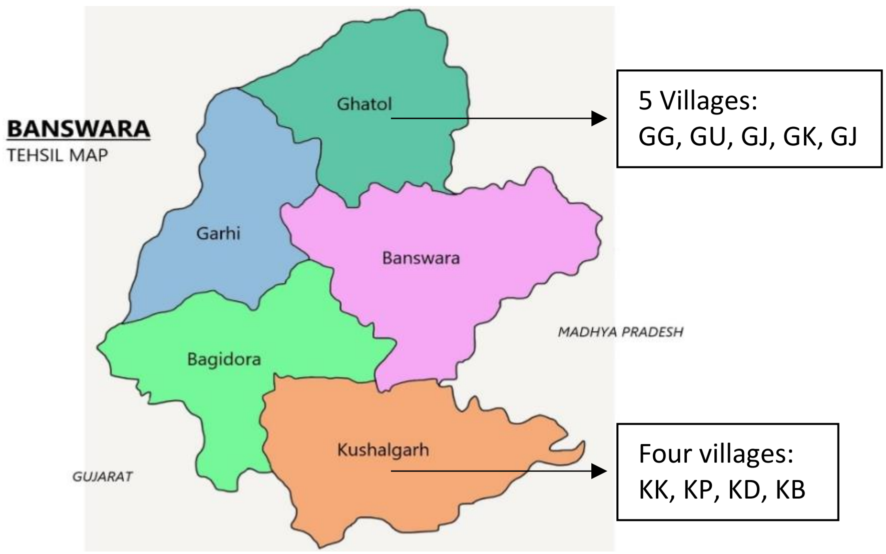


Figure 3-2 Banswara district map. Source: PANChSHEEEL report, 2020[50]

Building on the PANChSHEEEL project, the same villages were employed as case study villages for this PhD study, to leverage the links and rapport with the communities, who had already been sensitised to this work. However, given that this thesis will provide in-depth accounts of the study villages, the names of the villages have been anonymised to maintain participant confidentiality.

3.4.2 Socio-demographics of the study villages

The average area of the study villages was 2.5 km2[178], a walkable area largely comprised of agricultural land with the households or *phalas* (hamlets) mostly scattered around the territory. According to the last census in 2011, the average population size of the study villages was approximately 1300 people (Table 3-2). The population in the Kushalgarh villages, all pertained to Scheduled Tribes. In Ghatol instead, 3 of the 5 study villages were populated by a mix of Scheduled Tribes and Scheduled Castes (ST/SC) colonies and some non-tribal caste colonies (referred to as Other Backward Class (OBC)), as designated into social classes by the Indian Constitution. Based on the latest census[178], literacy rates were higher in the Ghatol villages (ranging from 43-48%), versus the literacy rates in Kushalgarh villages that ranged from 26 to 38%. Based on the information collected in the PANChSHEEEL household survey including 445 households across the study villages[24], it is also known that the vast majority of families in the study villages are agricultural landowners (90% in Ghatol, and 85% in Kushalgarh), and a minority are agricultural labourers with no landholdings (7% in Ghatol villages, 11% in Kushalgarh villages). Overall, it can already be observed from the socio-demographics presented in this section that there are some differences in the caste, education, and occupation distributions between the Kushalgarh and Ghatol villages, with potential implications on the hygiene and childcare practices that will be considered later on.

Table 3-2 Key demographics of study villages

Blocks	Ghatol					Kushalgarh			
Village names	**GU**	**GG**	**GK**	**GT**	**GJ**	**KB**	**KD**	**KP**	**KK**
Population	1199	1094	1731	1059	1518	1133	1607	1193	1130
Number of households*	254	241	370	233	326	208	198	243	239
Number of children (0-6 years)	209	205	297	203	300	282	250	218	238
Social groups	ST, OBC	ST	ST, SC, OBC	ST, SC, OBC	ST	ST	ST	ST	ST
ST/SC population (%)	54	100	85	92	100	100	100	100	100
Literacy rate (%)	48	43	43	48	48	26	28	37	38

*Number of households according to ration cards.
Source of information: District Census 2011[178]

3.5 Study partner in Banswara

As it can be inferred from the contextual information on the case study, the rural tribal communities of Banswara could be particularly hard-to-reach due to the hilly geographical areas they inhabit and the language and cultural gap. The process of community rapport-building was crucial to be able to develop a relationship between the research team and the study communities that ensured the study communities' involvement in research and a balanced relationship between the researchers and the participants was achieved. Therefore, working alongside a local partner who understood the local contexts and cultural dynamics was essential to conduct fieldwork research with this communities. For this PhD study, I was able to leverage the long-standing partnership developed with the Save the Children NGO Rajasthan office by my supervisory team during the PANChSHEEEL Project. Save the Children is a large international humanitarian aid organisation whose work in India focuses on deploying various nationwide programmes ranging from child protection, health and nutrition to education and poverty alleviation, all under a common goal of helping all children reach their full potential[192]. The Save the Children India NGO, and particularly their Rajasthan office branch with their team located in Banswara, were the local partners that enabled me to conduct the fieldwork phase of this PhD project.

The team of local fieldwork researchers that I worked with to conduct fieldwork comprised of two local male adults (HC and PP) who were fluent in both Hindi and Wagdi, the local tribal dialect, and knowledgeable of the study context and culture. Given their prior involvement in the PANChSHEEEL project, they were well acquainted with the needs of a research study in the topic of child health and nutrition, and they had also previously received capacity building training on several methods of data collection such as surveys and interviews, as well as on obtaining informed consent from study participants[50]. The local fieldwork researchers could be viewed as local experts, given their special insights on the communities' inner workings and the local environment, which enabled me to approach participants in a culturally sensitive manner. Hence, the local fieldwork researchers had a crucial role for community engagement, but also throughout the study and were involved in the preparation of data collection tools and protocols and the data collection itself, as well as in the analysis and interpretation of findings.

In addition to the team of local fieldwork researchers, during PANChSHEEEL, "Community Champions" were identified in each study village. Community Champions were residents in the study communities that were identified as focal people for having a leadership role and good rapport within their village, and they were recruited by the fieldwork researchers to act as gatekeepers. The local fieldwork researchers had maintained a continuous rapport with the Community Champions in each study village, therefore Community Champions were key for engaging with the rest of the village communities and provided support for the identification and approaching of participants and other research activities on the field[192].

Overall, the pre-established partnership with the Save the Children Rajasthan Office, the links with the Banswara office and their team of local fieldwork researchers, as well as the links with the study communities through Community Champions enabled the fieldwork phase of this study to take place.

4 Chapter 4. Methodology

4.1 Chapter overview

Chapter 4 describes the process of formative research and preliminary fieldwork that I carried out to define the methodology and data collection tools for this study. It follows by describing the qualitative and quantitative methods that I used for data collection during the fieldwork stage. Finally, I provide personal reflections on the ethical implications and other considerations that were taken into account during fieldwork.

4.2 Mixed-methods approach

Since the aim of the study was to develop a holistic understanding of the multiple risk factors and transmission pathways to enteric infection, an in-depth exploration of the study communities' realities was required. A comprehensive grasp of the study communities' realities needed to consider aspects relating to the natural and physical environment, as well as the socio-cultural aspects influencing their lives. Only the integrated use of multiple data sources from different disciplines, across the social and natural sciences, enabled me to consider all the relevant components of the system. Thus, it appeared fundamental to this study that a mixed-methods approach was used.

Once the methodological approach had been identified, specific methodologies ranging between the realms of qualitative research and microbiological analysis techniques were explored in the literature. It was soon clear that using mixed methods from across disciplines would not only involve integrating different data collection and analysis techniques, but it also compelled me to look at the problem from different perspectives. The social and the natural sciences are guided by different epistemologies, which shape the approach with which problems are addressed[193]. For instance, the natural sciences traditionally seek to understand the true workings of natural phenomena by means of experimental methods, interpreted in a neutral, objective, and rational manner (an approach coined as the positivism model). Qualitative research, however, recognises that human behaviour is complex and unpredictable, and needs subjective and critical analysis to be interpreted. Qualitative research understands that rather than capturing the "reality of the phenomena", the focus is placed on defining people's interpretations of the reality. It considers that there is no single "truth" about social phenomena, but rather different social constructs of it (termed as the naturalistic approach)[193]. A mixed-methods interdisciplinary approach compelled me to explore both interpretations of reality: the infection risk factors and pathways to infection, as perceived by participants and defined by the social abstract realities, and the pathogen transmission infection pathways as identified from the environmental microbial analyses. A mixed-methods approach would enable me to address the set of study objectives looking at the multifaceted factors across natures contributing to infant enteric infections. Once it was clear that a mixed-methods approach was going to be adopted, the following step was to define the specific methods that were going to be used to collect data that would enable me to address the study objectives. For that, a formative fieldtrip to the study site was performed. Below, I explain the purpose, procedures and learnings gained from the formative fieldtrip to the study site, and how they were used to formulate the final data collection methodology.

4.3 Formative fieldtrip to formulate the methodology

The purpose of conducting a formative fieldtrip was multifold. Firstly, it was necessary to establish a relationship with the local partners, the Save the Children Rajasthan Office, and particularly the team of fieldwork researchers based in Banswara that I would be working with. Even though they already had a longstanding relationship with my supervisory team, establishing rapport myself was essential for the planning of the project. Secondly, gaining an understanding of the study context and study communities was vital to be able to plan and formulate the study methodology, and to start building rapport with key local stakeholders in the study villages such as the frontline health workers and Community Champions. Thirdly, testing out different data collection methodologies would allow me to check the feasibility and cultural appropriateness of different data collection methods. Lastly, the purpose of the formative fieldtrip was to outline the resource needs for data collection, such as the required fieldwork team support, training, translation, time, and transport requirements to be able to collect data at the field site. With this in mind, in March 2019 I undertook the formative fieldtrip to the study site. For two weeks I stayed in the city of Banswara, the only place with lodging and amenities available for stay and that is within reach of the study villages. During those two weeks, I got acquainted with the Save the Children team based in the Banswara office, including the local fieldwork researchers with whom I would be doing fieldwork (PP and HC), and together we performed daily visits to the study villages. Two of the study villages, one in Ghatol (GG) and one in Kushalgarh (KD), were purposively selected as exemplary villages to conduct the formative research and preliminary data collection, based on those villages that were more easily accessible. The formative fieldtrip was carried out prior to ethics committee's applications, as its focus was on establishing rapport and a ground understanding of the study context to formulate the study methodology, thus, no personal identifiable data was recorded. This was discussed with the ethics committee at UCL prior to the formative fieldtrip.

4.3.1 Gaining access to the study communities

On my first days in Banswara, I was able to immediately visit the study villages and interact with different community members. The immediate access to the study village communities upon arrival was only possible thanks to the prior community engagement work done during the PANChSHEEEL Project by the local fieldwork researchers, who had developed a rapport with several community stakeholders. Visits to the study villages always began by first approaching one of these community stakeholders: either the frontline health workers at the Anganwadi centre, or the village school teachers, who were respected members of the community or the Community Champions, the members of the villages that were actively engaged in the research project activities[50]. Therefore, access to the study communities was always done through first visiting one of the several community members with whom the local fieldwork team had rapport. Those first informal encounters were useful to introduce myself and introduce the study purpose to key community stakeholders, who would then often act as gatekeepers to approach other households or community members that the local fieldwork researchers did not personally know.

4.3.2 Quantitative and qualitative methodologies assessed

Prior to conducting the formative fieldtrip, the initial review of studies investigating drivers to enteric infections and transmission pathways (Chapter 1) made it apparent that a wide range of methodologies from different disciplinary fields are used to investigate the topic of child enteric infections. Based on the information gathered in the literature, a formative fieldwork plan was drafted to test several qualitative and quantitative methodologies, and ultimately inform the formulation of the final data collection plan and tools.

Several qualitative methodologies ranging from participant observations to interviews and group discussions were considered. Traditionally, participant observation methods were exclusively used by anthropologists in ethnographic research, and interview methods pertained to qualitative sociological studies only. However, as disciplinary silos are broken down, different methods are increasingly used across disciplinary fields, and this particularly benefits WASH studies, which require of the interdisciplinary insights provided by the different methodologies[130].

Nowadays, it is agreed that the design of qualitative research methods is characterised by a continuous, flexible and adaptable approach[194], to respond to the dynamic and evolving needs at the time of data collection. Qualitative methods need to remain flexible and adaptable to enable researchers to explore new avenues, incorporate new concepts and shift directions as information emerges from the data collected. Particularly, in the initial stages of qualitative research design, a more general approach is required until a more selective focus can be placed on the most relevant concepts of study as they are gradually identified[194].

The iterative nature of qualitative methods means that completion of qualitative data collection is guided by the point at which theoretical saturation is reached when further data collection does not add new insights, as originally described by Glaser and Strauss[195]. Therefore, guided by the principles of flexibility and adaptability, the plan for the initial formative fieldtrip was to engage with the study communities using several different qualitative data collection methodologies in an unconstrained manner, enabling me to gauge the appropriateness of each, to later refine and formulate the final data collection tools accordingly. The qualitative methods that were tested during the formative fieldtrip included: transect walks across the villages, key informant interviews with frontline health workers and head teachers, focus group discussions with mothers of infants, natural observations of childcare centres' activities and mothers' group meetings, and household observations of domestic practices while unstructured conversations with caregivers were carried out (Table 4-1).

While the qualitative methodologies would allow me to understand the participants' perceived realities on enteric infection factors, quantitative data would enable me to capture the magnitude and frequency of specific quantifiable factors. Particularly, quantitative data on the levels of microbial contamination in the environment would be needed to characterise the faecal contamination levels in different contact points of the infants' surroundings and assess the pathways of pathogen transmission. Therefore, during the formative fieldtrip, we also set to assess methods to collect structured quantitative data of the environment, and different strategies to conduct microbial analysis to test for faecal contamination.

Table 4-1 summarises the research activities that were carried out during the formative fieldtrip, including the number of qualitative and quantitative data collection methods that were tested to collect different types of data ranging from more to less structured. It was envisioned that the composite of methods would allow me to address the first 3 of the study objectives; to explore the multiple enteric risk factors to infants (Obj. 1), to assess the key enteric infection transmission pathways to infants (Obj. 2), and to identify key barriers for child healthcare and hygiene promotion (Obj. 3), ultimately informing the co-development of recommendations for local programming (Obj. 4).

Table 4-1 Research activities and data collection methods tested during the formative fieldtrip

Research activities	#	Data collection methods tested	Objectives targeted
Village tours	2	- Transect walks with key community stakeholders - Structured spot-checks of village WASH-related resources (e.g. village canals, streams, ponds, water hand-pumps, wells)	- OBJ 1 - OBJ 1&2
Primary school visits	2	- Semi-structured interviews with head teachers - Structured spot-checks of school WASH-related resources (e.g. hand-pumps, handwashing stations, toilets, courtyards)	- OBJ 1 - OBJ 1&2
Anganwadi centre visits	2	- Unstructured observations of activities at Anganwadi centres - Structured spot-checks of Anganwadi WASH-related resources (e.g. hand-pumps, handwashing stations, toilets, courtyards) - Semi-structured Key Informant Interviews with frontline health workers (ASHA, ANM and AWW)	- OBJ 1&3 - OBJ 1&2 - OBJ 3
Mothers' group meetings visits	2	- Unstructured observations of mother's group meetings - Semi-structured Focus Group Discussion with mothers	- OBJ 1&3 - OBJ 1&3
Household visits	5	- Unstructured interviews with caregivers - Structured survey of housing conditions and household's WASH infrastructures - Semi-structured observations of caregiver's domestic practices (e.g. cooking, cleaning, handwashing and caregiving practices) - Structured observations of infant's exposures at home	- OBJ 1&3 - OBJ 1&2 - OBJ 1&2 - OBJ 2
Environmental sampling	12	- Water samples, earthen floor samples and hand samples tested using dipslides as a microbial analysis technique	- OBJ 2

4.3.3 Overall learnings from preliminary testing different data collection methods

By the end of the formative fieldtrip, it became clear that several different methods were complementary to each other and unveiled different aspects of the communities' inner workings. Transect walks allowed me to become acquainted with the villages' environment and their inhabitants. Group discussions revealed social dynamics and norms among mothers. Interviews with frontline health workers prompted more targeted and detailed information on the topics of interest in this study. Natural conversations (i.e., unstructured interviews) and participant observations remained among the most relevant data collection techniques, as they allowed for naturally unfolding issues of concern to the villagers to be explored. Structured data on villages, schools, and households' physical environment and WASH facilities allowed me to observe overall patterns from summary statistics. Finally, environmental sampling results provided another layer of understanding to the issue of infant's faecal exposures, but more importantly, they engaged participants in the study by sparking their curiosity on the microbial-level findings. The fieldtrip led to the conclusion that the use of a composite of different qualitative methodologies, combined with some structured quantitative data on the physical environment and environmental sampling would bring the most comprehensive information.

In addition, it was perceived that the informal, unstructured interactions with caregivers and frontline health workers were also key for the continuous engagement of the village communities in the study, and for the capturing of relevant topics that surfaced spontaneously. It was decided that alongside the formal research activities planned for data collection, unstructured interactions with the community would be fostered as much as possible to contribute to the comprehensive understanding of the case study. Following, learnings from the preliminary testing of each method and how these shaped the final methodology are explained.

4.3.4 Learnings from preliminary transect walks

Transect walks are a participatory appraisal method that consists of systematic walks through a defined community area alongside the local people, and they are particularly useful to explore WASH conditions[196]. During the fieldtrip, the preliminary transect walks proved a useful initial exercise to become acquainted with the village physical environment. The other two local fieldwork researchers and I were guided by Community Champions and other community members on tours across the villages. We walked around the villages' main road and different household *phalas*, we visited the different village water sources such as the canals, streams and ponds, and the village schools and Anganwadi centres in each village, where unstructured conversations with the schoolteachers, frontline health workers and other community members were held along the way.

Our presence in the study villages during the preliminary transect walks prompted interest among villagers that wanted to know the purpose of our study, which led to extensive naturally occurring unstructured conversations about the village WASH facilities and the communities' perceived challenges from the built and natural environment. The unstructured and non-directed format of these conversations allowed villagers to feel at ease to bring up topics that they were concerned about. The methodology for unstructured conversations held during transect walks simply involved expressing interest for the topics of concern, as they were brought up by the community and asking questions accordingly[193].

Detailed field memos were handwritten during transect walks, capturing the context, social interactions, and reflective notes, but preliminary testing of transect walks also made it evident that a more systematic approach would be needed to record information about specific elements that were consistent across the study villages. It was decided that in addition to the field memos capturing the unstructured observational and conversational information, a semi-structured tool to conduct spot-checks at different relevant locations such as the village schools, Anganwadi centres, canals, and ponds, would be useful to capture the frequency of specific characteristics of the village physical environment and WASH factors.

Finally, another added value of the transect walks was that they allowed researchers to collect photographs and visual evidence of the environment, complementing the textual evidence. Thus, thanks to the preliminary transect walks and in preparation for the fieldwork stage, it was decided that alongside field memos for unstructured data, a spot-check tool would be developed to capture specific information at relevant sites, and pictures would be collected to complement textual evidence with visual data.

4.3.5 Learnings from preliminary key informant interviews (KII)

In a semi-structured interview, the researcher determines the list of topics to be discussed, but the participant determines the relative importance of each of them, and is allowed enough time to develop their own views on the issues relevant to them about each topic of discussion[193]. During the formative fieldtrip, two preliminary semi-structured interviews were conducted with front-line health workers, one in Ghatol and one in Kushalgarh. While the preliminary interviews initially started with the ASHAs only, other frontline health workers present (i.e., AWW or ANM) ended up joining in in both instances.

The purpose of the preliminary interviews was to understand the main concerns regarding enteric infections from the frontline health worker's point of view. The broad topics that were prompted for discussion during preliminary interviews included: the concerns regarding enteric infections and the child healthcare services available, concerns regarding local domestic and hygiene habits, and discussions about the available WASH infrastructure at the village level.

Discussing these broad topics during the preliminary interviews allowed me to identify more specific issues of concern among frontline health workers. For instance, I realised that given the multiple responsibilities that fell upon frontline health workers, there was variability in the healthcare services that each frontline health worker focused on, and that it was important to understand their own perceived responsibilities. Frontline health workers also had different points of view on the burden and severity of child enteric infections in their village, and the healthcare seeking behaviours of parents. The role of non-registered physicians and spiritual healers in child health treatment practices was also brought up. In this manner, preliminary discussions with frontline health workers guided the development of the final topic guide for interviews, which was developed to include additional and more pertinent and specific topics of discussion (the final KII tool is presented in Section 4.4.3.2).

Another important learning from the preliminary interviews with frontline health workers was that they would prove more useful after the transect walks and the initial familiarisation with the study villages had taken place. In this manner, after a grounding understanding is developed during the initial fieldwork stages, more in-depth information on specific issues can be sought, given the specialist knowledge of frontline health workers on the topic of WASH and child health practices.

On the other hand, while visits to the primary schools and interviews with headteachers during the formative fieldtrip were very useful to engage with the communities, they provided limited insights regarding the infection risk factors and childcare practices for infants under the age of 2, at a pre-school stage. It was decided that they would not be part of the final methodology for data collection.

4.3.6 Learnings from preliminary focus group discussions (FGD)

The term "focus group" is used to describe a formal group interview[193]. During the formative fieldtrip, two focus group discussions were carried out at naturally occurring community meetings, where groups of pregnant and lactating mothers (10-15 mothers were present) already gathered on a regular basis. These included the VHND and PUKKAR events (explained in Section 1.6). Although focus groups in health research typically involve mixing people that do not know each other from different backgrounds, natural groups in which people do know each other also offer advantages, as they maximize interaction between participants[193].

Similar to the key informant interviews, during preliminary focus group discussions broad topics of discussion were prompted. These included: their perceptions on child enteric infections burden, causes and consequences, their perceptions on the village WASH resources and the healthcare services available, and their healthcare seeking practices for child treatment during diarrhoeal episodes.

Preliminary group discussions revealed that although there were social hierarchies within mothers that influenced the level of contribution from some other mothers, the discussions could be valuable to explore commonalities and disagreements in practices or beliefs among mothers. It appeared important to keep the topic guides simple with only a few key topics to allow discussions to be as flexible as possible and allow mothers to expand and debate each topic. This learning from the preliminary group discussions informed the development of the final topic guide, which focused on three key broad topics, and is presented in Section 4.4.4.2.

4.3.7 Learnings from preliminary observations at Anganwadi centres

The visits to the Anganwadi centres revealed that the most insightful activities relating to WASH and childcare practices occurred during the VHND, the monthly village-level events where mothers and infants attended the Anganwadi centres for take-up of different health services provided by the frontline health workers, such as vaccinations and child health and hygiene promotion (further details on VHND were described in Section 1.6). Thus, it was decided that observations of Anganwadi centres' activities would be carried out during the VHND events, which would enable the observation of how frontline health workers delivered health and hygiene promotion services and how they were being received by mothers and caregivers of infants. The preliminary Anganwadi observations informed the development of a semi-structured observation tool for village health events (i.e., VHND), to capture details on the physical setting, the activities and services delivered, and the health workers' and attendants' behaviours.

4.3.8 Learnings from preliminary household visits

Preliminary household visits involved the collection of different types of data from more to less structured, mainly rooted in the observation of participants in their domestic settings. Observational methods are cited as the gold standard of qualitative methods as they provide direct access to what people do in naturally occurring situations[193], and indeed, participant observations were also often insightful in providing contrasting or complementary information to the one that had been reported.

The purpose of the household visits was three-fold: 1) to collect structured information on the housing conditions and infrastructure, 2) to record infants' exposure contacts, and 3) to capture the childcare and domestic practices carried out by caregivers. To do so, different data collection methods were tested.

(1) Household survey

For the collection of quantitative data on the housing conditions and household's WASH infrastructure, a survey tool based on the WHO & UNICEF Core WASH Questions for Household

Surveys[197] was used during the formative fieldtrip. Five preliminary household visits were conducted during the formative fieldtrip (Table 4-1), and it was perceived that a slightly modified approach to collecting the household survey data was better suited than the traditional method. Upon arrival at a household and after introducing ourselves and the purpose of the study, we asked participants for a "guided house tour", where participants walked us through their household compound while explaining the use, purpose and perceptions regarding the different household spaces and WASH facilities. This method of visually surveying the housing conditions and infrastructure in conversation with the participants while walking around the house, appeared more appropriate and insightful than the traditional approach of asking multiple survey questions in a questionnaire-like manner. It was decided that this "guided house tour" approach would be used to collect the household survey structured data on housing conditions.

(2) Observations of infants' exposures

To be able to assess the infection risks to infants from different transmission pathways and address the second objective of this study, data on the infant's mouthing and exposure contacts was sought. To be able to conduct an accurate risk assessment, quantitative data on the infant's exposures, detailing the length, frequency, volume, and level of exposure to the different elements, is needed. Methodologies to annotate quantitative data on people's exposures range from structured observations to videography or diaries[198,199]. I decided to test a structured observations tool to annotate infants' exposures based on a tool developed by Ngure et al[67], which had been previously tested in the field to perform structured observations of infants' exposures in Zimbabwe.

Despite providing only limited resolution, structured observations would allow researchers to collect data real-time while being less intrusive and resource-intensive than videography methodologies, and do not suffer from the reporting bias of self-reported diaries[199]. During the formative fieldtrip, some challenges were identified when testing this structured observations' tool. Some of these challenges involved the difficulty in monitoring the number of times infants put their hands in their mouths, the duration of those contacts, or the volumes of water and food ingested in each instance.

Based on the challenges identified during preliminary fieldwork, the structured observations' tool was refined in preparation for the fieldwork stage. For instance, annotations of the infant's location (i.e., on the earthen floors, on a bed, etc) or the state of the elements mouthed (i.e., visibly dirty, fly-ridden, etc) were included, which helped capture the types and levels of exposures in a semi-quantitative manner. Further details on the final tool used to capture infants' exposures are presented in Section 4.4.2.5.

(3) Observations of caregivers' domestic practices

While the first two types of data collected during household visits involved structured quantitative data, to capture domestic practices, a semi-structured approach was tested during the formative fieldtrip. During the five preliminary household visits that were conducted, unguided observations of the domestic routines were carried out. Details on how the caregivers were observed to cook, wash the dishes, play with the child, or care for the animals were recorded in a simple headings table.

The preliminary household visits helped identify the key domestic practices that were perceived as relevant for infant hygiene and for which information was going to be gathered during fieldwork. Based on the preliminary observations of caregivers' domestic practices, it was decided that details about the instances when caregivers were observed: cooking, feeding, cleaning the dishes, clothes, or house spaces, caring for the animals, childcaring or handwashing practices were going to be captured in a semi-structured tool. The semi-structured tool would need to be complemented with observational and reflective notes arising from the unstructured conversations with caregivers and observations. Further details on the final tool used to capture caregivers' domestic practices are presented in Section 4.4.2.4.

4.3.9 Learnings from preliminary microbial analysis of environmental samples

The formative fieldtrip also helped in identifying the key locations at which environmental samples were going to be collected to determine the faecal contamination levels across the study villages and domestic environments (to address the second objective of this thesis). Based on the village tours and household visits, it was decided that environmental samples were to be collected both at the village level and at the household level.

To capture the environmental contamination levels at the village level, it was decided that water and soil samples were to be collected from the different village public spaces. In each study village, I planned to sample from all the different available public water sources, collecting at least triple repeats of each water source. Public hand-pumps, public wells, irrigation canals and local surface water bodies such as ponds and streams were sampled when present. Sampling was also planned for soil samples from the courtyards of all the schools and Anganwadi's available in each village, providing an indication of the faecal contamination levels across the public spaces that young children are regularly exposed to.

At the household level, it was decided that environmental samples from as many infant exposure contact points as possible at each of the study households visited would be collected, including water sources, earthen floors, and the hands of infants and caregivers. Although ingestion of contaminated food may be another key pathway of faecal pathogen transmission to infants[140], it was determined during the fieldwork trip that several reasons made analysis of food samples too challenging in this study. Firstly, the local field team believed that it could be perceived as culturally offensive to consider food as "dirty" and could influence the rest of the interactions with the study population. Secondly, food contamination levels could vary widely according to the time of sample collection, depending on whether the food had been recently cooked or was stale. Thirdly, the analysis of food samples added logistical challenges to the analysis part as it had to be homogenised and liquified first, a process that may bias the pathogen dose analysis by averaging it out across the full volume. Therefore, food contamination was not planned to be microbiologically analysed in this study.

The formative fieldtrip also proved useful to assess the laboratory facilities available in Banswara and explore the different possible microbial analysis techniques to determine faecal contamination levels and determine the most suited and feasible option. Given that the purpose of this study's environmental microbiological analysis was to assess the faecal contamination levels in the environment and make comparisons across villages and sample sources, resource-intensive molecular and biomarker determination techniques were discarded, although they would have been useful to reveal the pathogen's aetiology (human vs animal). Quantification of culturable Faecal Indicator Bacteria (FIB) colony counts was used instead. *Escherichia coli* bacteria are the most common FIB, and although there are limitations to the use of FIB for the characterisation of faecal pathogen contamination, the logistical advantages it poses due to its ease of survival, culture growth and colony count, contribute to *E. coli* still being widely used for faecal contamination estimates[200].

For the quantification of culturable *E. coli,* the Dip-slide method was tested during the formative fieldtrip. Dip-slides are portable sterile contact plates for bacterial growth and count, which can be used to sample liquids (i.e., water) and surfaces (i.e., hands, floor, and objects) by pressing the medium culture gel to a surface or by dipping it into a liquid (Image 4-1). Dip-slides contain a previously prepared agar gel that allows for colony-forming units enumeration after an incubation period[201].

Image 4-1 Agar gel dip-slides for quantification of culturable coliforms and E. coli

Given their simplicity and low-resource analysis requirements, dip-slides were tested during the formative fieldtrip on different environmental media (Table 4-2). They proved to be a great tool to engage participants in the environmental microbial analysis, but despite this, the preliminary tests during the formative fieldtrip revealed that dip-slides did not allow to quantify low levels of *E. coli* in water samples due to their low-detection limits. Dip-slides also did not allow to test floor surfaces, as the agar gel got too dirty when pressed against the earthen floors. Moreover, dip-slides only allow to draw semi-quantitative conclusions from the colony enumeration results, so they were discarded as a microbial analysis method, as would not have enabled a full quantification of pathogens.

Table 4-2 E. coli contamination levels on environmental samples tested with dip-slides

Environmental samples	***E. coli* per dip-slide agar**	**Level of *E. coli* contamination**
Water samples		
Public hand-pump (#1)	0	Very low (<10^2 CFU/mL)
Public hand-pump (#2)	0	Very low (<10^2 CFU/mL)
Public hand-pump (#3)	4	Very low (<10^2 CFU/mL)
Stored drinking water (#1)	0	Very low (<10^2 CFU/mL)
Stored drinking water (#2)	2	Very low (<10^2 CFU/mL)
Stored drinking water (#3)	0	Very low (<10^2 CFU/mL)
Earthen floors		
House courtyard floor (#1)	60	Moderate (approx. 12 CFU/cm2)
House courtyard floor (#2)	TDTC*	-
School courtyard floor (#3)	TDTC*	-
Hands and surfaces		
Infant's hand (#1)	0	Very low (< 1 CFU/cm2)
Mother's hand (#2)	2	Very low (approx. 0.4 CFU/cm2)
Aluminium plate (#1)	48	Moderate (approx. 12 CFU/cm2)

**TDTC: Too dirty to count*

Upon returning from the formative fieldtrip, alternative methods for the quantification of culturable *E. coli* were explored, bearing in mind the limitations in laboratory facilities in the field. The membrane filtration and plaque culture method using the Oxfam-DelAgua Fieldwork Testing Kit was explored. This methodology involved the filtration of liquid samples through a membrane filter using a vacuum system, and then the incubation of the membrane filter using selective culture media. This technique required additional laboratory equipment including material for sample collection and preparation, a vacuum system for filtration, as well as Petri dishes and culture medium and an incubator for culture growth. However, the DelAgua Kit provided all the material necessary to conduct basic microbial tests to measure water quality and was designed to be portable and fieldwork-friendly[202] (Image 4-2).

The DelAgua Kit would allow the quantification of *E. coli* loads in water samples, as well as in soil and hand-swab sample elutes, at the study field site, therefore, after pre-testing the kit in London, it was considered suitable to carry out basic microbial analysis at the study field site. Formative testing of water samples from Regent's Park (London) helped refine the procedural details of using the DelAgua kit and develop a protocol for environmental sampling and analysis. It was essential that the protocol described in detail the samples' collection, processing, and analysis procedures to be followed, so that the resource and lab requirements could be identified and addressed. The environmental samples protocol that was finally used is described in detail in Section 4.4.6.1.

Image 4-2 Oxfam-DelAgua fieldwork testing kit for environmental samples. Source: DelAgua

4.4 Fieldwork trip for data collection

Learnings from the formative fieldtrip informed the final fieldwork protocol, methodologies, and data collection tools that were prepared to conduct the main fieldwork stage. Upon returning from the formative fieldtrip, the final methods and tools were developed and refined. Once the methodology was defined, ethical approval from UCL as well as from an Indian ethics committee was sought and obtained (further details about ethics in Section 4.5). Six months after I had conducted the formative fieldtrip, I set out to do the fieldwork stage, which was conducted from September to December 2019. During this period, I was based at the district capital (Banswara city), and research visits to the study villages were carried out daily except on Sundays and national holidays. Field visits were conducted between 8:00 AM and 4:00 PM, the times that were advised to be suitable by the local fieldwork researchers. The team of field researchers was composed of two local fieldwork researchers from Save the Children (PP and HC), and myself. The methods and procedures that were carried out during the fieldwork trip are described in detail hereunder. Lastly, ethical considerations and reflections that emerged during the fieldwork stage are also presented. Table 4-3 summarises the number of fieldwork research activities that were carried out across the study villages to collect qualitative and quantitative data. Further details of each data collection methodology are provided below.

Table 4-3 Summary of research activities carried out

Data collection methods	#	Type of data
Village-level		
Transect walks	9	QUAL/QUANT
Unstructured village observations	9	QUAL
School spot-checks	18	QUANT
Anganwadi centres spot-checks	10	QUANT
Water bodies (ponds, canals, streams) spot-checks	20	QUANT
Environmental samples from villages	103	QUANT
Groundwater samples	28	QUANT
Surface water samples	30	QUANT
Soil samples	25	QUANT
Interviews with frontline health workers	12	QUAL
Focus group discussions with mothers	4	QUAL
Health event observations	4	QUAL
Household-level		
Household visits	42	QUAL/QUANT
Visual survey of households' built environment	42	QUANT
Unstructured household observations	42	QUAL
Caregiver's domestic practices observations	42	QUAL/QUANT
Unstructured conversations with caregivers	42	QUAL
Infants' exposures observations	47	QUANT
Environmental samples from households	233	QUANT
Hand samples	83	QUANT
Water samples	97	QUANT
Floor samples	53	QUANT

4.4.1 Transect walks

Transect walks were conducted across the 9 case study villages, and they were the first research activity carried out in each study village, giving us, the fieldwork researchers, the chance to become acquainted with the village environment and several community members (Image 4-3). At least two fieldwork researchers (PP and/or HC and I) were present for the transect walks. Transect walks lasted between one and a half to two and a half hours each, and they all started

Image 4-3 Transect walks

by approaching a Community Champion or a key community stakeholder such as a frontline health worker with whom the fieldwork team already had a prior engagement. The routes through the villages were not pre-defined and were guided by the community members according to the points of interest in each village. However, as defined during the formative fieldtrip, we made sure to always visit some key village locations to conduct the structured spot-checks. These locations included the village water bodies (the irrigation canal, the village drains, and the public wells and ponds, if there), and all the primary schools and the Anganwadi centres present in the village. In each village there were 1 to 2 Anganwadi centres and 2 to 3 primary schools. Across the 9 study villages, 18 primary school spot-checks, 10 Anganwadi centre, and 20 water body spot-checks were carried out (Table 4-3).

4.4.1.1 Data collection tool: Village spot-checks

The spot-check tool was developed to capture the state of the public WASH infrastructures, including the state of Anganwadi and school toilets and water hand-pumps, the state of the water sources across the village, including the village drains, ponds, canals… The tool was based on the key indicators used for monitoring community WASH facilities in USAID studies[203]. The tool can be found in Appendix B. In addition, pictures of the public WASH infrastructures were taken to record visual information, and they proved useful to further stir conversations about the environment with community members. The transect walks resulted in extensive unstructured natural discussions between the fieldwork researchers and several community members about topics of concern relating to the village environment, WASH factors and child health, which were prompted by our presence. For instance, while we were checking out a newly installed electric borewell connected to a reverse osmosis system to treat water in one of the villages, a few families approached us to explain to us the issues they had with that tap, and how they used it accordingly. I recorded the qualitative information from the village transect walks and unguided conversations in extensive field memos while completing spot-checks that gathered structured quantitative data at key locations.

Alongside conducting the village transect walks, I collected the environmental samples from the public domains such as the village water bodies and school and Anganwadi water hand-pumps. Upon returning from the village visits, PP and I analysed the environmental samples. Further details on environmental sampling and analysis are explained later on (Section 4.4.6).

4.4.2 Household visits

4.4.2.1 Sampling and recruitment

Upon completion of the first village-level visits and transect walks, household visits were started (Image 4-4). Previous studies performing caregiver-infant household observations[16,67,71,134] used a sample size of 20 to 30 households. Based on the literature, I planned to observe approximately 20 households in each block: 20 in the Ghatol block, and 20 in the Kushalgarh block, 40 in total, although the adequacy of the final sample size was continuously evaluated, following the prevailing concept of theoretical saturation[195].

Image 4-4 Household courtyard captured during a household visit

Study households started being purposively selected from two of the study villages, one in the Ghatol block (GG) and one in the Kushalgarh block (KD), based on those villages with which the field team had developed the strongest community linkages and were more easily accessible by road. In each of those villages, only households with an infant aged 0-2 were considered. The Community Champions helped us identify the households with infants present. Households with infants present were purposively selected from spread-out locations in each village, from different *phalas*, since the aim was to maximise geographical scattering to capture possible variabilities. After visiting 10 households in each of the initial villages, information saturation was starting to be reached for those villages, since we had visited practically all *phalas* with infants present in them, and we had captured the lifestyles and contamination levels across them. Therefore, after 10 household visits in Ghatol (GG) and 10 in Kushalgarh (KD), I decided that we would move to other study villages to continue with household observations that would provide additional insights. Thus, the following study household visits were performed in two additional villages (GU and KB), one from each block. Finally, a total of 42 households were visited, 21 in the Ghatol block (10 in GG and 11 in GU) and 21 in the Kushalgarh block (10 in KD and 11 in KB). Household visits were carried out during morning times, for an average of 90 minutes each, amounting to 63 hours of structured observations in total. While purposive sampling can lead to a biased sample, given the observed homogeneity within villages, which had extremely similar built environments, socio-economic characteristics, and lifestyles, the unobserved households were not expected do differ significantly from the ones that were observed, with little impact to the general conclusions of the study. All the household visits were conducted by two fieldwork researchers (PP and I).

4.4.2.2 Consent

Accompanied by the community champions, selected households of infants were approached. To start, the purpose of the study was explained to the infant's caregivers by the fieldwork researcher that was fluent in Hindi and Wagdi (PP). The informed consent sheets were explained and discussed verbally, and doubts were resolved. Written consent to conduct the household visits was then sought from the infant's parents. While consent was sought from the infant's parents (mother or father), permission from household heads (often the grandfather) was also sometimes culturally required, in which case both signatures were obtained. While not all the village participants were literate (as seen in Table 3-2), they all felt comfortable signing and/or writing their own names.

4.4.2.3 Data collection tool: Household visual survey

After obtaining consent, participants were asked to show us around their household compounds, to conduct the "guided house tour" and record the characteristics of the house's built and physical environment while asking questions to the participants about the uses and their perceptions on the household characteristics and spaces. Information was captured on the household WASH facilities available such as water hand-pumps, stored water containers, handwashing facilities, toilets, the characteristics of the domestic animals within the compound, cleanliness indicators, etc. This information was noted down in the structured household visual survey tool that had been developed. The household visual survey tool was developed based on the WHO & UNICEF Core WASH Questions for Household Surveys[197] and amended after preliminary testing of the tool to make it context-tailored, for instance including a section to capture domestic livestock characteristics. The tool can be found in Appendix C.

4.4.2.4 Data collection tool: Observations of caregiver’s domestic practices

After the “guided house tours”, we asked caregivers to carry on with their domestic tasks as per usual. Given that household visits were performed in the morning times, caregivers were often engaged in a variety of domestic tasks, from cooking, to caring for the animals, to cleaning, etc. Details on the observed caregiver’s domestic practices were captured in a semi-structured tool. During these observation periods, the local fieldwork researcher conversant in Hindi and Wagdi (PP) generally engaged in unstructured conversations with the male caregivers and household heads in the household courtyards, while I was more often invited into the kitchen spaces or other places where female caregivers were carrying out cooking, cleaning, breastfeeding, and other domestic and childcare activities, following the social gender norms. I proceeded to record the caregiver’s handwashing opportunities, cooking and feeding events, household cleaning instances, infant bathing and faeces disposal practices, animal handling instances, and childcare practices observed in the semi-structured tool. The tool had been developed based on that by Ngure et al.,[67] which consisted on recording the *what, how, who,* and *when* details of the particular domestic practices of interest. Hence, the semi-structured tool, which can be found in Appendix D, collected semi-structured qualitative information on the caregivers’ domestic practices observed, and it was complemented by the extensive unstructured conversations and observations that were held with the infant caregivers during household visits.

4.4.2.5 Data collection tool: Observations of infant’s exposures

Alongside the observations of caregivers’ domestic practices, observations of infants’ exposures were conducted. This occurred concurrently since infants were generally playing nearby or being cared for by the caregivers. Across the 42 households, 47 infants under-2 were closely observed (in a few households there was more than one infant under-2). A tool to capture the infant’s mouthing and exposure contacts had been developed (Appendix E), which allowed me to annotate the level and types of exposures to potential faecal pathogen contacts for infants. Initially based on Ngure’s study tool[67], and further refined by formative research learnings, the tool recorded all items that were mouthed by the target child and their frequency. The tool allowed to classify infants’ behaviours into the different locations (*unimproved ground/ improved ground/ off-ground*) and activities (*playing/ sitting/ sleeping/ eating/ bathing*), and the different types of exposures (*mouthing/ ingestion*) they were carrying out at each point in time, the duration and frequency of exposures, alongside an assessment of the hygiene conditions of the environment where they were found (*Visibly dirty/ Not visibly dirty/ Fly-ridden*). In this manner, infants’ mouthing and exposure contacts were recorded systematically.

The period of household visits required daily trips to the study villages, which invariably led to daily informal interactions with the community. Before and after the household visits, we often paid visits to the villages' Anganwadi centres or schools and chatted with the frontline health workers and teachers. We also frequently visited the Community Champions' houses, to seek their help for selecting and approaching study households, which often led to tea and discussions about the research being done. Therefore, the period of household observations led to several rich unstructured discussions with different community members that, when relevant, were captured in the field memos. Overall, during household visits, quantitative and qualitative data were collected using structured and semi-structured tools. Concurrently, environmental samples were also collected from the different key points in the households (i.e., water taps, earthen floors, etc) and analysed upon returning from the study villages. Details on household environmental sampling are discussed later in the thesis (Section 4.4.6).

4.4.3 Key Informant Interviews

4.4.3.1 Recruitment and consent

As we carried out daily visits to the study villages to perform transect walks and household visits, we became increasingly familiarised with the places and built relationships with several members of the communities, particularly with the frontline health workers at the Anganwadi centres, with whom we interacted frequently when visiting the villages. These interactions helped us set up for the formal key informant interviews with the villages' frontline health workers, which we conducted subsequently. I aimed to interview all the ASHAs and ANMs available in the study villages. In each of the 9 study villages, there were one to two ASHAs available, depending on the size of the village, and one ANM. Finally, a total of 12 key informant interviews were carried out: 10 with ASHA's (5 in each block) and 2 with ANMs (1 in each block). While we were able to interview most ASHAs across the study villages, arranging interviews with the ANMs proved more challenging. The rapport that had been built with ASHAs, who were based at the village Anganwadi centres daily, helped to support the recruitment and interviewing process. However, ANMs were not necessarily residents of the study villages and held responsibilities at several villages at a time and were therefore often not present or available.

KII were carried out at the Anganwadi centres and lasted between 30 and 60 minutes each. Prior to the start of each interview, the informed consent sheet was provided and discussed, and written consent obtained. All interviews were audio recorded and conducted by at least 2 fieldwork researchers (PP and/or HC and me). While one of the researchers who was fluent in both Wagdi and Hindi moderated the interview, I collected observational and reflective notes on field memos capturing other non-textual information. At the same time, I prompted for further information from the frontline health workers as key conversation points arose that needed expanding.

4.4.3.2 Data collection tool: Topic guide for Key Informant Interviews

KII topic guides were developed after the formative fieldtrip. Based on the formative research learnings (Section 4.3.5), topic guides were designed to focus on 4 key topics: 1) the frontline health workers accounts of their own roles and responsibilities, 2) their accounts on the village burden and healthcare practices for enteric infections in infants, 3) accounts on the perceived infection risks and consequences for child health, and 4) their perceived barriers to village improvements in WASH infrastructure and behaviours. The topic guide tool (Appendix F) was gradually adapted even during fieldwork, but always grounded on those key topics.

4.4.4 Focus group discussions

4.4.4.1 Recruitment and consent

Towards the end of the fieldwork period, once we had developed a good rapport with several community members and families across the study villages thanks to the research interactions during transect walks, household visits, and interviews, we organised focus group discussions with mothers of infants. Given that we had been visiting four of the study villages for the household visits (GG, GU, KD, KB), those were the villages were we had built a stronger community rapport. It was therefore decided that 4 focus group discussions were going to be carried out in that subset of study villages. With the help of the Community Champions in each village, all mothers of infants were invited to attend the meeting on a specific day through word-of-mouth and self-selected mothers attended the focus group discussions. The fact that by the time we organised the FGDs it had been close to three months that we had been frequently visiting the study villages, helped the engagement through word-of-mouth and the number of people that recognised us and were acquainted with the project. The four FGD discussions were carried out at the Anganwadi centres of the four different villages. FGDs involved between 6-9 participants each (27 mothers in total) and lasted an average of 40 minutes. First, informed written consent was sought from all the mothers present. At that point, the majority were already familiar with the study purpose given previous interactions.

All three fieldwork researchers were present for the group discussions: PP took charge of explaining the study purpose and solving questions to obtain written consent. HC guided and moderated the discussions, which were conducted in a mix of Wagdi and Hindi. Meanwhile, I audio-recorded the discussions, collected observational and reflective notes in the field memos, and prompted for additional explanations as key topics of conversation arose. Outside of the formal audio-recorded discussions, the FGDs led to informal gatherings of mothers and prompted for informal, unstructured discussions which sometimes revealed valuable information outside of the audio-recorded discussions. Hence, in addition to the audio recordings, FGD's data was complemented with detailed field memos.

4.4.4.2 Data collection tool: Topic guide for Focus Group Discussions

Similar to the tool used to guide the key informant interviews, a topic guide tool was developed to guide FGDs. The topic guide tool was informed by formative research learnings that evidenced the need to focus on a few key topics only during group discussions. Those included: 1) mother's accounts on enteric infections burden in infants and healthcare-seeking practices, 2) mother's perceptions on infection risks and consequences for child health, 3) mother's concerns in regard to the village WASH and infrastructural conditions (Appendix G). The rural setting in which the FGD were conducted (Image 4-5) and lack of meeting rooms meant that children, animals, or men often interrupted the discussions, which was perceived to affect women's engagement. Men visitors were kindly asked to provide privacy for the meetings to be carried out, to avoid any potential impact on the mothers' discussions.

Image 4-5 Focus group discussions with mothers of infants

4.4.5 Health event observations

4.4.5.1 Recruitment and consent

During the fieldwork stage, we regularly engaged with the frontline health workers at the Anganwadi centres (particularly ASHAs and AWW, who were present on a daily basis). Given that I wanted to observe how the village health events were conducted, in particular the VHND events that occur on a monthly basis, we asked frontline health workers permission to come along to their next VHND, whenever it was, and observe the activities conducted. Throughout the fieldwork stage, the fieldwork researchers (PP, HC, and I) were invited to attend 4 different health events (i.e., VHND days), which occurred at the Anganwadi centres of 4 different villages (GU, GTC, KB, KP). The VHND observations lasted between 60 to 90 minutes each. While verbal permission to attend and observe the VHND events was obtained from the frontline health workers, no signed consents were collected given that no personal identifiable data was intended to be collected.

4.4.5.2 Data collection tool: Semi-structured headings table tool for health event observations

To capture the accounts of village-level health events and informed by the preliminary Anganwadi observations conducted during the formative fieldtrip, a semi-structured "headings table" tool was developed. Blank headings tables allow for free descriptions to be written under a set of structured headings so that qualitative data on a systematic set of key topics can be collated. I recorded details on the event's setting, organisers, attendants, topics of discussion and group dynamics on the "heading's table" semi-structured tool (Appendix H).

During the field trip, it was clear that our presence in those health events had a reactivity effect, where the frontline health workers and mothers were on their "best behaviour" since they knew in advance that they would be visited by a group of researchers. However, attending these events proved revealing in showing us what the participants' self-perceived "best practices" at those community health events were, and how those potentially differed from the "best practices" defined in the government guidelines regarding what VHND are supposed to entail. Thus, while reactivity bias is a limitation hiding the true behaviours, in this case, it was also useful in portraying the participants knowledge on what the VHND should entail.

4.4.6 Microbiological analysis methods

Alongside the transect walks and the household visits, environmental samples were collected from different village-level and household-level sources. Based on the previous evidence reviewed on the faecal exposure pathways to infant's in the home environment (Section 1.4), and based on the learnings from the formative fieldtrip (Section 4.3.9), several environmental sampling locations were chosen to capture the faecal contamination levels at key contact points for infants across the household and village environments. Thus, during the fieldwork period from September to December 2019, which coincided with the late and post-monsoon season in Banswara, water, soil and hand swab samples were collected from: the villages' water bodies (streams, ponds, canals…), the schools and Anganwadi's water hand-pumps and soil courtyards, the household's domestic water sources and stored drinking waters, the household's courtyard soil where the child played and crawled, the infant's hands, and the caregiver's hands. A total of 316 environmental samples were collected and analysed (by PP and me) every day upon returning from the study village visits (Table 4-4).

Table 4-4 Summary of environmental samples collected during fieldwork

Environmental samples collected	**Number of samples**
At the village-level	
Water samples	
Public hand-pumps in schools and Anganwadis	28
Surface water bodies such as local streams and ponds	30
Soil samples	
Courtyard floors in schools and Anganwadis	25
At the household-level	
Domestic water source samples	
Hand-pumps	40
Borewells	7
Open wells	7
Household stored drinking water	
Stored water from hand-pump source	37
Stored water from borewell source	3
Stored water from open well source	3
Hand swabs	
Infant's hand swabs	42
Caregiver's hand swabs	41
Soil samples	
Household courtyards floors	53
Total	**316**

4.4.6.1 Data collection tool: Environmental sampling and analysis protocol

Based on the environmental sampling collection and analysis techniques that had been tested during the formative fieldtrip and prior to the fieldwork trip, a protocol for environmental sampling and analysis of faecal bacteria was developed to guide the process (Appendix I). The environmental sampling and analysis protocol was developed based on several fieldwork laboratory practices such as the District Laboratory Practice by Cheesbrough[204]. Additionally, the SaniPath study analysis guidelines[205] were used to determine water sample collection and dilutions that would likely be necessary, and other study's guidelines were followed for the collection and pre-processing of soil[70] and hand[206] samples.

4.4.6.2 Sample collection

Water samples were collected in 200mL sterile Whirl-Pak bags. In the case of tap water samples (hand-pumps and borewells), water was allowed to flow for 5 seconds before collecting the sample. In the case of open wells, water samples were collected using the designated buckets used by locals to access well water. In the case of surface water bodies like streams, samples were collected from the most accessible places that people could use as bathing spots, and Whirl-Pak bags were dipped against the current flow.

Hand swabs were taken from the individual's dominant hand using a cotton swab soaked with PBS (phosphate-buffered saline) solution, swabbing across the palm and up all five fingers, and immediately placed black in a sterile 50mL conical tube with PBS as described by Carrasco et al[206].

For the collection of floor soil samples, the area of interest where infants had been observed or where they were reported to play was first identified. A composite of three 100cm^3 (10x10 cm) floor areas was taken by scraping the top layer of soil with a sterile spatula and collecting the soil in Whirl-Pak bags, which usually amounted to an almond-size mass of soil.

4.4.6.3 Sample processing and bacterial culture

All samples were placed in a cool box and analysed within 6 hours of collection. This was done in the afternoons and evenings, upon returning from the field visits by two fieldwork researchers (PP and me). Different volumes (100mL, 10mL, 1mL) of the water samples were analysed. Soil and hand-swabs were eluted in 50mL conical tubes with PBS, manually vortexed for 6 minutes, and let settle for 15 minutes. The supernatant was then pipetted and diluted with different volumes of PBS. Water samples and dilutions were filtered through 47mm, 0.45µm Millipore filters (Merck Group). Millipore filters were cultured with MColiBlue24 Broth (Merck Group), a selective growth medium for total coliform and *E. coli* bacteria growth. Petri dishes were incubated at 35^{o}C for 24h, as specified by the supplier[207].

E. coli colony-forming-units (CFU) enumeration was carried out when there were between 1-300 CFU/filter (Image 4-6), otherwise, they were annotated as non-detects (0 CFU) or TNTC (too numerous to count- +300 CFU/filter)[205]. Where different dilutions of the same sample all resulted in readable CFU counts (1-300 CFU/filter), the CFU count from the largest volume analysed was used as the final *E. coli* count and the other results excluded[205]. Based on the manufacturer's instructions and the dilutions used, the upper detection limit was 300 CFU *E.*

coli/1mL of water, 3.000 CFU/hand-swab, or 300.000 CFU/gram of soil, and the lower detection limit was 1 CFU/100mL of water, 1 CFU/hand-swab or 100 CFU/g of soil. Further details can be found in the environmental sampling and analysis protocol (Appendix I). The final *E. coli* counts for each sample were expressed as culturable *E. coli* CFU/100mL for water samples, *E. coli* CFU/hand-swab for hand samples and *E. coli* CFU/gram of soil, and all the information was stored in a spreadsheet.

Image 4-6 Petri dish with culturable E.coli CFU (blue dots) to be enumerated

4.4.7 Data collection tools

To recap, several qualitative and quantitative data collection methods were used during the fieldwork stage. The data collection tools were developed based on the literature and on the learnings from preliminary testing of the different methodologies during the formative trip. Table 4-5 summarises the list of methods and data collection tools that were used during the fieldtrip, and the appendices where they can be found.

All tools were printed on paper so that data could be collected in pen and paper at the field site. The use of technological equipment to collect data was perceived to further widen the cultural gap between participants and researchers, in a study setting where even ownership of mobile phones was scarce.

Table 4-5 Final data collection methods and tools used

Methods	Data collection tools	Appendices
Transect walks	- **Spot-check tool** to collect structured data of the village WASH facilities, including in schools, Anganwadi centres and public water sources. - **Camera** to collect pictures of the environment - **Field notebook** to collect field memos of unstructured conversations and village observations	- Appendix B
Household surveys	- **Household visual survey** to collect structured data of the physical environment - **Camera** to collect pictures of the environment	- Appendix C
Observations of domestic practices	- **Domestic caregivers' practices observation tool** to collect semi-structured data on caregiver's behaviours - **Field Notebook** to collect field memos of unstructured conversations and observations	- Appendix D
Observations of infants' exposures	- **Infant's exposures observation tool** to collect structured data on the infant's mouthing tallies	- Appendix E
Key informant interviews	- **KII Topic guide** to guide interviews - **Audio recorder** - **Field notebook** to collect field memos capturing observational and reflective notes	- Appendix F
Focus group discussions	- **FGD Topic guide** to guide discussions - **Audio recorder** - **Field notebook** to collect field memos capturing observational and reflective notes	- Appendix G
Health event visits	- **Health event observation tool** to capture semi-structured data on the accounts of health events - **Field notebook** to collect field memos capturing observational and reflective notes of the events	- Appendix H
Environmental samples	- **Environmental Sampling Protocol** - **Whirl-pack bags** and other materials for the collection of samples - **Field Notebook** to collect details of the sample collection time and place	- Appendix I

4.4.8 Timeline

Figure 4-1 shows a timeline of the research activities that I carried out during the year 2019, including the formative fieldtrip to formulate the methodology and the fieldwork stage for data collection.

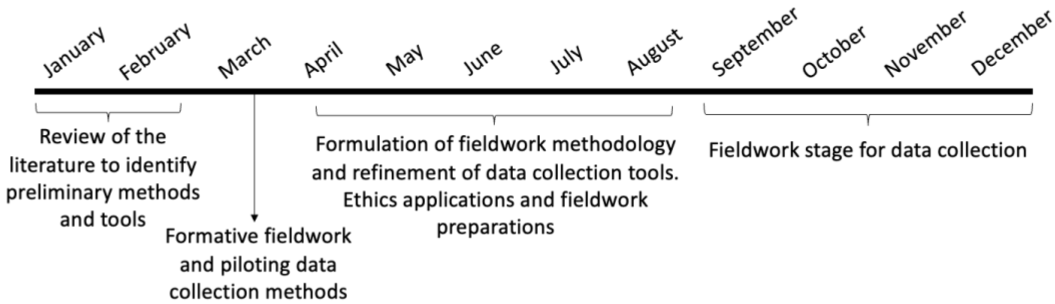


Figure 4-1 Timeline of research activities carried out during 2019

During the fieldwork stage, several cultural and geographical challenges of working with remote tribal communities determined the time requirements for data collection. Due to the poor road access, it took 1 to 2 hours by car to reach the study villages, and road accesses were sometimes blocked on rainy days due to flooding. Tribal communities also celebrated several religious holidays during which time it was not appropriate to conduct research, and the crop calendars also kept families busy in agriculture work during harvesting seasons, which also impeded doing data collection. In addition, the local field team advised against visiting the tribal communities in the afternoons or near election times due to potential social turmoil and safety concerns. These factors, in addition to the time required to analyse the environmental samples upon returning from the field every day, limited the amount of data that could be collected each day at the study villages. At the same time, the relatively slow pace of data collection enabled me to reflect on the interactions after each village visit, to adapt the data collection tools to include new topics of interest that continuously emerged and to have the time to better understand cultural aspects of the Banswara population. A Gantt chart below (Figure 4-2) summarises the time requirements to conduct the village and household-level research tasks.

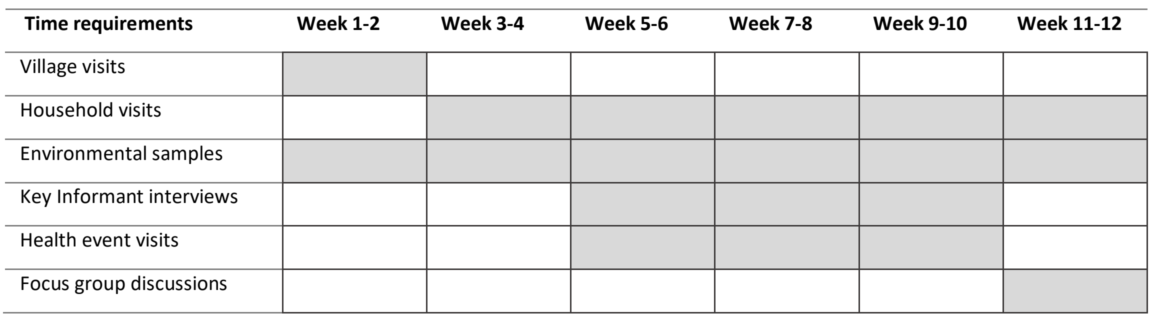


Figure 4-2 Gantt chart of research activities carried out during the fieldwork stage

4.5 Ethics

Ethical approval was obtained from the UCL Research Ethics Committee (Project ID: 147003/001) in the UK and the Indian Institute of Health Management Research (IIHMR) Institutional Review Board in India (Project ID: 04052019) to conduct this fieldwork research. Further ethical approval was obtained from both institutions in August 2020 to include post-covid amendments to conduct further online interviews with stakeholders. The ethical approval letters from UCL and IIHMR can be found in Appendix J. Ethics applications included details on the proposed methods, data collection tools, informed consent forms, as well as a detailed data management plan, occupational health hazards and a risk assessment. The process of preparing the ethical applications triggered reflections on some crucial ethical considerations for fieldwork, but at the same time, it was challenging to find a common ground between the requirements of the two different institutional review boards and the fieldwork realities. For instance, several iterations of the informed consent sheet were required before a suitable length and wording was agreed on between IIHMR and UCL. The final version of the informed consent sheets included information that was detailed enough on participants' rights and data privacy (as per UCL requirements) but had been simplified enough into a lay language to be considered appropriate by IIHMR. Informed consent sheets can be found in Appendix K. Some important ethical considerations and challenges that were faced when seeking consent at the field site are described hereafter.

4.5.1 Ethical considerations

The topic of study (WASH practices and infection risks) and the methods employed (observational and qualitative methods, and environmental sampling) were not particularly intrusive methods or sensitive topics. However, much thought was given to account for the cross-cultural nature of the research and to develop a culturally sensitive approach. Working with tribal populations who have been historically marginalised and discriminated against posed additional ethical challenges due to inherent power imbalances. Cultural sensitivity requires the acquisition of cultural knowledge of the social group, including social, family, religion, historical and political backgrounds[208]. Despite limitations on what I could learn about the socio-cultural setting prior to the fieldwork stage, I carefully considered the main beliefs and practices, I became conversational in Hindi language, and I strived to immerse myself in the culture while there, by regularly consciously reflecting on the need to adapt to the different socio-cultural norms for the success of this research. Cross-cultural difficulties were mostly overcome by a fieldwork team that was composed of local people from Banswara, who not only knew the language and cultural norms, but also personally knew the study communities and some of the participants, having worked with them for several years and having built a good rapport.

The inclusion of young children in the study was justified as they were the target population of the study, and their risk of discomfort was minimal, as they would only be observed in their domestic setting and with the presence of their caregivers. Infants mostly did not notice being involved in the study. The risk of discomfort to parents during household observations was also considered, as researchers were intruding on their private domestic space, but this was overcome by the process of informing parents of the purpose and duration of the observations and obtaining consent. Researchers remained mindful to give participants space in sensitive situations such as people changing clothes or breastfeeding, etc. Observations were carried out during daylight hours and stopped in case participants needed to leave the house unexpectedly. Overall, respect and empathy guided the process of ethical fieldwork with tribal communities.

4.5.2 Seeking consent

During the fieldwork stage, the process of obtaining consent from participants often involved extensive verbal explanations on the details of the study and discussions on their concerns, rather than participants reading the information sheets themselves. However, participants mostly did ask to keep the information sheets for later reference. While consent was sought from the infant’s parents, permission from household heads was also sometimes required. In the households where the grandfather was present and the infant’s parents were young adults, it was often the case that it was culturally required to obtain consent from the male elder, as they were considered the household heads. In addition to a written consent for the collection of data, a separate informed consent sheet for the collection of pictures for the purposes of dissemination and publication was also prepared. When pictures of infants were captured, written consent was sought from the infant’s parents, so that pictures could be used later on in research outputs to visually depict relevant information about the research topic. Different strategies were used to ensure an adequate comprehension of the study goals, procedures, risks, and benefits. Community Champions were previously briefed, and on many occasions, they helped us explain the study details to the participants, and to prompt them for further questions and concerns to be shared. Furthermore, several of the community members had already been exposed to research activities during the PANChSHEEEL Project and were therefore already acquainted with what it meant to be a participant in a research project. Best efforts to thoroughly communicate the information were carried out, but it became clear the process of seeking informed consent needed to be very different from that specified as per the UCL templates. Perhaps an important knowledge gap remains on the best strategies to obtain informed consent across settings with different levels of literacy, beliefs, and comprehension of the nature of research and voluntary participation[209]. In communities where people may not be aware of what a research study is and what "being a participant" entails, informative community meetings where the study is explained may be required prior to asking for informed consent sheets to be signed. The role of Community Champions that acted as a bridge between researchers and participants was essential to build trust among the communities on what it meant to participate in this study. For this study, I was able to benefit from the prior work done under PANChSHEEEL on research sensitisation with the study communities.

4.6 Fieldwork reflections

The experience and practice of fieldwork led to some key reflections and practical learning points that are briefly discussed hereafter.

4.6.1 Reflections on data collection methods

The interdisciplinary mixed methods used in this study led to an unconventional methodological approach: the study was not a purely qualitative research project, nor a conventional epidemiological health study, nor a microbiological study, or an ethnography. However, the methods used were needs-driven and leveraged from all these different fields. The dynamic and complex set of variables influencing infection pathways that existed in the study settings demanded a flexible methodological approach. Integrating the different methods "made sense": Regardless of the research activities that one may want to carry out in rural Banswara, it was apparent that it was culturally required to start by visiting the different village stakeholders and becoming acquainted with the village environment, and then speaking to individual villagers. Thus, the village transect walks, school and Anganwadi visits, and household visits allowed us to gradually become familiar with the different parts of the study setting and community. The collection of environmental samples alongside the village and household visits further engaged participants and appeared to bring a balance to the transfer of information between researchers and participants during data collection: As we asked participants about their domestic practices and beliefs, they were curious to learn more about the germs that were present in their environment. Participants often asked about the process of microbial analysis and they asked us to show them pictures of the germs that we had found in their village or household, and what that meant. In that manner, the integrated methodologies allowed us to progressively interact with the study communities in a more natural and instinctive way.

4.6.2 Researcher's positionality

Positionality refers to the researchers' worldview and the position adopted by them. Put simply, positionality refers to "where the researcher is coming from", and it is important because it influences how research is conducted, analysed and presented[210]. My position as a foreigner clearly meant that I was an "outsider" to the tribal communities in Banswara. This presented significant limitations and challenges. An "insider" would share social, cultural, and linguistic characteristics and would be able to infiltrate communities' with much more ease, and potentially be able to "become one of them" and elucidate more intimate and hidden characteristics, that were not captured as an "outsider"[208]. However, my position as an outsider also provided me with the opportunity to constantly ask naïve questions and analyse social life from a more critical removed perspective[193], and be perceived by participants as a "curious stranger". Participants appeared keen to show "a stranger" their way of living and seemed appreciative of the curiosity and interest. Questions from myself, as a stranger, were perceived as more genuine due to the lack of familiarity with the culture and setting, so while I was allowed to ask "dumb" questions, the same from an insider may have been perceived as illegitimate, inquisitive or with hidden interests[210].

Even the local fieldwork team colleagues were sometimes surprised by some of the questions I posed, as they had never themselves wondered about those specific cultural aspects that I asked about. In several instances, the local fieldwork team colleagues became important sources of information, with whom day-to-day reflections in the field were discussed, or with whom relevant gaps and questions were uncovered. They themselves provided key historical, political, and cultural background remarks.

My position as a young female allowed me to interact with young mothers, who were sometimes surprised by how different lives we had, being the same age and gender, and were keen to learn about my own daily routine, as I asked them questions about their routines. During household observations, I was often invited to be present in some women-exclusive settings, such as in the case of breastfeeding, or cooking in the kitchen, which would have not been possible if I were a male. On the other hand, my position as a young female in a patriarchal society where males are assumed to be in charge sometimes made the interactions with older male leaders, such as Sarpanch village leaders, more difficult.

My position as a white-caucasian and European national also created a power imbalance between myself and a community without the same socio-economic opportunities. Efforts were taken to overcome this. When culturally acceptable, I refused different treatment, for instance, I sat or squat in the same way participants were during conversations, and when offered food and drinks, I consumed the same as the community people. Guidance from the local field team colleagues was key to not err on any crucial issues of cultural insensitivity. Despite these efforts, I tried to remain critical of the power imbalance due to my race and socioeconomic status. I often wondered to what extent people were agreeing to participate and engage in discussions due to a genuine will to participate in the study or due to the social pressures to satisfy the requests of a white foreigner. I believe it was often curiosity to interact with a foreigner that led to their willingness to participate, and I questioned to what extent I was taking advantage of that. These reflections were sometimes uncomfortable. However, towards the end, it became apparent that perhaps this two-way exchange of information, in which I asked about their lives and they were also curious to learn about mine, was natural, and that keeping research as natural social interactions helped balance the power imbalances between the *researcher* and the *researched.*

Lastly, my positionality in terms of my beliefs also influenced how the research was conducted. One of the theoretical views that drove this study was my belief that global health inequities are unfair, and that all children deserve equal opportunities to reach their developmental potential. I highly regard education and health and believe that access to them as well as to basic WASH is a fundamental human right. Such macro-level assumptions are often implicit, but they substantially impacted the theoretical approach to research[193]. Acknowledging this positionality made me realise that my beliefs were not as universal as I may have thought. For instance, some participants may have regarded nurturing their spirituality or social needs above their dietary or health needs. As participants were puzzled at my lack of concern for not having a religion or a husband, I was equally surprised at their sometimes lack of concern for not having clean water or a toilet. This mismatch often challenged my core assumptions and made me reflect on the theoretical underpinnings of the study.

4.6.3 Language

One of the cornerstones of this project has been reflecting on the great deal of transformations that are needed as a young, white, London female student to work with traditionally marginalised rural tribal communities in India. It was clear from the beginning that one of these crucial transformations was acquiring the language skills to communicate with the study communities myself. For the duration of the PhD, I have been enrolled in a Hindi language courses, reaching a B1 language level. Despite not being able to become fully fluent, a conversational level of Hindi proved essential for many aspects during the fieldwork stage. To be able to interact with women in contexts where my male fieldwork team colleagues were not able to, to follow conversations during interviews and contribute with prompts and questions, to be able to ask questions myself as they emerged during observations, but more importantly, acquiring basic conversational skills allowed me to connect with participants by denoting a genuine interest and commitment to learn about their culture.

4.7 Data analysis

Finally, the analysis of the data actually began while still in the fieldwork stage. Every day, upon returning from the field site, the data collected on the paper tools were transcribed to online text and spreadsheet documents, which triggered a constant state of reflexivity. Preliminary ideas, questions and early themes that arose while conducting fieldwork and transcribing data were noted down, guiding further questions and observations during the data collection. However, upon returning from the fieldwork stage in Banswara, the formal data analysis to address the study objectives was undertaken.

The qualitative and quantitative data collected comprised of pictures and field notes from the unstructured observations and conversations across the 9 villages and 42 household visits, 48 structured spot-checks of the village's key locations, transcripts of 12 interviews and 4 group discussions, 42 spreadsheets containing the household survey data, data on the infant's exposures and caregiver's domestic practices, and the *E. coli* contamination levels of 316 environmental samples (Table 4-3). To address each specific study objective, different parts of these data sources were harnessed, and different specific analysis methods were used to respond to each study objective. The following thesis chapters (Chapters 5, 6, 7 and 8) present the results addressing each of the study objectives (Objectives 1, 2, 3 and 4). The data analysis procedures that were followed to obtain the chapter-specific results are described in detail in each of the following results chapters accordingly.

5 Chapter 5. Holistic concept mapping of pathways to infection

5.1 Chapter overview

Thus far, in this thesis I have provided a review of the literature on enteric infections in infants, a contextualisation of the case study setting in the tribal district of Banswara, and detailed accounts of the mixed methods I used for data collection during the fieldwork stage. In this Chapter 5, I focus on exploring the range of multifaceted factors at the individual, household, and village-level that were found to contribute to enteric infection transmission in infants in the tribal villages of Banswara. Hence, this chapter presents the research findings that address objective 1 of this study:

> **Objective 1: To holistically explore the multiple and multifaceted risk factors at the individual, household and village-level contributing to infant enteric infections.**

In this chapter, I explain how some of the data collected during fieldwork in Banswara was used and analysed to address study objective 1, I present the results of the analysis, and discuss the findings, providing some concluding remarks.

5.2 Data harnessed

From all the qualitative and quantitative data that was collected during the fieldwork stage in the case study villages in rural tribal Banswara (details in Chapter 4), only some of the data was used and analysed to address the first study objective in this chapter. The data that was used included: Textual qualitative data in field memos from the unstructured observations and conversations held during village transect walks (n=9), the health event observations (n=4), the household visits (n=42), the transcripts from the 12 KIIs with frontline health workers and the 4 FGDs with mothers of infants. In addition, structured quantitative data on the households' built environment and WASH infrastructure, the caregiver's domestic practices, and the infants' exposures captured during household visits were also harnessed to address the study objective in this chapter. Table 5-1 summarises the data sources that were harnessed for analysis in this chapter.

Table 5-1 Data sources harnessed for analysis in this thesis chapter

Data sources	**Type of data**	**Number of events**
Village transect walks' unstructured observations field memos	QUAL	9
Health event observations' field memos	QUAL	4
Key informant interviews' transcripts	QUAL	12
Focus group discussions' transcripts	QUAL	4
Household visits' unstructured observations and conversations field memos	QUAL	42
Household visual surveys' structured data	QUANT	42
Caregivers' domestic practices' semi-structured data	QUAL/QUANT	42
Infants' exposures structured data	QUANT	47

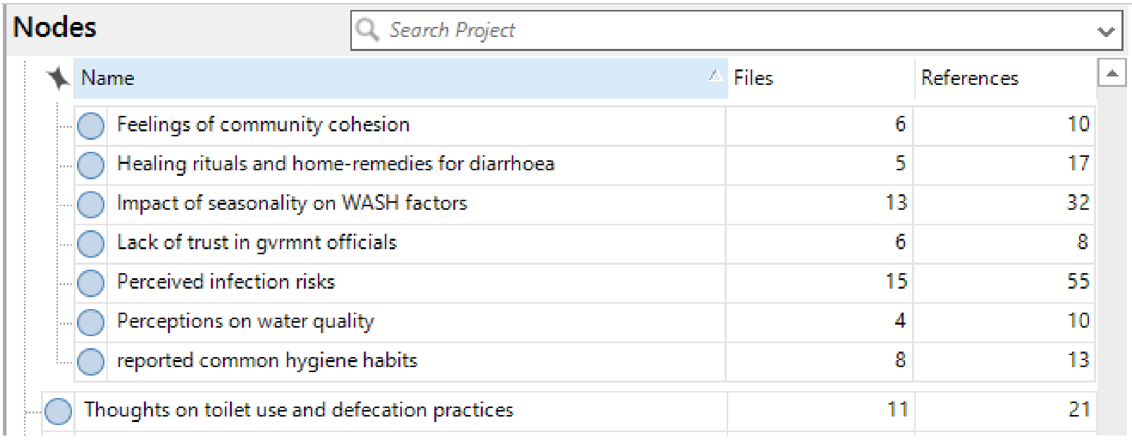
5.3 Data analysis

5.3.1 Data coding and thematic analysis

Firstly, the structured quantitative data that had been collected during household visits on the (1) household's-built environment, (2) the infant's exposures, and (3) the caregivers' domestic practices was summarised into descriptive tables. The data collected for each household had been transcribed into spreadsheets, therefore, the summary tables and summary statistics were drawn using MS Excel spreadsheets.

Secondly, all the textual data from interview and discussion transcripts (qualitative data) and field memos (observational data) were imported into the NVivo Software (NVivo 12.1) for data coding and thematic analysis. The thematic analysis of the data was guided by the objective of this chapter, which was to identify the multiple and multifaceted factors contributing to enteric infections in infants in the study setting. In other words, the analysis was directed at identifying answers to the question: *Why may infants in this setting end up getting exposed to enteric pathogens?*

The first stages of data coding involved a familiarisation and search of repeating ideas across the data. Text fragments were initially coded into a large number of categories (or nodes in NVivo) describing relevant concepts relating to enteric infection drivers. For instance, every fragment of text that talked about how villagers described or were observed to perceive the quality of the water they drank such as "*People here don't filter the hand-pump water, and that is a major cause of infection*", was coded under the tag "Perceptions on water quality". Figure 5-1 shows an example of the preliminary codes in NVivo, arising from the qualitative textual data. Codes were then gradually grouped into themes that described more abstract analytical concepts. In this manner, the themes provided more overarching analytical explanations on the factors contributing to infant enteric infections identified. Hence, themes were inductively derived from the coded data[211].


Nodes

Search Project

Name	Files	References
Feelings of community cohesion	6	10
Healing rituals and home-remedies for diarrhoea	5	17
Impact of seasonality on WASH factors	13	32
Lack of trust in gvrmnt officials	6	8
Perceived infection risks	15	55
Perceptions on water quality	4	10
reported common hygiene habits	8	13
Thoughts on toilet use and defecation practices	11	21

Figure 5-1 Example of preliminary codes in NVivo extracted from the qualitative data

The resulting qualitative themes were substantiated with the descriptive quantitative data from the household surveys and structured observations. For instance, while housing conditions had been identified as a key theme contributing to enteric infection transmission from the observational data captured in field memos, descriptive quantitative summary data from the households' built environment complemented the theme. Pictures of the village and household settings were also used to further visually support the accounts provided by the qualitative themes and quantitative information with vivid visual data. Thereby, textual, tabular and pictorial data were brought together to provide detailed and comprehensive descriptions of the factors contributing to infant enteric infections identified in the themes.

5.3.2 Concept mapping

Following the identification of the themes that described multiple factors contributing to infant enteric infections, the themes were classified into the socio-ecological model framework[167], the conceptual framework that grounded the understanding of the study context (as explained in Section 2.2.3). Guided by the socio-ecological framework, themes were categorised according to whether they were describing individual-level, household-level or village-level factors within the wider community, and according to whether the factors pertained to the physical-environmental, socio-cultural, institutional or socio-economic domains. In this manner, themes that emerged from the coded data were grounded across different domains (i.e., socio-cultural, physical-environmental factors…) and agency levels (i.e., individual, household-level factors…)[211].

The factors that were identified as potential drivers of enteric infections were often conceptually interlinked, across domains and across hierarchal levels. For instance, food hygiene practices are inevitably shaped by the housing conditions and kitchen infrastructures, which were in turn are linked to the family financial capabilities. To visually represent the identified themes in an integrated manner, as a network of interlinked factors, a concept map was drawn.

The concept map was derived from the coded data and analytical themes identified. Each factor that had been identified from the data to play a role in the infant enteric infection burden was represented as a node in the concept map. The conceptually interlinked factors were represented by lines in the concept map. These linkages did not necessarily represent causal relationships between factors, but rather conceptual linkages and influences (i.e., the household-built environment influences domestic practices, or the distribution of work within families shapes childcare practices). The concept map was drawn based on the socio-ecological framework, so that factors (or map nodes) were visually arranged into the individual-level, household-level and societal-level factors, from the most proximal to the most distal drivers to infection. Finally, a colour code was used to characterise factors from different domains (physical-environmental, socio-cultural, institutional, socio-economic factors…).

Concept mapping was a useful tool to illustrate the system as a whole and observe emergent patterns, as the concept map enabled the portrayal of the multiple and diverse arranged as a chain of interlinked events that led up to infant enteric infections. The representation of findings as qualitative themes, substantiated with direct quotes, photos, and descriptive quantitative tables provides a comprehensive picture of the infant enteric infection drivers in rural tribal Banswara. However, the representation of the infection drivers in the form of a concept map further enables the reader to develop a holistic understanding of how the multiple factors interlinked across hierarchal levels (individual, household, village-level) and domains (physical-environmental, socio-cultural, institutional, socio-economic factors…).

5.4 Results

The core themes identified from the qualitative and observational data to be factors contributing to the transmission of infant enteric infections in the study villages of rural tribal Banswara are summarised in Table 5-2.

Table 5-2 Core themes identified on the factors contributing to infant enteric infections

Level	Core themes: ***Why are infants getting enteric infections?***
Individual	Infants' exploratory and mouthing behaviours introduce multiple faecal exposure contacts
Household	Housing conditions are not hygiene-enabling
	Traditional domestic hygiene practices pose additional infection risks
	Division of childcare among different carers influences child hygiene
	Housing conditions are stratified by caste
Village	Villages' natural and built environment hinders safe WASH practices
	Limited local livelihood and employment opportunities hamper families' finances
	Caregivers perceive a lack of self-efficacy to address infection risks: "Yes, it happens, but what to do?!"
	Unreliable local governments fail to deliver public services and infrastructure

Figure 5-2 presents the concept map, where all the factors contributing to infant enteric infections identified are depicted in a visually arranged manner, showing their interlinkages. These results, together with Figure 5-2, were published at the open-access BMC Public Health journal[212]. The most immediate infection drivers are depicted at the bottom of the concept map, followed by gradually more and more distal drivers at the family and community levels, forming pathways of interlinked factors of different natures that provide conceptual explanations about how and why infants in the study setting may end up exposed to enteric infection pathogens.

The following sections present each one of the core themes that provides an explanation as to why infants in the study setting may end up getting exposed to enteric infection pathogens. The themes are substantiated by qualitative evidence (quotes and direct observations), quantitative summary data, and pictures. The themes are presented in a conceptual order, unpicking the different levels of the socio-ecological levels (individual, household, community-levels).

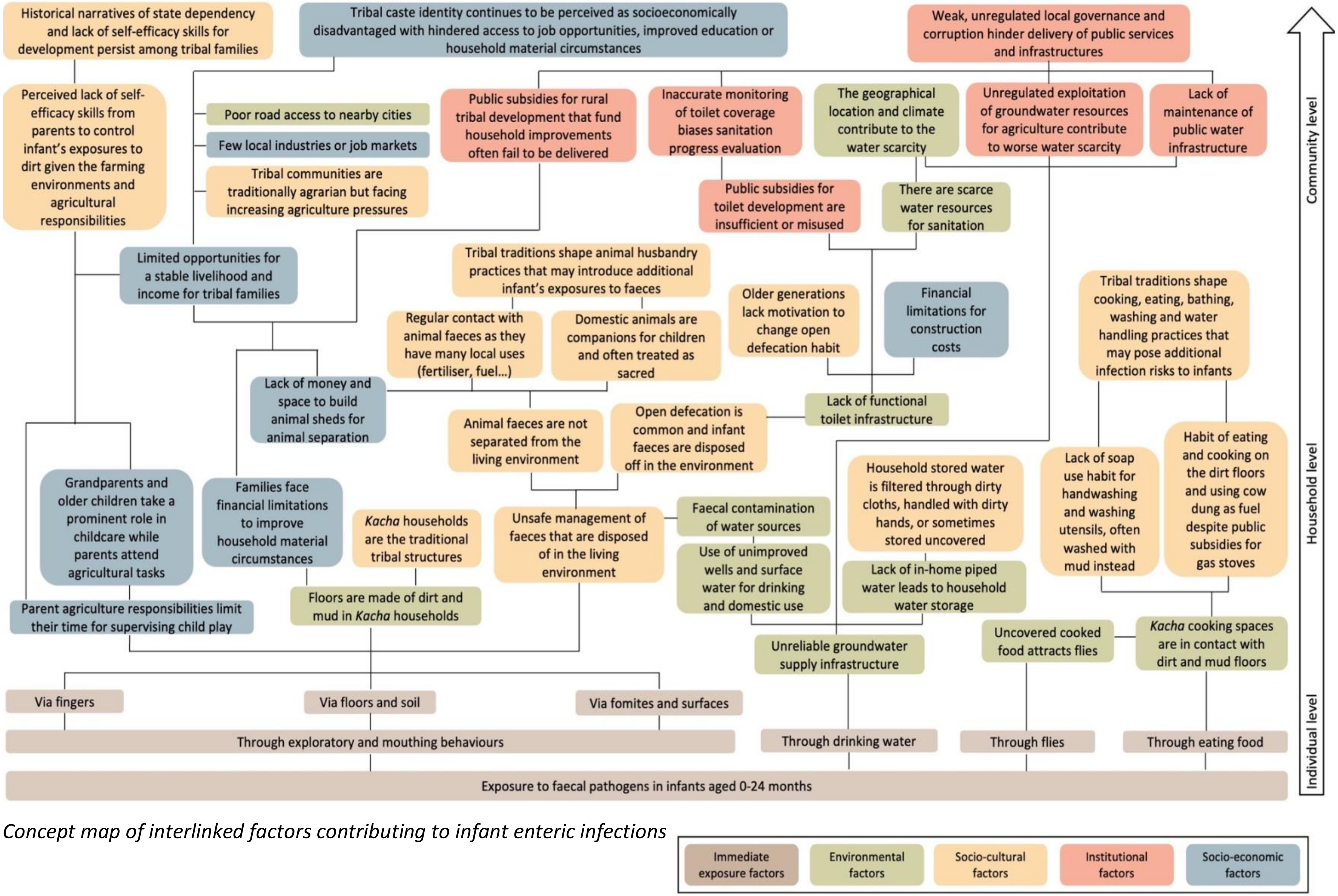


Figure 5-2 Concept map of interlinked factors contributing to infant enteric infections

5.4.1 Individual-level factors

Across the 42 household visits that were carried out during fieldwork, 47 infants between the ages of 0 and 2 were closely monitored and their mouthing tallies and exposure contacts were captured. The structured observations of infants revealed the multiple elements that they were coming into contact with and that were a potential source of exposure to faecal pathogens. This enabled the identification of the infant's most immediate pathways to faecal exposure, hence, the most proximal drivers of infection. Figure 5-3 depicts a submap of the main concept map comprising the individual-level most proximal drivers to faecal pathogen exposure for infants. Following, the individual-level theme is presented.

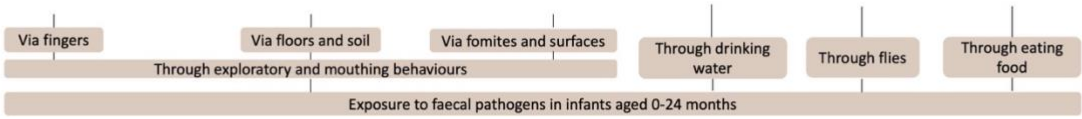


Figure 5-3 Individual-level factors submap comprising the immediate faecal pathogen exposures for infants

5.4.1.1 Theme: Infants' exploratory and mouthing behaviours introduce multiple faecal exposure contacts

During the first two years of life, infants gradually faced additional faecal exposure occasions. As infants progressed through their developmental stages, their exploratory and mouthing behaviours such as crawling and putting things in their mouths, increasingly exposed them to dirt and dirty elements in their household environment. Infants were observed to come into contact, touch, mouth or ingest a range of different elements that could act as transmission vectors for enteric pathogens (Table 5-3). However, infants' exposures varied significantly according to their developmental stage (i.e., immobile, semi-mobile, fully mobile infants).

Immobile infants (newborns aged ~0-5 months) were only observed at two single locations during the household observations: the caregiver's arms and their sleeping places. Therefore, the newborns immediate exposure elements were limited to the caregivers' hands and clothes while being held and the mothers' breasts during breastfeeding (and sometimes grandmother's breasts as well, which were used as a pacifier method). Women's *sari* cloths were often used as cloths for bed linen and to wrap up newborns. The cloths were often visibly dirty and also constantly mouthed (Image 5-1).

Table 5-3 Frequency of infants exposed to the different potential pathogen vectors as observed, by mobility levels

Exposure elements	Immobile infants (N=11)	Semi-mobile infants (N=13)	Mobile infants (N=23)
Flies on mouth/nose/eyes	64% (7/11)	69% (9/13)	74% (17/23)
Ingestion of drinking water	9% (1/11)	23% (3/13)	35% (8/23)
Ingestion of food items while sitting on the floor with constant floor-hand-mouth contacts	0% (0/11)	31% (4/13)	57% (13/23)
Mouthing of breasts	73% (8/11)	54% (7/13)	39% (9/23)
Mouthing of own fingers	100% (11/11)	100% (13/13)	100% (23/23)
Mouthing of own fingers immediately after hand contact with dirt	0% (0/11)	77% (10/13)	74% (17/23)
Mouthing of cloths, often visibly dirty and used as bed linen to wrap newborns	45% (5/11)	8% (1/13)	0% (0/23)
Mouthing of miscellaneous objects in the environment, mainly visibly dirty plastic or plant elements.	0% (0/11)	62% (8/13)	61% (14/23)
Direct ingestion of soil while crawling	0% (0/11)	15% (2/13)	39% (9/23)

Image 5-1 Visibly dirty cloths used to wrap up newborns

Semi-mobile infants (infants that crawl but do not walk, typically ~5-12 months) were at the onset of exploratory and mouthing behaviours and their increased mobility introduced additional pathways to enteric pathogen exposure. Semi-mobile infants were often observed playing and crawling around the household courtyards and mouthing different objects. In households with earthen floors, infants were constantly exposed to the floor soil while crawling and mouthing their own soiled hands, mouthing soiled objects, or directly ingesting soil and other debris in their living environment. The introduction of solid feeding at this stage also created additional exposures to enteric pathogens, as infant feeding often happened while sitting on the earthen floors with constant hand-to-mouth and floor contacts (Image 5-2).

Image 5-2 Image depicting infant's exposure to soil while eating on the earthen floors

Fully mobile infants (infants able to walk, typically ~12-24 months) were observed to often play further away from the house. Instead of staying in the household courtyard only, once infants became mobile, their play areas further extended around the household *phalas* (hamlets) and their surroundings, and they were observed to be more often cared for by other older children from the neighbouring houses, rather than adults. Around the *phalas*, there were typically several domestic animals such as cows, bulls, and goats. The *phalas* were typically surrounded by agricultural fields, and sometimes water bodies such as streams, drains, or ponds. Consequently, mobile infants were sometimes seen playing around the animals' spaces where animal faeces accumulated (observed in 6 instances), or in local drains (seen twice) around their *phala*. As infants gained mobility, their play spaces expanded, and they came into contact with new infection risk areas during play.

Overall, this theme identified the immediate faecal exposure factors at the individual level. Although the faecal exposures were markedly different for infants at different developmental ages, mouthing of their own soiled fingers and contact with flies on the face appeared to be the most consistent elements of exposure, and hence potential important vectors of pathogen transmission across all ages (Table 5-3).

5.4.2 Household-level factors

Following the socio-ecological framework and reading the concept map from bottom to top, after exploring the individual-level and most proximal drivers of infection, factors at the family and household-level that were contributing to the immediate faecal exposure pathways were identified. Factors across different domains (physical-environmental, socio-cultural, and socio-economic factors, represented by coloured boxes in Figure 5-4) were uncovered as potentially contributing to infants' enteric pathogen exposures in the study households. The following sections present the household-level themes identified.

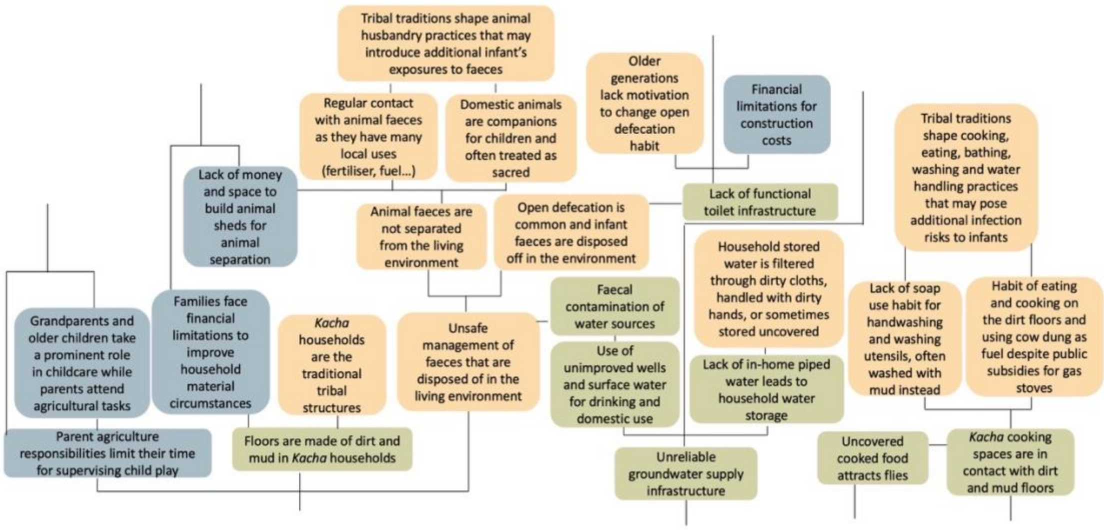


Figure 5-4 Household-level submap depicting environmental (green), socio-cultural (yellow) and socio-economic (blue) factors contributing to infants' faecal exposures

5.4.2.1 Theme: Housing conditions are not hygiene-enabling

The most common type of houses observed across the study villages were infrastructures made from rudimentary materials such as thatch or tarpaulin used for the roofs and a mix of mud and cow dung used for the walls and floors. This type of housing was locally referred to as *Kacha* houses. For those living in *Kacha* houses, the nature of the construction materials (i.e., mud), together with the lack of access to basic services such as electricity and running water hindered the adoption of safe hygiene habits. Instead, the housing conditions in *Kacha* houses contributed to poorer food, personal and domestic hygiene practices, as is discussed in further detail hereunder. Table 5-4 summarises the housing conditions and WASH infrastructures as observed across the 42 households visited during fieldwork.

Table 5-4 Housing conditions and WASH infrastructure across study households

Household's characteristics	**Overall (N=42)**
Kacha houses	36 (86%)
Gas-stove ownership	18 (43%)
Space for storage of kitchen utensils	33 (79%)
Main water source	
Public hand-pump	32 (76%)
Private electrical borewell	8 (19%)
Open unimproved well	2 (5%)
Distance to main water source >100m	16 (38%)
Storage of drinking water in the premises	41 (98%)
Drinking water containers covered	33 (80%)
Storage of hygiene water in the premises	16 (38%)
Some type of toilet construction present	17 (40%)
Improved toilet facility available	5 (12%)

Floors: While the majority of the houses in the study villages were of the *Kacha* type, a few very different houses were present across the study villages (Table 5-4), which were referred to as *Pucca* households. *Pucca* households were made from higher quality materials, with walls and roofs made of cement, and finished floors with tiles. The differences in the housing conditions between *Kacha* and *Pucca* households were striking, as it can be seen in Image 5-3. The differences in the flooring material between *Pucca* and *Kacha* houses was of particular relevance when looking at the factors contributing to infants' faecal exposures. While the *Pucca* households' tiled floors could be swept, mopped, and cleaned, the same was not possible in

Image 5-3 Living room of a Pucca house (left) versus living room of a Kacha house (right)

Kacha households, due to the nature of the flooring material (i.e., earthen floors). Earthen floors were typically made by mixing mud and cow dung and then spreading it on the floors and letting it dry until thickened consistency was reached. While earthen floors harden when dry, soil constantly casts off the floor surfaces, contributing to the objects and clothes around the house becoming soiled and potentially contaminated with pathogens treaded from the floors. Therefore, the housing conditions and particularly the flooring materials in *Kacha* households did not facilitate a hygienic environment for infants to crawl and play in the house.

Kitchens: Kitchens were typically comprised of clay-stoves (locally referred to as *chulhas*), which had been built on the earthen floors, as seen in Image 5-3. *Chulhas* used biomass (i.e., sticks, wood) or dried cow dung cakes as fuel. In addition, almost half of the households visited (43%, Table 5-4) owned a gas-stove, which families reported that it had been subsidised by a government scheme that aimed to improve the cooking conditions. However, practically none of the families that owned a gas-stove reported using it for cooking food, due to a preference for *chulhas*. Some households owned designated storage facilities to store food and kitchen utensils off-the-floor and protected from flies (Image 5-4, right), but some others did not, which led to kitchen utensils left lying around or on the floor, as seen in (Image 5-4, left). Overall, the lack of infrastructures for food preparation, eating and storage meant that these activities often occurred on the floors, hindering the separation of food from the earthen floors, and hindering safe food hygiene habits. Once again, the housing conditions, in this case, the kitchen infrastructures in particular, did not facilitate a hygienic environment for food preparation and storage, introducing additional opportunities for faecal pathogen transmission.

Image 5-4 Lack of storage facilities for kitchen utensils (left). Safely stored off-the-floor kitchen utensils (right)

Water taps: At the time of visit, the majority of households (76%, Table 5-4) relied on a public mechanical hand-pump as a source of water for domestic use and drinking (Image 5-5, left). However, several of these families reported having to temporarily rely on other water sources during the dry season when groundwater became scarce. The alternative water sources used were mainly open wells, which are unprotected dug wells as seen in Image 5-5 (centre) that are considered an unimproved drinking water source as per the WHO guidelines[27]. All the open wells observed during household visits (n=7) had visibly murky water and solid waste and debris. Only 5% of the households visited reported relying on open wells throughout the year. Finally, another small percentage of the households (Table 5-4), instead of using the public hand-pumps, had installed a private electrical pump in their household compound (Image 5-5, right). Families that owned a private electrical pump explained that the benefits of the private electrical pumps were not having to share them with other households, not having to manually pump the water, having the water source closer to the house, and they also claimed that they had fewer shortages of water from those pumps because they tapped into deeper groundwater aquifers than the public hand-pumps. However, due to electricity shortages, they had to schedule the times for the electrical pumping of water. Hence, striking differences between the accessibility, reliability, and cleanliness of the water were observed between the different water sources available across the study households, potentially leading to distinct water and hygiene practices according to the household water source.

Image 5-5 Domestic water sources: Mechanical hand-pump (left). Unimproved open well (centre). Electrical borewell (right).

Practically all the families visited collected drinking water in the household premises, which they stored in metal containers that were re-filled every one or two days from the water sources. Drinking water storage containers were mostly kept covered (Table 5-4), and further details on water handling and treatment practices are discussed later on (Section 5.4.2.2). If the main domestic water source was relatively far from the house (>100m), it was also common for families to collect water for other purposes, such as for hand washing or washing dishes, in addition to storing drinking water. The lack of piped water supply infrastructure within the household premises led to the need for fetching and storage of water, providing further opportunities for water to become contaminated at point-of-use and making it more difficult to maintain water free from contamination and to carry out personal hygiene tasks such as handwashing.

Toilets: Almost half of the households visited had some type of toilet construction, but actually very few (12%) had a safely managed improved toilet (Table 5-4). As per the WHO/UNICEF guidelines, safely managed improved sanitation facilities include pit latrines that are not shared with other households and in which excreta are safely disposed of[27]. The majority of the households either had no toilet facility available, or a toilet construction that had been started and left unfinished, with no pit (Image 5-6).

Image 5-6 Example of an unfinished latrine construction

Unstructured conversations with villagers during transect walks and household visits explained the large number of toilet facilities that had been left unfinished. Reportedly, the government funds provided to aid in the construction of latrines in rural villages under the *Swachh Bharat* Mission were perceived to be insufficient to cover the full construction costs in the area. Therefore, it was common for people to start the construction of a latrine by building the walls and roof and placing the latrine slab, as seen in Image 5-6, at which point villagers could take a picture of the facility that would allow them to cash in the government *Swachh Bharat* funds. After the funds had been acquired, few finished the latrine facility by digging the pit and making it usable, and instead, they were often used for storage. As explained by a frontline health worker, many of the toilet facilities had been constructed for the official records but remained to be finished and used.

> *"Most of the toilets are halfway under construction and incomplete. The old people do not like to go, and the young people want but say that the toilets are not in working condition. There is a nearby drain where they defecate. And money is also too little, 12.000 rupees [£120*] in total [provided by the government fund], so people have started to construct it a little bit and left it as it is. Here, the toilets are only for namesake [for the official records]. No toilet is in proper condition."- Frontline health worker, Ghatol*
>
> **1 INR=0.01 GBP on 01/10/2021*

Therefore, there was a widespread lack of improved toilet infrastructure across the study villages, which did not enable safe defecation and infant excreta disposal practices, potentially contributing to the contamination of the environment with faecal pathogens and increasing faecal exposure risks to infants.

Overall, this theme identified several factors relating to the physical environment at the household level that were contributing to the spread and exposure to faecal pathogens for infants. In summary, the key physical-environmental factors at the household-level identified to be contributing to infants' faecal exposures were: the household's earthen floors where infants crawl and play that can harbour microorganisms and cannot be sanitised, the kitchen infrastructures that do not facilitate safe food hygiene practices since the food is in close contact with the earthen floors, the domestic water sources that do not facilitate reliable and easy access to clean water, and the widespread lack of improved toilet facilities that lead to the contamination of the environment with human excreta.

5.4.2.2 Theme: Traditional domestic hygiene practices pose additional infection risks

The previous theme delved into the infection risk factors relating to the household physical environment. However, regardless of the household infrastructure, some traditional hygiene practices and habits that increased the risk of infant's faecal exposures and hence enteric infections were also observed.

Cooking, eating and food hygiene practices: Traditions and socio-cultural norms play a strong role in defining dietary and cooking practices[130]. Across the study villages, breastfeeding was the normative practice for feeding infants during the first 6 months and up to the second year[50].

According to the PANChSHEEEL study, 94% of mothers reported doing exclusive breastfeeding for the first six months and starting to introduce semi-solid foods soon after that[50]. During household observations in this study, 30 cooking events were captured, the large majority performed by women (Table 5-5). The preparation of food was observed to happen on big metal platters while sitting on the earthen floors next to the *chulhas,* with constant hand-to-floor contacts (Image 5-7). While the use of off-the-ground gas stoves (which had been provided by a public scheme to several families) could decrease the time burden for collecting biomass as fuel and the risk of food contamination from hand-to-floor and from the animal excreta (i.e., cow dung cakes) used as fuel, they were seldom used. A strong preference for *chulhas* remained.

"Chulha [clay-stove] is cheaper than LPG [gas-stove] and makes tastier rotis [flat bread]"-Mother, Kushalgarh

Image 5-7 Image depicting a cooking event with frequent hand-floor contacts

Food was usually cooked in the mornings and evenings and stored throughout the day. Stored cooked food was observed in 31/42 households visited and, in the majority of cases, it was kept covered or partly covered to avoid flies. Since infants ate smaller rations but more frequently, they often ate stored food. During the household observations, 21 instances where children ate solid food were captured. The types of food consumed by infants were mostly rotis (flat bread), mixed with goat or cow's milk that was available from the livestock, or spiced vegetables (Table 5-5). All infants were observed to self-feed by hand practically the whole time they were eating. The observed infant eating events mainly occurred with infants sitting on the earthen floors, which led to frequent hand and food contacts with the soil from the earthen floors (Image 5-8). Handwashing with soap was not observed prior to any of the cooking and feeding events captured, which are critical times for handwashing. In addition, out of 29 instances in which caregivers were observed to wash kitchen utensils such as plates and cups, in only 3 soap was used. The rest of the kitchen utensils were washed with mud or rinsed with water only (Table 5-5). Mud can contain enteric pathogens acting as a source of potential enteric infections[213]. While families commonly had soap available and it was reportedly considered cheap, they associated the use of soap to particular times such as cloth-washing or bathing, but not to times surrounding food events.

> *"We wash our hands and pots [kitchen utensils] sometimes with water only, sometimes with soil. Also sometimes with soap, but not so much because we are not habitual. We use it [soap] in occasions such as washing clothes. We use it [soap] only when are hands are very dirty like after making dung cakes"- Mother, Ghatol*

Image 5-8 Image depicting an infant feeding event with frequent hand-floor contacts

The traditional way of cooking food in *chulhas* by the earthen floors, of washing utensils using mud, or of sitting infants on the earthen floors for them to eat food by themselves, were engrained cultural habits. However, these cooking and eating practices could also be increasing the opportunities for infant's faecal exposures, through the repeated soil-hand-food contacts.

Table 5-5 Cooking and eating practices and related food hygiene behaviours

Cooking and infant feeding practices	**N (%)**
Number of cooking events observed	30
Food cooked by females (vs males)	28/30 (93%)
Handwashing with soap observed prior to cooking	0/30 (0%)
Number of kitchen utensils washing events observed	29
Utensils washed with soap	3/29 (10%)
Utensils washed with mud or water only	26/29 (90%)
Number of observations of cooked food stored	31
Stored cooked food covered	17/31 (55%)
Stored cooked food partly covered	12/31 (39%)
Stored cooked food uncovered	2/31 (6%)
Number of infant feeding events observed (solid food)	21
Infant self-feeds (vs fed by a caregiver)	21/21 (100%)
Infant handwashing with soap observed prior to eating	0/21 (0%)
Location of infant during eating event	-
Sitting on earthen floor	16/21 (76%)
Sitting on top of a mat	1/21 (5%)
Sitting on improved floor surface	4/21 (19%)
Type of food consumed	-
Snacks (biscuit, sweets, peanuts)	7/21 (33%)
Weaning food (milk with bread or rice)	6/21 (29%)
Adults' food (bread and spiced vegetables)	8/21 (38%)

Personal and infant hygiene practices: Similar to the cooking and feeding practices, there appeared to be a common way of carrying out personal and infant hygiene practices. Some of the local personal hygiene habits and preferences that were observed could be introducing additional risks of infection to infants by increasing their exposure to highly contaminated water. For instance, local surface water bodies such as streams and ponds were widely preferred for bathing and washing clothes (Image 5-9). When surface water bodies were available (many dried up during the summer months), mothers reported going there for bathing, bathing infants, and washing clothes there rather than at the hand-pumps, due to the abundance of water that facilitated the tasks. However, the infants' exposure to surface water bodies during bathing events could pose significant infection risks. Surface waters could be highly contaminated with faecal pathogens given the local widespread open defecation practices, and studies have estimated that children involuntarily ingest an average of 37 mL of water per hour during bathing and swimming events[102]. Further details on the faecal contamination levels of the villages' surface water bodies are explored in the following chapter of this thesis.

> *"The old people do not like to go to the toilet. (…) There is a nearby stream where they defecate"- Frontline health worker, Ghatol*

Image 5-9 Image depicting a local stream with people bathing

Despite reports of bathing at the local streams, newborns and infants that were not yet mobile were seen to be bathed at home. Seven infant bathing events were captured during household observations. In all the instances, infants were bathed by female caregivers, at the household courtyards, using water collected from public hand-pumps and soap, dried in visibly clean towels, and then changed into visibly clean and fresh new clothes (Image 5-10).

Image 5-10 Infant bathing event

At the beginning of each household visit, the infant's visible level of cleanliness was recorded in the infant's structured observation tool (Appendix E). Most infants had visibly dirty hands, and several had visible dirty faces as well (Table 5-6). "Visibly dirty" was considered when visible traces of soil and dirt were observed, following other studies criteria[67]. A third of the infants had visible skin rashes or pimples, another potential indicator of poor hygiene. Infant faeces disposal practices were seldom observed during household visits. However, over half of the infants (25/47) were not wearing lower-body clothes. It was reported that this practice facilitated the disposal of infant excreta, which simply needed to be collected and disposed of, without having to change the clothes every time the child urinated or defecated. However, this infant faeces' disposal practice could further contribute to the contamination of the domestic environment with faecal pathogens. The infant hygiene and faeces disposal practices captured highlighted the lack of resources available to facilitate infant hygiene, such as an easier access to clean water for bathing and resources for the safe disposal of infant faeces.

Overall, the local preference for bathing at the local streams, and the lack of resources for safe infant faeces disposal could contribute to infants' enteric infections by exposing infant's to highly contaminated water during bathing and contributing to the faecal contamination of the domestic environment.

Table 5-6 Infant's visible hygiene-related characteristics

Infant hygiene	**N (%)**
Infant visibly dirty?	
No	13/47 (28%)
Visibly dirty hands and feet	27/47 (57%)
Visibly dirty hands, feet and face	17/47 (36%)
Flies on infants' face?	
No, or only a few around the child	26/47 (55%)
Yes, many flies on infant's faces	21/47 (45%)
Skin infections observed?	
No or not observed	31/47 (66%)
Yes, pimples or rashes	16/47 (34%)
Infant wearing clothes?	
Upper-body clothes only	25/47 (53%)
Upper and lower-body clothes	22/47 (47%)

Drinking water handling practices: The struggles with water scarcity were frequently emphasised by villagers, who often pointed out that groundwater from hand-pumps often appeared murky, mixed with soil, or dried up completely, particularly during the dry season, and particularly those from the villages in the Kushalgarh block.

> *"The major problem is of water. From where do we get water for everyone? We have electricity and roads in our village. Our only concern is drinking water." "Water is too little compared to the demand. Everyone goes to the same hand-pump to fetch water" -Mother, Kushalgarh*

Given the water scarcity problem, people resorted to different sources and strategies to access safe drinking and domestic water. Perceptions on the water quality of local sources and what "good" water treatment and handling techniques were, varied widely. There was a lack of consistent knowledge and clarity on what water sources or treatment techniques were safer. In Kushalgarh, 18 of the 21 households visited reported their main hand-pump "going dry", "mixed with soil" or "tasting bad" during the summer season and having to resort to alternative water sources. Instead, all Ghatol-block families (n=21) reported being able to rely on groundwater sources for domestic water all year round. When facing water scarcity from hand-pumps, most families reported walking to find a farther away hand-pump that was not depleted or resorting to drinking from unimproved open wells nearby. Some families reported preferring the unimproved open wells over groundwater from hand-pumps due to the fluctuations of water in some of the hand-pumps, however, open wells were visibly murky, contaminated from spilt water, waste, algae, animal excreta and other objects (see in Image 5-5).

> *"If hand-pump water is not clean, we consume from wells. The well water is the best in summers, but here there is less number of wells so we have to drink unclean water"-Mother, Kushalgarh*

Among villagers as well as front-line health workers, sieving drinking water through a cloth was widely considered as a good and hygienic practice that would make drinking water safe. Image 5-11 shows how cloths that were used to sieve the drinking water before storing it in the drinking water containers, were sometimes visibly dirty. Over half (57%) of the households visited reported using cloths, at least sometimes, to sieve drinking water, but none of the households reported boiling or using any other water treatment strategy.

Image 5-11 Drinking water being sieved through a cloth

> *"We tell people to sieve water with the cloth to get rid of soil and animals in it. Not filtering hand-pump water is the major cause of infection". -Frontline health worker, Kushalgarh*

The lack of clarity on how to access safe drinking water in the face of difficult circumstances with water scarcity led to unsafe water treatment strategies, such as sieving water through dirty cloths, or resorting to unimproved open wells. These water handling and treatment practices were potentially introducing further faecal exposures to infants through the point-of-use contamination of drinking water.

Animal husbandry practices and domestic hygiene behaviours: All but one of the study households owned some domestic animals, mostly ruminants (cows, goats, bulls and buffaloes), and less commonly, chickens (Table 5-7). However, enclosed animal spaces or sheds to separate livestock from the living and child play areas in the house were rarely available, so animals were mostly kept close by in the household courtyards or even in the house bedrooms during the night (Image 5-12).

Table 5-7 Animal husbandry practices in the study households

Animal husbandry practices	**N (%)**
Households with any domestic animals	41/42 (98%)
Households with ruminants (cows, goats, bulls and buffaloes)	41/42 (98%)
Households with poultry (chickens)	13/42 (31%)
Location of ruminants during the day	
Courtyard or within 20m of the house	32/41 (78%)
Separate shed or 100m+ away from house	9/41 (22%)
Location of ruminants at night	
Indoors, same room as people	8/41 (20%)
Indoors, different room as people	16/41 (39%)
Outdoors or separate shed	17/41 (41%)
Visible animal faeces in the animal areas	41/41 (100%)
Visible animal faeces in the rest of the house	22/41 (54%)

Image 5-12 Domestic animals kept close-by in the household courtyard

Ruminant domestic animals were observed to be core subjects for the local livelihoods, as they were critical for agricultural tasks as well as for their by-products such as milk and cow dung. Cow dung was used as fertiliser, as cooking fuel and as housing material. Ruminant animals were not only essential for the tribal livelihood in a practical sense, but also at an emotional level. Families described feelings of affection and sacredness towards them. For instance, cows were used in religious celebrations and the ownership of livestock was a sign of higher social status. Consequently, families protected their domestic animals by keeping them close by during the day and often slept in the same room at night. The many local uses of cow dung meant that animal faeces were often present across the living environment, providing multiple opportunities for infants to come into contact with them during child play, and potentially even ingest them given their mouthing behaviours. Image 5-13 shows an example where infants were in close contact with cow dung, which in this instance was being used to pave the courtyard floor.

All family members were seen to be caring for the animals, but particularly children were observed to often play with them. Animals were reported to be "like friends" for children. It is likely that the feelings of care and attachment towards domestic animals influenced the lack of infection risk perception from animal and animal faeces.

> *"Children play [with animals], and they become friends. He can't get ill by playing with a baby goat"- Mother, Kushalgarh*

> *"We cannot tell people to not keep animals as it is their livelihood. The cow is used in farming and is also used for manure. Also, the cows and buffaloes give milk which is also used."-Frontline health worker, Ghatol*

Image 5-13 Infants' close contact with animal faeces while cow dung is being used to pave the floor

A striking contrast was observed between the villagers' attitudes towards poultry and those towards ruminants. As ruminants were carefully tended to, chickens did not appear to receive the same care. Upon arrival at household visits, when there were chickens around, they were often "shooed" away, and the families often justified that chicken and eggs were not consumed by them and were only used for selling. Traditionally, tribal populations' diets included chicken and eggs, but nowadays, influences from Hinduism and their vegetarian diets are becoming increasingly engrained into the culture of the tribal populations of Banswara. Hence, while some families still had chicken, their population was reported to be declining, as neighbours increasingly complained about them due to the dirt they were perceived to spread around the *phalas*. While poultry has been identified as an important vector of enteric pathogen transmission for infants in other countries[63], it appeared they may be less of a concern for the infant's risk of enteric infection in rural tribal villages in Banswara.

> *"There are no chickens here. Even if someone tries to keep [chickens], no one lets them carry on their activities as [the chickens] spread a lot of germs. Here people usually keep cows, buffaloes and goats only" – Front-line health worker, Ghatol*

> *"[Keeping chickens in the house] is bad as they spread infections and diseases are born from them" – Front-line health worker, Ghatol*

Overall, the traditional practices to do with cooking and feeding, bathing and washing, treating drinking water, and handling domestic animals entailed some unsafe hygiene behaviours that were potentially introducing additional enteric infection risks to infants at the household level.

This theme identified several factors relating to the socio-cultural domestic practices that were potentially contributing to the spread and exposure to faecal pathogens for infants. For instance, the fact that cooking and eating happened in close contact with the earthen floors, that bathing happened in surface waters, that water treatment involved sieving it through a cloth even when they had to resort to unimproved water sources, or that animals and animal faeces were not separated from the infant and living environments are some examples of domestic practices that were potentially contributing to infant's enteric infections. A lack of understanding of how these domestic practices can contribute to faecal pathogen transmission may be introducing additional enteric infection risks to infants at the household level.

5.4.2.3 Theme: Division of childcare among different carers influences child hygiene

The distribution of agriculture, domestic, and childcare responsibilities was seen to influence the hygiene behaviours surrounding infants. As it has been explained previously, although tribal populations traditionally followed a nuclear family model where parents lived independently with their children, current-day family structures more often followed the joint family model (living together with grandparents) or lived in *phalas* where neighbouring families shared domestic and childcare tasks. In all the study households, extended infant caregivers were observed in addition to the mother and father of the child.

Distribution of childcare was observed as follows: Mothers took a prominent childcare role during the first few months after birth for breastfeeding. However, soon after, as infants started to gain mobility and dietary independence from mothers, childcare was taken over by other carers. This was due to the fact that young adults, typically the mothers and fathers at the reproductive age, were the ones mainly responsible to tend to agricultural tasks given the physical strain involved. Particularly with the feminisation of agriculture, the burden of childcare was increasingly placed on other carers soon after birth. Grandparents, older siblings, and other adult neighbours were often seen in charge of infant feeding and bathing while parents engaged in agriculture, and other children from neighbouring houses often supervised child play.

Grandparents and older children, who are rarely considered as main child carers, and often not targeted in health promotion schemes, were observed to have a prominent role in childcare, even during the first 2 years of life. Mothers often reported that they were unable to keep track of infants' exposures to dirt and their hygiene behaviours, as they often spent long hours engaged in agriculture, and they relied on others for childcare.

> *"At times children eat mud and clay. They roam around the whole day under the sun and they eat and drink anything which leads to diarrhoea. We go to work every day so we are unaware of their act and only come to know about it when we come back from work"- Mother, Kushalgarh*

This theme identified how factors relating to the distribution of work and childcare among families was leading to caregivers other than the infant's parents such as grandparents and older children being in charge of childcare during the infants' first two years. Since grandparents and older children are not typically targeted by health and hygiene promotion services and often have different perceptions on infection risks and child health, the distribution of childcare could also be contributing to poorer infant hygiene practices and increased infant's faecal exposures.

5.4.2.4 Theme: Housing conditions are stratified by caste

As it has been discussed in Section 5.4.2.1, the housing conditions were strikingly different between *Kacha* and *Pucca* households, shaping hygiene behaviours and infection risk factors. At the same time, housing conditions were distinctly stratified by social castes.

While the study villages in Kushalgarh block were inhabited by families from Scheduled Tribes exclusively, 3 of the 5 villages in the Ghatol block had mixed communities of tribal and non-tribal caste households. Non-tribal caste families in the study villages invariably owned *Pucca* houses with cemented floors, private electrical borewells within the premises, separate animal sheds, and electricity, among other infrastructural and material features that may influence domestic and infant hygiene. By contrast, among tribal families, improved housing conditions and *Pucca* houses were less common.

There appeared to be a marked stratification where, even within the same village, tribal families lived in rudimentary *Kacha* households and non-tribal families lived in improved *Pucca* households. Tribal families claimed that financial constraints were their main limitation to improve their housing conditions and infrastructure. They often pointed out that despite their willingness to build improved facilities such as separate animal sheds or latrines, financial difficulties hindered their ability to do so.

> *"[Families] don't have enough money to make separate facilities for the animals"-Frontline health worker, Ghatol*

This theme identified how social caste stratification still played a role in the marginalisation of tribal caste families, who were less likely to have access to improved housing conditions and household WASH infrastructure, therefore contributing to poorer WASH practices and ultimately, infant's faecal exposures.

5.4.3 Village-level drivers

Following on from the household-level factors, the top layer of enteric infection drivers in the concept map delves into the wider-level factors within the village and community level (Figure 5-5). Physical-environmental, socio-cultural, socio-economic, and institutional factors were found to have potential trickle-down effects ultimately contributing to infant's enteric infections and are presented in this section under several themes.

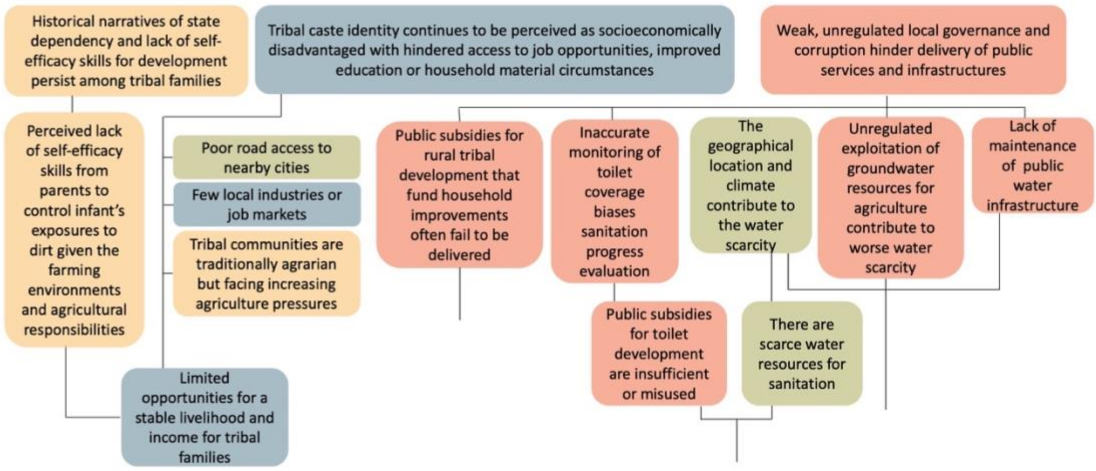


Figure 5-5 Village-level submap depicting physical-environmental (green), socio-cultural (yellow), socio-economic (blue), and institutional (red) factors contributing to infants' faecal exposures

5.4.3.1 Theme: Villages' natural and built environment hinders safe WASH practices

Infants' infection risk factors relating to the households' built environment were already presented in a previous theme (section), however, characteristics of the villages' natural and built environment were also found to shape WASH conditions and contribute to further enteric infection risks.

Striking contrasts between the monsoon and dry season can be observed in the local landscapes. Most rainfall occurs during the monsoon seasons, and the dry seasons see people facing a perpetual issue of water scarcity. The scarcity of water from rainfall during the dry seasons is accompanied by a public water supply infrastructure that was reportedly insufficient to cover the drinking and domestic water demand. In addition, water for irrigation of crops was not available in the Kushalgarh villages that were not canal-irrigated, further hindering local livelihood. The water scarcity situation in Banswara is already serious, with the groundwater table levels in some parts of the district such as the Kushalgarh block already being categorised as "semi-critical" by the State Ground Water Department[177]. However, modern-day pressures such as the rising population, climate change, and consequent increases in the water demand for agricultural growth and industrialization are only worsening the situation. The lack of sufficient water to cover basic needs was consistently emphasised by villagers during fieldwork, who highlighted how the lack of sufficient water was often the root cause for several WASH constraints such as the lack of toilet uptake, the use of unsafe drinking water or bathing practices (see Section 5.4.2.2).

> *"There is no water in the summers. Nowadays we get water from the hand-pump but in summers it dries up"- Frontline health worker, Kushalgarh*

> *"There is no water here for drinking purpose, so how will the people here use it for toilets?"- Frontline health worker, Kushalgarh*
>
> *"The major problem is of water. From where do we get water for everyone? We have electricity and roads now in our village. Our only concern is drinking water"-Mothers, Kushalgarh*

This theme highlighted how factors relating to the villages' natural and built environment, such as a semi-arid climate in Banswara and an insufficient public water supply, also contributed to poorer WASH and thus, infant's faecal exposures.

5.4.3.2 Theme: Limited local livelihood and employment opportunities hamper families' finances

The families' livelihoods also inevitably played a role in child hygiene and the infants' infection risks, by enabling or hindering the families' financial opportunities to improve the WASH conditions surrounding infants. Sustenance agriculture was the main form of livelihood across the rural tribal study villages in Banswara, where the crop's harvests were used for consumption and to be sold at local markets. However, the rising population and climate changes have placed increasing pressures on land and water availability for agriculture, which has resulted in more and more men seeking complementary forms of income. Complementary forms of income were sought either from jobs at local industries or markets or by migrating to larger cities. However, the job opportunities around the study villages were very limited, and particularly more so for the tribal population, who has traditionally been agrarian and has only more recently started to introduce itself into the job markets (see Section 3.3.3 of the thesis for more details on the history of Banswara's population livelihoods). A few distinct ways of securing a livelihood and an income were captured across the study villages.

The study villages in the Ghatol block had easier access to job opportunities, since they were closer to the district capital and major district roads, in comparison to the study villages in the Kushalgarh block. Across the households visited in Ghatol, a third of the families relied fully on their crops for livelihood, but a majority (57%) had a male in the family that had a job at a local industry, to complement the family agriculture (Table 5-8). While females in the *Bhil* community had always contributed to agricultural work, the shift in males taking up jobs in local industries further contributed to the feminisation of agriculture. It was surprising to observe that the livelihoods of the few non-tribal families that lived in the Ghatol study villages were strikingly different to the livelihoods just explained for tribal families in the same villages. Non-tribal families in the Ghatol study villages relied on men migrating to other countries for long periods of time to send back remittances to sustain the family. Meanwhile, the mothers could stay at home without having to engage in agriculture and fully devote their time to being housewives.

The situation was somewhat different in the Kushalgarh study villages, which were further away from the district capital and more poorly communicated to local industries and job opportunities. All the families in the Kushalgarh study villages were from tribal castes, and except for two males who had a government job, none of the other males from the families visited in Kushalgarh reported having a job nearby to complement their agricultural livelihoods. In addition, due to the lack of an irrigation canal in Kushalgarh, harvesting was not possible during the dry months, and families were left with no mode of subsistence. As a consequence, most of the families visited in Kushalgarh practised short-term migration to large cities in nearby states to seek temporary jobs during the dry season months (Table 5-8). Short-term migration was explained to involve the whole nuclear family (parents and children) travelling together for a period of 3-4 months to survive the dry period when crops could not be harvested in their plots by taking up temporary jobs.

Table 5-8 Study families' livelihoods and parents' occupations

Livelihoods and occupations	**Ghatol**	**Kushalgarh**
Households visited	Overall (N=21)	Overall (N=21)
ST/SC caste, n (%)	17 (81%)	21 (100%)
Father's occupation, n (%)		
Agriculture only	6 (29%)	1 (5%)
Agriculture + short-term seasonal migration	0 (0%)	18 (86%)
Long-term migration: job abroad	3 (14%)	0 (0%)
Agriculture + local job	12 (57%)	2 (9%)
Mother's occupation, n (%)		
Housewife	6 (29%)	3 (14%)
Housewife + agriculture	15 (71%)	18 (86%)

Hence, the different types of livelihood modes captured influenced not only the family's finances but also shaped infants' caregiving practices. Fathers that had a local job inevitably placed an additional agricultural burden on mothers, with a potential impact on less caregiving time, but, in turn, increased the family's income and financial opportunities to improve the housing conditions and WASH infrastructure in contrast to those that only had agriculture. On the other hand, fathers from non-tribal families that migrated abroad and sent remittances allowed mothers to dedicate their full-time to childcare and domestic tasks while being away for several continuous years. Finally, for tribal families in Kushalgarh where local job opportunities were very limited and harvesting was difficult during the dry season, temporary seasonal migration was adopted as a strategy to survive the dry summer months. However, temporary seasonal migration potentially placed additional difficulties for parents to maintain a clean environment for infants while travelling.

The precarious livelihoods for the rural tribal families visited, given the increasing challenges in sustenance agriculture and the limited local job opportunities hindered their financial capacity to improve the WASH conditions of their household environment, and constrained the availability of time for childcare. Furthermore, it is plausible to think that the state of poverty among these tribal communities was shaping their reasoning, pushing domestic and child hygiene concerns down their list of priorities, below securing a stable livelihood and food.

This theme highlighted how socio-economic factors such as the limited livelihood opportunities available in rural Banswara were hindering the tribal families' financial opportunities to improve their housing and WASH conditions, and ultimately potentially contributing to poorer hygiene and increased faecal exposures surrounding infants.

5.4.3.3 Theme: Caregivers perceive a lack of self-efficacy to address infection risks: "Yes, it happens, but what to do?!"

Parents often recognised several of the enteric infection risk factors to infants such as not washing hands, infants mouthing soil, flies landing on food, or "bad" eating and drinking habits overall.

> *"[Infants] get infection in the stomach as they don't wash their hands and roam around the whole day. They get infected because of their bad eating and drinking habits. Small children are unaware of hygiene habits (…) and might be eating the mud, eating stale food". -Mothers, Ghatol*

Despite parents' general awareness of hygiene habits and infection risks, they still often emphasised the challenges they faced to interrupt faecal pathogen transmission pathways. Throughout our discussions about potential infection risk factors, parents across the study villages repeatedly retorted by saying *"…But what to do?!".* Villagers often argued that the rural farming environment where they lived, with houses made of mud and dirt and animals around, hindered their ability to interrupt faecal exposures and improve infant hygiene.

> *"At times children eat mud and clay. Our kids can even put their hands in the cow dung, and it has so many germs which is the cause of their illness. If we do not have farms and animals around us, then our kids will be also clean. Even if we try to keep our kids neat and tidy, they again get themselves in dirt and mud". "It happens, but what to do?!"- Mothers, Kushalgarh*

Self-efficacy describes an individual's belief and confidence in their capacity to execute the behaviours necessary to produce specific performance attainments[214]. In this case, it is used to refer to the parents' perceived ability to interrupt infants' faecal exposures and infection risks to attain optimal child health and growth. Among tribal families in the study villages, there was a perceived lack of control over infection risks and a perceived lack of self-efficacy to interrupt infant faecal exposures. Instead, it appeared that non-tribal families that lived in the same study villages had increased self-efficacy, as they commonly sought out job opportunities abroad, invested in improving their household infrastructures, and more often considered private health and education options to improve their children's development opportunities. Among the tribal community, the lack of self-efficacy was paired with a sense of dependency on the government for the development of their WASH infrastructure. Conversations about issues to do with water supply, toilets and even household infrastructure often centred around how government funds and efforts were insufficient, portraying the government as the one responsible for such improvements.

Hence, this theme captured the narratives by parents on how they often felt unable to address infant enteric infection risks and did not know "*what to do*". The parent's perceived lack of self-efficacy to interrupt faecal exposures could also be an additional infant enteric infection risks.

5.4.3.4 Theme: Unreliable local governments fail to deliver public services and infrastructure

Another theme that was often captured during unstructured conversations throughout the study communities was the mistrust in local political leadership. Different forms of political corruption were often discussed. There were reports of bribes during Sarpanch elections, of favouritisms towards friends and relatives for the distribution of developmental aid funds, of misuse and embezzlement of public funds and resources for the village development. Other forms of corruption such as the weak monitoring of frontline health workers roles also hindered child health and public development schemes reaching the rural communities.

Weak monitoring of local village political governance remained a remarkably relevant factor hindering the delivery of public funds for the development of the village and household WASH infrastructure and other child health services. Additionally, exposure to unfairness and dishonesty in the leadership roles may have an emotional impact on the population's commitment, initiative and perceived self-efficacy to address their day-to-day predicaments and improve WASH conditions in their environment.

The mistrust between the villagers and some public health services was captured in a few conversation instances.

> *"I sometimes give advice, support and suggestion but some people from the community tell me bad words."- Frontline health worker, Kushalgarh*

> *"No good services provided there, [the rural childcare centre] is only there for the government records, they don't provide good support". - Mothers, Ghatol*

This theme captured how institutional factors such as unreliable local governments could also have important trickle-down effects on infant hygiene and infection risks through hindering the publicly funded village WASH development projects and breaking the community's trust in public child health and hygiene promotion services.

5.5 Discussion and conclusion

The set of individual, household, and village-level themes comprising physical-environmental, socio-cultural, socio-economic, and institutional factors presented in this chapter provided a comprehensive understanding of the multiple and multifaceted factors that may be contributing to enteric infection in infants in rural tribal Banswara. The following paragraphs discuss how these findings provided new insights about the enteric infection risk factors for infants in the study setting and highlighted the need to consider the multiple factors in an integrated holistic manner.

5.5.1 New insights into infant enteric infection risk factors

5.5.1.1 Individual-level

Observations of the infant's immediate exposures (individual-level factors), revealed that infants, particularly when they started to gain mobility and crawl, were often seen mouthing soil, soiled hands, or soiled objects from their household environments. The ingestion of soil and mouthing of soiled hands and objects during exploratory play is an age-specific infection risk factor, clearly not as relevant for adults, which may explain its relative neglect in typical WASH programmes[215].

Only recent BabyWASH-focused studies have recognised the role of soil ingestion as a route of pathogen transmission to infants in rural environments[16,71,74,216]. In fact, a recent study in rural

Bangladesh has even suggested that soil ingestion and mouthing of soiled hands could actually be the primary pathway of faecal exposure for infants under-2, even more important than the food or drinking water routes of transmission[94]. Infant's exploratory and mouthing behaviours are essential for their cognitive development, so solutions to interrupt the soil faecal transmission pathway have had to focus more on addressing the hygiene levels of the child play spaces at home rather than avoiding the infants' exploratory behaviours. For instance, the role of domestic animals in contributing to the faecal contamination of child play spaces at home has been strongly emphasised[71]. Solutions to separate infants from the earthen floors and animal faeces using play-pens or play-mats for child play have just started to be tested[62,133,134], with preliminary results suggesting that while the impact of play-pens in reducing infant's exposures to faecal pathogens is not yet fully clear, caregivers found several other benefits to using play-pens, such as the ability to keep children safe while carrying out domestic tasks.

Hence, for infants living in rural environments and earthen households, the exposure to soil during exploratory child play may be a key enteric infection risk factor, one that has been largely neglected, and for which effective and feasible strategies to improve the hygiene of child play spaces remain largely unidentified. BabyWASH programmes and interventions will need to acknowledge it as a key infection risk and identify effective solutions to address it.

5.5.1.2 Household-level

After exploring the infant's immediate exposures, this chapter dug deeper into the drivers of enteric infection by exploring household-level factors. At the household level, the *Kacha* structure that was so prevalent among tribal families in the study villages did not facilitate a hygienic environment. Understandably, the earthen floors and walls, the *chulhas* used for cooking, the unreliable water hand-pumps off-the premises, and the lack of improved toilets or animal sheds made it difficult to keep a clean hygienic house.

In addition to being dependent on the available resources and infrastructure, the ways in which people cook, eat, or bathe are often deeply engrained cultural practices and habits[217]. Influenced by a combination of the housing conditions, the traditional cultural habits, and a potential lack of understanding of infection risks, several unsafe domestic practices that could be introducing additional enteric infection risks were observed during cooking and feeding events, bathing and handwashing instances, water handling and treatment, and animal husbandry practices.

While tribal communities may have carried out domestic and hygiene practices in a particular way for a long time (such as defecating in the open), the increasing population and water scarcity issues are introducing new challenges that may require a shift in these practices to avoid new infection risks. To improve the hygiene behaviours at home, behaviour change research suggests that the range of factors influencing behaviours need to be identified and modified in a targeted manner, since hygiene behaviours are determined by a combination of the infrastructure and material resources available, by the engrained subconscious habits, and by the socio-cultural norms and values associated to the behaviour[116,218].

However, conducting key changes in the house may be crucial to trigger overall domestic hygiene improvements. In Rwanda, for example, improving the flooring material of households has had a positive domino effect on several other domestic hygiene behaviours overall[66]. In Nepal, conducting "kitchen makeover" competitions to revalorise how kitchen settings were perceived was seen to improve several food hygiene behaviours all at once[140]. Hence, infrastructural, habitual, and socio-cultural factors all need to be addressed to improve the hygiene practices at the household level.

5.5.1.3 Village-level

Following on from the individual and household-level factors, the chapter then presented several wider community-level factors with important trickle-down effects on the more proximal pathways to infant enteric infection. The geographical setting (a water-scarce area), the socio-economic conditions (a general state of poverty and limited livelihood opportunities for tribal castes) and institutional factors (political corruption and mistrust) may have further hampered the parent's perceived ability and motivation to improve infant hygiene.

Parent's frequent quote of *"Yes, this happens…but what to do?"* was insightful in portraying their perceived lack of control over the infant's exposures to dirt and faecal pathways, given the rural and farming environment in which they lived. Instead, it was often the government and public services that were perceived to be responsible for the development of village WASH conditions and who had the power to drive these changes.

Some studies have argued that the history of discrimination of tribal communities may have contributed to a general state of resignation, leading to tribal people missing opportunities and benefits that are not taken advantage of[219,220]. Another ethnographic analysis of the tribal *Bhil* communities argued that the *Bhil* rhetoric of state-dependency for development has long-established roots[191]. It argued that *Bhil* dependency on the government services for development may arise from how tribal communities have been viewed and classified by the government in the past as disadvantaged communities that need to be developed. Since the Independence of India, modernising and developing tribal communities has remained a nation-wide goal, which has led to tribal communities being the target of numerous development programmes that may have unintentionally contributed to the continuation of this perceived dependency on the state for their development and perceived lack of self-efficacy to do it themselves[191]. Hence, the tribal families perceived inability and state dependency to address hygiene and infection risks were possibly influenced by the tribal populations' rooted identities.

Overall, tribal communities continue to be a marginalised and deprived population, with limited job, education and health opportunities allowing them to move up the social ladder and improve their living conditions[191]. Studies have found that a high socio-economic status threshold needs to be surpassed before child undernutrition and stunting can be eliminated, independent of any WASH-specific improvements[221], and yet tribal castes still faced evident socio-economic limitations.

In addition, weak governance systems and corruption have been suggested to be the biggest barrier to improving health in developing countries[222], and yet, rates of absenteeism among community health workers in rural India may be as high as 60%[223]. Transparent governance remains a fundamental challenge at the global scale, and WASH programming would benefit from acknowledging these limitations and designing programmes that reduce incentives and opportunities for corruption from the outset[223]. For instance, the situation with the government-funded latrine facilities that was captured across the study villages where most households did not have an improved latrine facility in-use, depicted the mismatch between the government records, that claim that toilet coverage in Banswara is up to 95% and it is declared an open defecation-free district[189], and the village level realities.

These wider-level factors relating to the context's historical, socio-cultural, socio-economic, and political aspects are too often neglected in over-simplistic WASH development programmes that focus on short-term changes at the individual or household-level[128], and they need to be better recognised in future BabyWASH programmes, given their potential trickle-down effects on child health and infections.

5.5.2 A holistic understanding of enteric infection drivers

Since the aim of this thesis chapter was to develop a holistic understanding of the multiple infection risk factors, the concept map allowed the reader to understand the interconnectedness between these factors. The concept map depicted the conceptual pathways to enteric infections: the chain of interlinked factors that provided explanations to how the infant enteric infections may come to be. The interlinked factors ranged across diverse dimensions (physical, socio-cultural…), supporting the need for interdisciplinarity in tackling this complex problem. The utility of the concept map relied on the fact that it instantly conveyed the complexity, interconnectedness and diversity of the factors influencing child enteric infections, allowing the reader to observe emergent patterns[224].

For instance, from the concept map, one can see how the infants' immediate exposures to faecal pathogens through contact with dirty fomites, floors, and fingers during their exploratory play time at home, are largely due to the poor housing conditions in *Kacha* houses, but could ultimately be partly explained by the tribal castes' identities, which are still seen as a disadvantaged and marginalised group who perhaps think of themselves as unable to improve their living and housing conditions, and at the mercy of the state development programmes. Instead, the concept map shows that the infants' exposure to pathogens through contaminated water could be ultimately rather explained by the geographical and institutional barriers that hinder safe water supplies. Pathogen exposures through food, on the other hand, while also influenced by the resources available, could perhaps have more to do with the engrained cooking and eating habits rather than the tribal identities or institutional factors. Thus, different infection risks appeared to be rooted in different conceptual pathways with different degrees of personal, societal, or institutional responsibility needed to address them.

These conceptual pathways to infection risks depicted in the concept map show how wider-level factors such as caste inequalities, socio-economic limitations, or institutional mistrust can have trickle-down effects that end up influencing the infant's immediate infection risk factors. Previous use of holistic concept maps to elucidate factors contributing to poor sanitation also drew attention to the wider-level factors such as institutional and cultural patterns[224]. Nevertheless, one limitation of the concept map is that it does not assess the relevance or weight of the different factors and interlinkages.

Overall, a progression toward more comprehensive integrated approaches is being called for in the WASH sector, as the need for a holistic understanding of all key pathways of infant exposure to faecal pathogens was set out in the latest WHO marching orders[21]. The concept map developed in this chapter proposes a new approach to developing a holistic understanding of the multifaceted factors contributing to infections, advancing knowledge towards the WHO call[21].

5.5.3 Strengths and limitations

This mixed methods analysis has some strengths and limitations. Firstly, given that this was a case study that focused on a rural tribal community of Rajasthan, the generalisability of the evidence presented is limited. Several of the practices, behaviours or beliefs presented and discussed here may be specific to the *Bhils.* However, other characteristics such as the *Kacha* housing infrastructure issues are widespread across many resource-constrained rural settings, and the reflections on these factors may serve as an exemplary case for numerous similar rural villages in India. Despite the limited generalisability of the findings, the strengths of having focused on an in-depth understanding of the case study were that it enabled me to draw more intricate findings and reflections, such as the discussion on how the tribe's identity and historical roots may be influencing today's behaviours.

One of the main limitations on the "depth" of the data collected was the duration of the household observations, which could not be prolonged due to feasibility reasons. To really understand the village realities and daily routines, observing the domestic activities that occur during a full day would have been desired. However, the infant's parents often needed to tend to their agriculture responsibilities and were not available at home for long periods of time during the day, and observations later in the evening were deemed not appropriate by the local fieldworkers. Hence, while I strived for developing a comprehensive understanding of the grounding realities, there were some aspects of the study communities' daily lives that were missed out. Another concern is to do with the time validity of the study, particularly since hygiene habits may have been influenced by the COVID-19 pandemic. Only 3 months after the fieldwork stage, at the beginning of the pandemic, I received videos from my fieldwork colleagues in Banswara showing the study communities building improvised handwashing stations, to facilitate handwashing with soap.

The use of mixed methods and integrated qualitative and quantitative data from observations and conversations allowed for a versatile analytical approach with some limitations and strengths. For instance, subjectivity was inherent to the process of qualitative data collection and analysis, as qualitative methods do not seek to provide objective and reproducible results. Instead, their reliability depends on the researcher's insights, and their credibility can be evaluated through its communicability and transparency[194]. In this analysis, coherency was sought by bringing together information from different stakeholders across different locations and study villages, for example contrasting the information on what was observed vs reported, or on the accounts of parents vs frontline health workers. Communicability refers to the reader's perceived reality of the data collected[110]. In this chapter, to communicate the reality of the data, vivid data in the form of quotes and pictures that yielded abundant details were presented. Lastly, transparency on the processes and experiences lived by the researcher by means of providing detailed accounts is key for the trustworthiness of the research. The reflections on the researchers' role and positionality during the data collection stage that were presented in

Section 4.6.2 acknowledged the "inevitable bias"[225] introduced to the research process by the researchers.

5.5.4 Conclusion

Multiple factors from diverse natures (physical-environmental, socio-cultural, institutional, socio-economic) were seen to contribute to the enteric infections' transmission in infants living in rural tribal villages in Banswara.

This chapter's findings suggest that future interventions addressing child enteric infections need to look beyond WASH factors as currently defined (i.e., water and sanitation facilities and handwashing behaviours), and recognise the impact of broader interdisciplinary factors in each context. For instance, an arid geographical climate, unreliable local politics, limited livelihood opportunities, social caste stratification, tribal attitudes towards WASH development, poor housing infrastructure, unsafe traditional domestic and hygiene practices, and other factors were found to play a role in the infant's enteric infection burden in rural tribal Banswara. A concept map enabled a holistic, integrated understanding of how these multifaceted factors interlinked to contribute to infant's faecal exposures, forming conceptual pathways of understanding as to how infants end up getting enteric infections.

Rural tribal communities in Banswara remain a marginalised and deprived population with limited opportunities for upward mobility. Empowering tribal communities and restoring their perceived sense of self-efficacy for progress in hygiene and child health may be key aspects of future interventions targeting infant infections and growth in this setting.

Future BabyWASH programming is likely to require broader interdisciplinary approaches to account for the complex interrelationship between infection risk factors at all levels, including individual technical and behavioural aspects, as well as wider socio-cultural, economic and policy aspects.

6 Chapter 6. Infection risk assessment of multiple microbial exposure pathways

6.1 Chapter overview

The previous chapter of this thesis, Chapter 5, delved into the range of multifaceted factors contributing to the infant's enteric infection burden in the study setting. Factors relating to the built environment, people's attitudes, behaviours, and societal influences were described and mapped out to capture the conceptual pathways to infant enteric infections in rural Banswara. In this Chapter 6, I look at the pathways to enteric infections from another angle. Rather than following the pathway of conceptual reasons on how enteric infections come to be, in this chapter I focus on exploring the pathways of enteric pathogen transmission to infants. In the previous chapter, Section 5.4.1.1 presented a summary of all the elements that infants were observed to ingest or mouth during the study household visits. All these elements presented potential vectors of pathogen transmission. For instance, drinking contaminated water, eating contaminated food, mouthing their hands after contact with soil or soiled objects, directly ingesting soil while crawling, or flies laying on their mouth were all observed to be potential pathogen exposure pathways contributing to enteric infections in infants. One of the limitations of the analysis in Chapter 5 was that it did not allow to assess the relative weight of the different factors in terms of their contribution to the enteric infection burden. However, comparing the contribution of the different faecal pathogen exposure pathways on the child's total enteric infection risk could prove useful to identify the most critical exposure pathways that pose the highest risks, informing targeted efforts in future BabyWASH programmes. Hence, this chapter presents the research findings that address objective 2 of this thesis:

> **Objective 2. To assess the faecal contamination levels in the infants' environment and evaluate the risks of enteric infection from multiple transmission pathways.**

To address the second objective of the study, I used the microbial data collected during fieldwork and analysed it by means of a quantitative microbial risk assessment. In this chapter, I explain how the QMRA analysis was conducted, and I then present the results obtained. Finally, I discuss how the findings compare and contribute to the body of literature.

6.2 Data harnessed

This chapter used the data collected in the case-study villages in rural tribal Banswara from September to December 2019. In particular, findings from this chapter are based on the microbial data from the 316 environmental samples collected, as well as the 47 direct observations of infants' exposures during household visits.

As it was explained in Section 4.4.6 of this thesis, a total of 316 environmental samples (Table 4-4) were collected and analysed through the membrane filtration and plate culture technique. Briefly, in each of the nine case-study villages, water and soil samples from all the primary schools and Anganwadi centres available were collected, as well as samples from the local surface water bodies (i.e., streamlets and ponds). In each of the 42 households with an infant under-2 that were visited, the infant's and caregiver's hands were swabbed, and a soil sample from the household floor was collected. In addition, samples from the household's domestic water source and the household stored drinking water were also collected. As it was described previously in Section 5.4.2.1, domestic water sources in the study houses varied, ranging from public mechanical hand-pumps, electric borewells or unimproved open wells.

Moreover, as explained in Section 4.4.2.5, during the 42 household visits, structured observations of 47 infants between the ages of 0 and 2 were conducted, and all the elements they came into contact with, recorded. This chapter used the microbial data collected as well as the information from the infant's immediate exposures tallies to conduct a microbial risk analysis, the results for which are presented hereafter.

6.3 Data analysis

6.3.1 Faecal contamination levels

Microbial data comprised of a spreadsheet where the *E. coli* concentrations in the 316 environmental samples collected were expressed as CFU per 100mL of water, per 1 gram of soil, or per hand-swab, accordingly. To assess the faecal contamination levels across the study village and household settings, the microbial data was imported into R software version 1.4.1103 to carry out descriptive statistical analyses.

First, the percentage of *E. coli* positive samples in each environmental media was investigated. Then, to assess the distributions of *E. coli* loads, the non-detect and TNTC (too numerous to count) samples were imputed. Following WHO guidance on how to treat microbial censored data[200], bacterial colony counts that resulted in TNTC were imputed by substituting them for the maximum detection limit (300 CFU *E. coli*/1mL of water, 3000 CFU/hand-swab, or 300.000 CFU/gram of soil), and non-detects (0 colony-counts), were included in the statistical summaries by substituting them for the lowest detection limit (1 CFU/100mL, 1 CFU/ hand-swab or 100 CFU/g of soil).

After treatment of censored data, the statistical summary analyses were carried out to assess whether there were significant differences in the contamination levels between different study villages (i.e., Kushalgarh vs Ghatol block villages), and between different sample sources (i.e., hand-pumps vs well water). The non-parametric Wilcoxon Rank-Sum test for non-normal distributions was used[226].

6.3.2 Quantitative Microbial Risk Assessment Framework

In addition to assessing the levels of faecal contamination of the environment, the objective of this chapter was to evaluate the risk of infection from different exposure pathways. For that, a risk assessment approach, where the risk of enteric infection from each individual exposure pathway can be quantified, was appropriate.

Assessing the infection risks in the study setting required an integrated understanding not only of the microbial loads but also of the infant's day-to-day exposures to contaminated elements. Quantitative Microbial Risk Assessment (QMRA) is a framework that, by triangulating different types of data and using mathematical models, allows to characterise the infection risks associated with environmental exposures[227]. For instance, a food production company may use the QMRA framework to determine the risk of *E. coli* infection among their consumers, after a crop of lettuces has been sprayed with biosolids. Knowing the pathogenic loads in biosolids and then in lettuces, the frequency and quantity of lettuces consumed and the number of consumers, and the pathogen infectivity, the company is able to characterise the infection risks from their activity and ultimately introduce measures of risk control[227].

The QMRA framework encompasses 4 different steps to characterise risks from environmental exposures, as defined by the WHO QMRA Guidelines[200] (Figure 6-1):

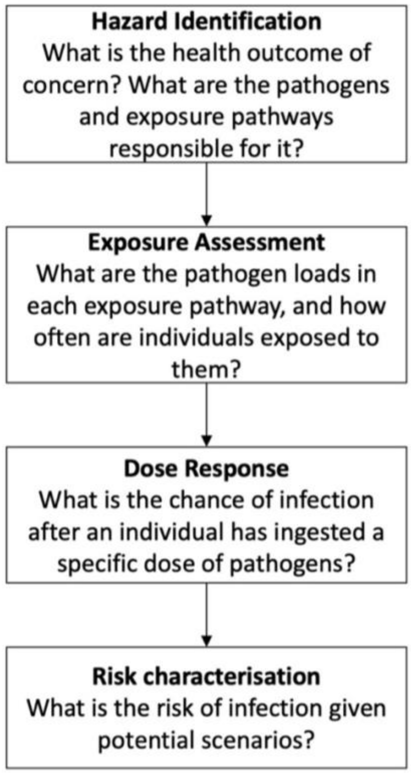


Figure 6-1 Steps under the Quantitative Microbial Risk Assessment (QMRA) framework

(1) Hazard identification: The first step involves formulating the problem. That is, determining the hazardous events or exposure pathways that will be assessed. This involves defining through which routes the individuals are exposed to the pathogens and identifying the reference pathogens that are responsible for the health outcomes of interest. For instance, in our study, the first step involved determining the pathogens responsible for enteric infections in infants in rural Banswara, and defining all the potential exposure pathways (i.e., drinking contaminated water, mouthing dirty hands…) to be assessed.

(2) Exposure assessment: The following step involves the quantification of pathogens that individuals are exposed to. Firstly, the pathogen loads in each exposure pathway are quantified (i.e., what is the concentration of pathogens in water, on hands…?). Then, the magnitude and frequency of exposure to each pathway are estimated for different scenarios (i.e., How much water do infants drink every day? How often do they mouth their fingers?). This step allows estimating the dose of pathogens that individuals are exposed to from each exposure pathway.

(3) Dose-response: Dose-response models are used to estimate the probability of infection associated with a dose of pathogens ingested, so they estimate the ability of pathogens to infect an individual given a particular ingested dose (i.e., Once a pathogenic organism

is ingested, what is the chance they colonise and multiply in the host gut?). Therefore, the dose-response model parameters depend on the infectivity of each pathogen and the susceptibility of the exposed population and have been previously defined based on experimental data.

(4) Risk characterization: The last step involves estimating the probability of harm (i.e., quantifying the infection risk) by putting together the previous steps in the framework. Risk characterisations can involve simple point estimates of risks (deterministic models), or probabilistic risk assessment models that will ensure more robust estimates. Probabilistic models allow reflecting the stochastic nature of environmental variables (such as the inherent natural variation of the pathogen concentrations in water depending on location or time) and the uncertainty in measurement methods (such as limitations in how accurately researchers can quantify pathogen concentrations or exposure levels). The last step of risk characterisation often involves an assessment of how variability and uncertainty affect the overall risk estimate, for instance, by means of a sensitivity analysis.

One of the main advantages of the QMRA framework is its flexibility in the level of sophistication required to draw conclusions. The uses of a QMRA framework range from simpler screening-level risk assessments based on deterministic models, point estimates and assumptions, to comprehensive probabilistic QMRA based on extensive resources in terms of data and expertise in mathematical modelling[200]. It has been highlighted that one key consideration of QMRAs is to select the adequate risk assessment approach suited to the study purpose and scope for risk management[200]. In the case of this study, the purpose of the analysis was to address Objective 2, to assess the faecal contamination levels in the infants' environment and evaluate multiple transmission pathways in terms of their contribution to the overall enteric infection risks. Hence, the QMRA framework was used for screening the relative importance of different pathways using the microbial and exposure data that had been collected, but inevitably relying on assumptions from the literature for some parameters that would have required a much more resource-intensive data collection process. However, the screening approach to this risk assessment could serve as a formative step to highlight the need for a more detailed analysis of particular high-risk pathways or scenarios.

Following the QMRA approach, a probabilistic QMRA model was developed to estimate the enteric infection risks for infants in rural tribal India from different exposure pathways. The specific analytical steps that were followed are described hereunder.

6.3.3 Hazard identification

The step of hazard identification involved identifying the health outcomes of interest and its aetiological pathways to be analysed, meaning determining which pathogens and transmission pathways will be considered in the risk assessment.

6.3.3.1 Health outcomes

The health outcome of interest in this study was defined as enteric infection. Enteric infection can be understood as the point at which pathogens invade the gut and begin to multiply[228]. Infection is the first step that may then lead to gut inflammation (i.e., the body's immune response to infections), disease (i.e., when cells are damaged), and/or symptoms (i.e., signs of infection or disease)[228]. The difference between considering infection as the outcome of interest rather than disease symptomatology is noteworthy. Traditionally, the impact of enteric infections was evaluated by looking at the presence or absence of diarrhoeal symptoms or acute gastrointestinal illness as health outcomes, but it is now understood that enteric infections can significantly disrupt the gut, even in the absence of diarrhoeal symptoms and acute gastrointestinal illness[228]. These gut altering consequences stemming from enteric infections are known as EED (Environmental Enteric Dysfunction), a condition with potential long-term effects on child health and development that was described in more detail in Section 1.3.3 of this thesis. The study of EED and subclinical enteric infections poses new challenges, given the lack of observable symptomatology. By focusing on infections rather than symptomatic illnesses such as diarrhoea or acute gastroenteritis, the limitation of overlooking the potential child health impacts of EED and asymptomatic illnesses was avoided.

6.3.3.2 Reference pathogens

The following step involved identifying the pathogens responsible for enteric infection in infants in rural Banswara. It is not possible to consider all human enteric pathogens, so representative reference pathogens from the literature are typically selected[200]. For the selection of reference pathogens that represented the predominant aetiological agents for enteric infections in infants in rural Banswara, local considerations were taken into account. Given the observed widespread presence of domestic animals across the infant's environments in the study setting (especially cattle and poultry), Enteropathogenic *E. coli* (*E. coli* O157:H7) and *Campylobacter jejuni* were selected as reference enteric bacteria. *E. coli* O157:H7 and *Campylobacter* are common zoonotic pathogens with bovine and avian sources, respectively[200]. Additionally, Rotavirus, a common cause of gastroenteritis, particularly in children and in developing countries, was selected to include both bacterial and viral agents as reference pathogens. These three pathogens were selected among the most common enteric bacteria and viruses as per WHO guidelines[200].

6.3.3.3 Exposure pathways

It would be ideal to be able to consider all the possible exposure pathways and hazardous scenarios through which infants may come in contact with enteric pathogens in a study. This could include multiple exposure pathways such as via drinking water, via mouthing hands or fomites, via ingesting food or soil, and it could also include multiple diverse scenarios under which these risks take place, such as in the scenario where domestic animals are present vs no animals, during monsoon vs dry season, and a long list of other possible exposure circumstances. It is apparent that it is not feasible to analyse the full range of pathways and scenarios that may lead to infants' faecal exposures, hence, this study focused on a few primary pathways. The primary faecal transmission pathways considered for analysis in this study were selected based on the reviewed evidence on what the key faecal exposure pathways to infants may be[229], plus on what was observed during the formative fieldtrip (Section 4.3.9). Observations of infants during the household visits captured the range of elements that infants mouthed or ingested. These elements included drinking water, bathing water, solid food, breasts during breastfeeding, own and caregivers' fingers, visibly dirty cloths, and objects from around the house, soil from the earthen floors, and flies (results presented in Section 1.1.1), and they could all potentially be pathogen transmission vectors. However, several of them could not be analysed. Sampling breasts was considered inappropriately intrusive, sampling food was perceived to not be culturally desirable (Section 4.3.9), and logistical difficulties in the microbial analysis procedures prevented sampling faecal contamination levels in flies or miscellaneous objects and cloths. Therefore, the following five faecal transmission pathways were considered for analysis:

1) Pathway 1: Ingestion of drinking water from household stored vessels
2) Pathway 2: Involuntary ingestion of water during bathing events at local surface water bodies
3) Pathway 3: Direct ingestion of soil while crawling around the household courtyard
4) Pathway 4: Mouthing of own hands
5) Pathway 5: Mouthing of caregiver's hands during feeding events

Based on the structured observations of infants, it was assumed that these 5 exposure pathways captured a comprehensive portion of the overall pathogen exposures that infants in the study settings faced, enabling the estimation of the overall infection risks. Microbial ingestion through eating contaminated food was the single remaining pathway that was not assessed, and this was due to feasibility constraints.

Additionally, the infant infection risks from Pathways 1 and 2 across different scenarios were also evaluated. During fieldwork observations, it was apparent that different study households used different water sources for domestic and drinking use. For instance, some households used the local streams for bathing, and some did not, some households collected drinking water from an open well rather than public hand-pumps, and some others used a private electrical borewell (Section 5.4.2.1). There were observable distinct scenarios regarding the domestic water sources that the study households used, thus, it was deemed appropriate to compare the infection risks to infants in the different domestic water source scenarios. It is noteworthy that while households differed in terms of the water sources they used for drinking and washing, they all reported carrying out similar water handling and treatment practices. Practically all households stored drinking water in metal containers at home, which were refilled from the water sources every one or two days, and none of them reported treating drinking water except occasionally sieving it through a cloth to get rid of soil when it appeared murky (water handling and treatment practices were described in detail in Section 5.4.2.2). Therefore, in addition to the QMRA model comparing the aforementioned exposure pathways to infants, it was decided that an additional water-QMRA model would be developed to compare infection risks to infants from drinking and bathing water across the different domestic water source scenarios observed in the study villages. While these different scenarios are theoretical, they mirror distinct commonly observed scenarios across the study households. For the water-QMRA model, two single exposure pathways were considered; Pathway 1: Ingestion of drinking water from household stored vessels, and Pathway 2: Involuntary ingestion of water during bathing events. In this case, different possible scenarios based on the different domestic water sources used were compared:

1) Scenario 1: Family 1 has had the means to install a private electrical borewell in their house compound, which they use as the main source of domestic water throughout the year, as it does not deplete during the dry months. Every morning, they turn on the electricity to collect water from the electrical borewell and store it in a metal container to drink from throughout the day. Family 1 lives far from ponds or streams and has easy access to water at home through the electrical borewell, so they also use it for hygiene and bathing. The infant is bathed using pots and buckets and water from the electrical borewell.

2) Scenario 2: Family 2 is settled in a *phala* compound that shares a public hand-pump for domestic water access throughout the year, which does not deplete at any time throughout the year. Every morning, women in the family collect water from the nearby hand-pump and store it in metal containers to drink from throughout the day. Women visit the local stream nearby for bathing and laundry on a weekly basis, and as soon as children are mobile (12 months old and above), they are taken alongside for bathing. Up until then, they are bathed using pots and buckets of water from the hand-pump source.
3) Scenario 3: Family 3 is settled in a particularly water-scarce area, with low groundwater levels during the dry months. Family 3 uses a public hand-pump as a domestic water source during the months that it is available (mid-June to February), however, during the dry season (March to mid-June) when hand-pumps become dry, an open well is used as a domestic and drinking source instead. Water is collected from the source, either hand-pumps or wells, every day and stored in metal containers at home. During the months when streams flow full (during monsoon season, Mid-June to end of September), women go to the local streams weekly for bathing and laundry, taking children along once they are mobile (12 months+). During the rest of the months, bathing is carried out with pots and buckets from the domestic water source.

6.3.4 Exposure assessment

The step of exposure assessment involved estimating the magnitude and frequency of exposure to each reference pathogen in each environmental medium. This required identifying the pathogen concentrations in each pathway, as well as the frequency of exposure to them.

6.3.4.1 Pathogen concentrations

To estimate pathogen concentrations in the environment, microbial testing of each specific reference pathogen in the environment would have been preferable, but it would have also required resource-intensive laboratory analysis techniques. Instead, the enumeration of *E. coli* bacteria was a more feasible approach in a setting where laboratory facilities were limited. Therefore, the *E. coli* concentrations measured across environmental media in the study villages were used as proxies to estimate the enteric pathogen concentrations in the environment in this microbial risk assessment. Given the difficulties in the microbial analysis of specific pathogens, faecal indicator bacteria such as *E. coli* are commonly used as proxies for the presence of specific enteric pathogens[200]. *E. coli* is generally considered a good proxy, as it is an organism almost exclusively of faecal origin and has a similar persistence in the environment to that of human bacterial pathogens, although not as good for viruses[200]. Pre-established *E. coli* to pathogen ratios are found in the literature[200,230] (Table 6-1). *E. coli* to pathogen ratios allowed to estimate the *E. coli* O157:H7, *Campylobacter* and Rotavirus concentrations from the empirical *E. coli* counts. Although the use of *E. coli* to pathogen ratios is common, it needs to be used with caution. For instance, while *E. coli* is excreted by almost all humans and warm-blooded animals and will be detected in most faecal contaminated media, the specific enteric pathogens would only be excreted by infected individual[200]. Moreover, faecal indicator ratios may differ geographically and by seasons[231]. It has been argued that while these ratios may not be appropriate to monitor a specific pathogen of concern in a specific region, they are of great value for estimating human health risks from exposure to specific pathogens (i.e., QMRA) [40], and the literature comprises several examples of their use[230,232].

Table 6-1 E. coli to pathogen ratios

Pathogen	***E. coli* ratio**
E. coli O157:H7	1:0.08
Campylobacter	1:0.66
Rotavirus	1:0.00005

Source: WHO, 2016[200]

To be able to use the empirical *E. coli* concentrations measured from the environmental samples in the QMRA models, it was important to consider their variability and uncertainty, since the concentration of faecal pathogens in the natural environment may vary between sites and between times. In the context of rural Banswara, climate seasons are likely to be one of the most important factors in the temporal variability of pathogen concentrations[177]. Monsoons, rains, temperatures, and floods influence the spread of faecal pathogens across the environment[233]. In this study, all samples were collected during the post-monsoon season, since access to the study villages during the monsoon seasons was unfeasible due to flooding, which eliminated the variability between different seasons but also limited the generalisability of findings to other seasons. Variability between sites (different households, different villages, or different blocks) is also inherent to the stochastic nature of the environment. To account for the time and space variability in pathogen concentrations, the *fitdistrplus* package[234] from R was used to fit a log-normal distribution to the empirical *E. coli* concentrations measured, and estimate the mean and standard deviation (SD) parameters, by means of the maximum likelihood estimation (MLE) method, as done in other studies[235,236]. Rather than using point estimates (i.e., means or medians) as model input parameters for *E. coli* concentration, stochastic probability distributions were used. Table 6-2 summarises the *E. coli* distribution input parameters that were used for the QMRA models.

Table 6-2 QMRA model input parameters: E. coli loads in the environmental media analysed

Model variables	**Input parameters**
QMRA model comparing 5 exposure pathways	**Log-normal (mean log, SD log)**
Culturable *E. coli* in stored water (CFU/mL)	Ln N (0.37, 1.87)
Culturable *E. coli* in surface water (CFU/mL)	Ln N (3.23, 1.57)
Culturable *E. coli* in courtyard soil (CFU/mg)	Ln N (16.85, 1.84)
Culturable *E. coli* per hand-swab of infant (CFU/hand-swab)	Ln N (5.64, 1.91)
Culturable *E. coli* per hand-swab of caregiver (CFU/hand-swab)	Ln N (5.06, 1.85)
QMRA model comparing 3 domestic water scenarios	**Log-normal (mean log, SD log)**
Culturable *E. coli* in hand-pump water (CFU/mL)	Ln N (-2.41, 2.03)
Culturable *E. coli* in stored handpump water (CFU/mL)	Ln N (0.33, 1.72)
Culturable *E. coli* in borewell water (CFU/mL)	Ln N (-2.70, 2.34)
Culturable *E. coli* in stored borewell water (CFU/mL)	Ln N (-0.94, 2.90)
Culturable *E. coli* in well water (CFU/mL)	Ln N (1.20, 1.32)
Culturable *E. coli* in stored well water (CFU/mL)	Ln N (2.17, 0.51)
Culturable *E. coli* in surface water (CFU/mL)	Ln N (3.23, 1.57)

6.3.4.2 Exposure volumes and frequencies

Once a distribution of the pathogen concentrations in each pathway had been simulated, the next step for quantifying pathogen exposures was estimating the exposure intake. Intake volumes of water, soil and hand residue could not be quantified during household observations in this study. Therefore, data from the literature was used to determine the magnitude and frequency of exposure to drinking water, bathing water, soil and hands by infants under-2, as input parameters for the QMRA models.

- Drinking water intake: Ingestion of drinking water was considered to occur daily for infants from the age of 4 months onwards. Although not all infants were observed to drink water during household visits (Table 5-3), mothers commonly reported giving infants drinking water from the age of 4 months onwards. Structured data collected across the study villages on infant feeding habits during the prior PANCHSHEEEL study confirmed that infants in the study villages started drinking water at 4 months[50]. To estimate the volume of water ingested by infants from the age of 4 months onwards, estimates from the U.S. Environmental Protection Agency (U.S. EPA) Exposure Factors Handbook[237], the most comprehensive and widely used source for exposure estimates, were used. According to the U.S. EPA, the mean drinking water ingestion volumes are 187 mL/day (95th percentile: 981) for infants aged 4 to 5 months, 269 mL/day (95th percentile: 989) for infants aged 6-11 months, and 146 mL/day (95th percentile: 565) for infants aged 12-23 months[237]. Although water intake estimates based on Indian populations would have been better tailored to the context, U.S. EPA-equivalent exposure estimates in other settings are limited. Formative research in low-resource settings such as rural Zimbabwe estimated that infants aged 12 months ingested 400 mL water/day[67], and in rural Bangladesh infants under-2 were assumed to ingest 100 mL/day[229], supporting the assumption that estimates across these ranges were plausible for similar rural settings. Despite the lack of tailored water consumption estimates for Indian infants, the use of widely-used reference values for exposure presents the advantage it is transparent and comparable to other risk calculations[200], therefore it was decided that drinking water intake estimates for this study would be based on the age-specific U.S EPA values. Based on previous studies, the daily volume of water ingested was assumed to follow a log-normal distribution[235]. The log-normal distribution parameters were derived[238] from the age-specific mean and 95th percentile reported in the U.S. EPA Exposure Factors Handbook[237]. Since the log-normal distribution is skewed, finding its distribution parameters from the summary measures available (i.e., mean and 95th percentiles) was not straightforward, and it was done following the algebraic relationships described by Strom and Stansbury[238]. Derivation of distribution parameters can be found in Appendix L. The age-specific drinking water intake distributions that were used in the final QMRA models are shown in Table 6-3.

Table 6-3 QMRA model input parameters: Drinking water intake distributions

Model variables	**Literature estimates***	**Input parameters**
	(Mean, 95th percentile)	**Log-normal (mean log, SD log)**
Drinking water intake (mL/day) for infants aged 0-5 months	62, 327	Ln N (3.37, 1.23)
Drinking water intake (mL/day) for infants aged 6-11 months	269, 988	Ln N (5.24, 0.85)
Drinking water intake (mL/day) for infants aged 12-23 months	146, 565	Ln N (4.58, 0.89)
*Source: U.S. EPA, Exposure Factors Handbook Chapter 3, 2019 Update[246]		

- Bathing water intake: Similarly, the U.S. EPA Handbook recommends using the value of mean=38 mL/bathing event (95th percentile: 96) to capture children's involuntary ingestion of water while bathing and swimming[237]. Across the study villages, mothers commonly reported taking infants to local streams for bathing on a weekly basis, once they started being mobile (12 months +). Hence, the risk associated with infants bathing at the local surface water bodies once a week from the age of 12 months onwards, assuming a log-normal distribution[239] and deriving the distribution parameters[238] from the U.S. EPA values[237] (Appendix L) was evaluated. The bathing water intake distributions that were used in the final QMRA models are shown in Table 6-4.

Table 6-4 QMRA model input parameters: Bathing water intake distributions

Model variables	**Literature estimates***	**Input parameters**
	(Mean, 95th percentile)	**Log-normal (mean log, SD log)**
Bathing water intake (mL/bathing event) for infants aged 12-23 months	38, 96	Ln N (3.49, 0.55)
*Source: U.S. EPA, Exposure Factors Handbook Chapter 3, 2019 Update[246]		

- Direct soil intake: Across our household visits, structured observations of infants revealed that the direct ingestion of courtyard soil was not uncommon among children who were crawling and playing around the households (Table 5-3 in Section 5.4.1.1). It was assumed that infants' direct ingestion of soil happened daily, as it had been seen in other studies in similar settings[16,67,94]. The volume of direct soil ingested by infants on a daily basis was estimated based on a similar study in a rural setting of Bangladesh[94], where domestic animals and earthen-floor households were also common. In this Bangladeshi study by Kwong *et al*[94], the infant's geometric mean ingestion of soil was estimated at 162 mg/day (for those aged 3-5 months), 224 mg/day (6-11 months) and 234 mg/day (age 12-23 months), of which 12% (19 mg), 40% (90 mg) and 38% (89 mg) were ingested via direct ingestion of soil while children were crawling and playing in mud or earthen floors, respectively. Other exposure assessments, particularly those from higher-income countries such as the U.S EPA[240], have typically overlooked the direct ingestion of soil and only considered the indirect ingestion via mouthing of soiled objects, hands, or inhalation of dust. However, this Bangladeshi study[94] allows to quantify this potentially important exposure pathway for infants that live in households with earthen floors, rather than tiled or wooden floors. The volume of direct soil ingested was assumed to follow a log-normal distribution[236], with parameters derived from Kwong *et al*[94]. The age-specific direct soil ingestion intake distributions that were used in the final QMRA models are shown in Table 6-5, and were derived from the estimates provided by Kwong *et al*[94] and the algebraic relationships described by Strom and Stansbury[238] (Appendix L).

Table 6-5 QMRA model input parameters: Direct soil ingestion distributions

Model variables	**Literature estimates***	**Input parameters**
	(Mean, SD)	**Log-normal (mean log, SD log)**
Direct soil intake (mg/day) for infants aged 0-5 months	19, 2	Ln N (2.73, 0.69)
Direct soil intake (mg/day) for infants aged 6-11 months	90, 2	Ln N (4.26, 0.69)
Direct soil intake (mg/day) for infants aged 12-23 months	89, 2	Ln N (4.25, 0.69)

*Source: Kwong *et al*[94]

- Hand-to-mouth contacts intake: Hand-to-mouth contacts with the infant's own hands were observed across all infants in all the study households, therefore the infection risks from daily exposures to this pathway were assessed for all infants between 0-2 years. The amount of hand residue ingested via hand mouthing on a daily basis was calculated by multiplying the frequency of hand-to-mouth contacts by the fraction of hand residue transferred from hand-to-mouth at each mouthing contact.

Based on Kwong *et al.*'s study in rural Bangladesh[95], which video-recorded infants over 300 hours and noted down all their hand-to-mouth contacts, the mean frequency of hand mouthing for infants 6-11 months old was 52 contacts per hour awake, and 51 times for infants 12-23 months old[95]. Fits to the experimental data suggested that infant's frequency of hand-to-mouth contacts was best described by a Weibull distribution, so Weibull-distributed frequencies were simulated for this model, based on the published distribution parameters[95] (Table 6-6). Even though mouthing frequency distribution parameters were not available for infants 0-6 months old due to a small number of observations, for this study, mouthing frequencies for 0-6 months old were considered to match those of 6-11 months old. Since the hand-to-mouth frequencies were expressed per hour awake, to calculate per-day frequencies, the number of hours infants are awake per day were selected from an age-specific normal distribution[241] (Appendix M).

Table 6-6 QMRA model input parameters: Hand-to-mouth frequencies

Model variables	**Literature estimates***	**Input parameters**
	(Mean, SD)	**Weibull (shape, scale)**
Hand-to-mouth frequency (hand contacts/hour awake) for infants aged 0-5 months	52.4, 34.4	Wb (1.58, 58.22)
Hand-to-mouth frequency (hand contacts/hour awake) for infants aged 6-11 months	52.4, 34.4	Wb (1.58, 58.22)
Hand-to-mouth frequency (hand contacts/hour awake) for infants aged 12-23 months	51.0, 20.2	Wb (2.66, 56.62)
*Source: Kwong et al., 2020[95]		

The fraction of hand residue transferred per hand-to-mouth contact takes into account the fraction of the hand that is mouthed and the fraction of the hand residue that is transferred from hands to the mouth and lips. Per every hand-to-mouth contact, Kwong *et al.*[229], determined that 50% of the hand-to-mouth contacts are with the oral area (i.e., mouth), and 50% with the peri-oral area (i.e., lips). In the oral hand-to-mouth contacts, 19% of the hand is mouthed, and the transfer efficiency from hand to mouth is of 67%. In peri-oral contacts, only 2% of the hand is mouthed, and the transfer efficiency from hand to lips and then to mouth is assumed to be of 30%. Therefore, the overall fraction of hand residue transferred ($Fraction_{HT}$) per overall hand-to-mouth contact can be estimated as per Equation 1 :

Equation 1 Fraction of hand residue transferred per hand-to-mouth contact

$$Fraction_{HT} = (0.5 * 0.19 * 0.67) + (0.5 * 0.02 * 0.30) = 0.067$$

Hand-to-mouth contacts could be contacts with the infant's own hands or contacts with caregivers' hands, particularly common during child feeding episodes. It was observed by Kwong *et al*., that, out of all the hand-to-mouth contacts, 4% (0-6 months), 47% (6-11 months), 23% (12-23 months) were with the caregiver's hands while eating and feeding[95] (Table 6-7). The rest of the hand-to-mouth contacts were considered to be with the infant's own hands, either when self-feeding or while playing and crawling. Moreover, exposure from each hand-to-mouth contact was considered independent of contact duration, and the time between hand-to-mouth contacts was not considered either, meaning that hand recontamination was assumed after each contact, an approach that has been previously used in prior hand-to-mouth exposure assessments[235]. Overall, the hand-mouthing frequency distributions per age group, the sleeping hours' distribution per age group, the fraction of hand residue transferred at each hand-to-mouth contact, and the fraction of hand-to-mouth contacts that occurred with the infant's and the caregiver's hands, were the parameters used to estimate ingestion of faecal pathogens via hand-to-mouth contacts. Log-normal, Normal and Weibull distributions describing the infant's intake of water, soil and hands were drawn from the distribution parameters derived from the literature and included in the probabilistic model. Using stochastic distributions rather than point estimates for the exposure intake assessment allowed me to account for the individual variabilities in the exposure levels.

Table 6-7 QMRA model input parameters: Hand-to-mouth contacts with caregivers' hands

Model variables	**Literature estimates***
Fraction of hand residue transferred ($Fraction_{HT}$)	0.067
Fraction of hand-to-mouth contacts that involved caregiver's hands for infants 0-5 months	0.04
Fraction of hand-to-mouth contacts that involved caregiver's hands for infants 6-11 months	0.46
Fraction of hand-to-mouth contacts that involved caregiver's hands for infants 12-23 months	0.23
*Source: Kwong et al., 2020[229]	

6.3.5 Dose-response model

Once the *E. coli* concentrations and the exposure intakes had been defined as per the previous steps, the next step involved estimating the pathogen dosages. The pathogen dose is the product of the pathogen concentrations found in each environmental medium multiplied by the frequency and magnitude of exposure (e.g volume of water or mass of soil) to each pathway from the literature. For each pathway analysed, the pathogen doses were calculated as described in Equation 2 to Equation 6.

Equation 2 Daily pathogen dose from drinking water

$$Dose_{day,drinking\ water}\left(\frac{CFU}{day}\right) = E.coli\ load\ \left(\frac{CFU}{mL}\right) \times E.coli\text{:}\ pathogen\ ratio\ \times drinking\ water\ intake\ \left(\frac{mL}{day}\right)$$

Equation 3 Daily pathogen dose from bathing water

$$Dose_{day,bathing\ water}\left(\frac{CFU}{day}\right) = E.coli\ load\ \left(\frac{CFU}{mL}\right) \times E.coli\text{:}\ pathogen\ ratio\ \times\ bathing\ water\ intake\ \left(\frac{mL}{day}\right)$$

Equation 4 Daily pathogen dose from direct soil intake

$$Dose_{day,soil}\left(\frac{CFU}{day}\right) = E.coli\ load\ \left(\frac{CFU}{g}\right) \times E.coli\text{:}\ pathogen\ ratio\ \times\ direct\ soil\ intake\ \left(\frac{mg}{day}\right)$$

Equation 5 Daily pathogen dose from hand-to-mouth contacts with infant's own hands

$$Dose_{day,child\ hand}\left(\frac{CFU}{day}\right) = E.coli\ load\ \left(\frac{CFU}{hand}\right) \times E.coli\text{:}\ pathogen\ ratio\ \times\ frequency\ of\ contacts\ \left(\frac{hand\ contacts}{hour\ awake}\right) \times hours\ awake\ \left(\frac{hours\ awake}{day}\right) \times Fraction_{hand\ residue\ transferred} \times\ Fraction_{child\ hands\ contacts}$$

Equation 6 Daily pathogen dose from hand-to-mouth contacts with caregiver's hands

$$Dose_{day,caregiver\ hand}\left(\frac{CFU}{day}\right) = E.coli\ load\ \left(\frac{CFU}{hand}\right) \times E.coli\text{:}\ pathogen\ ratio\ \times\ frequency\ of\ contacts\ \left(\frac{hand\ contacts}{hour\ awake}\right) \times hours\ awake\ \left(\frac{hours\ awake}{day}\right) \times Fraction_{hand\ residue\ transferred} \times\ Fraction_{caregiver\ hands\ contacts}$$

Once the daily exposure doses were calculated, dose-response models were employed to estimate the infectivity corresponding to each pathogen dose. In this manner, if an infant in the study setting ingested 100mL of drinking water per day, and 30 CFU of *E. coli* were observed in 100mL of water, the probability of infection (i.e., probability of the pathogen colonising and multiplying in the gut) following exposure to the daily dose of 30 CFU of *E. coli* was estimated. Dose-response models simulate the ability of pathogens to pass host defences and colonise the gut, therefore, dose-response model parameters depend on each specific pathogen. Dose-response model parameters for each pathogen have been defined in previous studies that have fitted models to experimental data, and now allow risk assessors to simulate the infectivity of each pathogen. Based on the collection of published literature[200], a β-Poisson distribution has been proposed to describe the infectivity of *Campylobacter*, Rotavirus as well as *E. coli* 0157:H7. β-Poisson models are based on the theory that every microorganism acts independently and has an independent probability of infection once it enters the host, where the variability in infectivity between each individual microorganism is assumed to be β-distributed[200]. Hence, β-Poisson dose-response models were used to estimate the probability of infection with *E. coli* O157:H7, *Campylobacter*, and Rotavirus after exposure to a given pathogen dose, according to the following model equation (Equation 7) and pre-established model parameters for each pathogen (Table 6-8)[200]:

Equation 7 β -Poisson dose-response model

$$P_{\text{inf,day}} = 1 - (1 + Dose_{day}/\beta)^{-\alpha}$$

Table 6-8 β-Poisson model parameters

Pathogen	Model parameters
E. coli O157:H7	α=0.2099, β= 42.79
Campylobacter	α=0.1450, β=7.58
Rotavirus	α=0.2531, β=0.426

Source: (Haas et al., 1999)[242]

The α and β parameters determine the probability of infection ($P_{\text{inf,day}}$) given a specific daily dose ($Dose_{day}$) for each pathogen and exposure pathway. Figure 6-2 depicts the β-Poisson cumulative distribution function for *E. coli* O157:H7, *Campylobacter*, and Rotavirus: In the vertical axis, the probability of infection for each pathogen given different daily doses (x-axis) is observed. Rotavirus appears to be the most infectious pathogen of the three since any given dose was estimated to have a higher probability of infection.

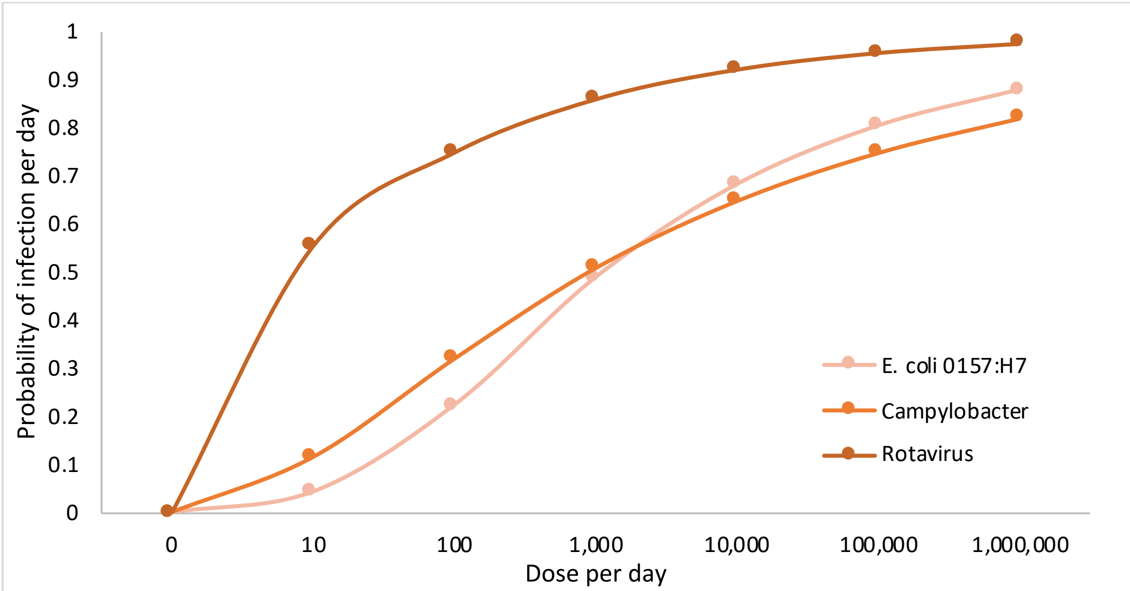


Figure 6-2 β-Poisson cumulative distribution function for E. coli O157:H7, Campylobacter, and Rotavirus

Table 6-1 to Table 6-8 summarises all the input parameters and distributions drawn either from the literature or this study that were used for the risk assessment model. Appendix N comprises a compiled table with all the model input parameters

6.3.6 Risk characterisation

To propagate uncertainty and variability from the stochastic input distributions to the risk estimates, a two-dimensional Monte Carlo model was developed, using the *mc2d* package[243] in R software version 1.4.1103. Using the *mcstoc* function, the model generated 10,000 independent iterations that were assigned randomly sampled pathogen concentration values from the simulated stochastic log-normal distributions of the input variables. The stochastic distribution for the pathogen concentration input variable was based on the mean and standard deviation estimated parameters from the log-normal fit of the empirically measured *E. coli* concentration data. The probability density functions for the exposure intake variable (i.e., the intake frequencies and volumes) were based on the distribution parameters extracted and derived from the literature for each exposure pathway (Table 6-3 to Table 6-6). The probability density functions represented the variability in concentration and exposure values. Then, the model calculated the daily probability of infection for each independent simulation based on the β-Poisson dose-response equations. Results were expressed as daily infection risks per exposure pathway (drinking water, bathing, ingesting soil, mouthing own hands, or mouthing caregiver's hands). Monte Carlo simulations were set to a seed value of 41 to ensure reproducibility.

Given that the first 2 years of an infant's life are a recognised critical period, when enteric infections and gut disruptions have the largest consequences on child growth and development[8], the accumulated risk of enteric infection over the course of the first 2 years of life of an infant was calculated. To calculate the 2-year accumulated infection risk ($P_{\mathrm{inf}(2years)}$), the model subsampled *n* number of daily probabilities from the 10,000 generated simulations without replacement, where *n* is the number of daily exposures during the first 2 years of life. The probability of infection over the first 2 years of life was calculated following Equation 8[200]. Based on information collected during household visits regarding the frequency of exposure to the pathways assessed, the total number of days infants were exposed to the different exposure pathways from birth until age 2 were estimated (Table 6-9).

Equation 8 Two-year accumulated risk of enteric infection

$$P_{\mathrm{inf}(2years)} = 1 - (1 - P_{\mathrm{inf,day}})^n$$

Table 6-9 Exposure frequency to the different exposure pathways analysed

Exposure Pathways	**Local considerations**	**Number of exposure days over the first 2 years of life (n)**
Pathway 1: Ingestion of drinking water	In the study setting, infants aged 4 months and older were given drinking water, which was consumed on a daily basis from then onwards.	608 days (daily exposures, for 20 months)
Pathway 2: Involuntary ingestion of water during bathing events at local streams	Bathing at the local streams was reported to be carried out weekly, with infants starting to join approximately from the age of 12 months and onwards, once they started being mobile.	52 days (weekly exposures, for 12 months)
Pathway 3: Direct ingestion of soil while crawling around the household courtyard	Ingestion of courtyard soil was considered to happen daily once infants are semi-mobile (5 months and onwards) and sit and crawl around the earthen courtyard floors	517 days (daily exposures, for 19 months)
Pathway 4: Mouthing of own hands	Hand-to-mouth contacts considered to happen daily during the infant's first two years	730 days (daily exposures, 24 months)
Pathway 5: Mouthing of caregiver's hands	Hand-to-mouth contacts considered to happen daily during the infant's first two years	730 days (daily exposures, 24 months)

Finally, as explained in Section 6.3.3.3, different scenarios were observed across the study villages, where households used different sources for domestic water. Hence, the enteric infection risks when infants were exposed to different domestic water sources were also assessed so that the different scenarios could be compared. To do so, the accumulated risk of infection after two years of drinking water and bathing water in Scenario 1, 2 or 3, was calculated. Following the reported and observed frequency of exposure to the different water sources (Section 6.3.4.2), the number of yearly exposures to the different water sources was summarised in Table 6-10.

Table 6-10 Exposure frequencies under the different scenarios analysed

Exposure Pathways	**Local considerations**	**Number of daily exposures over the first 2 years of life (n)**
Pathway 1: Ingestion of drinking water		
Scenario 1	Family exclusively uses a private electric borewell for drinking which does not deplete in the dry season. Infants reportedly start consuming water from age 4 months onwards	608 days drinking from private borewell
Scenario 2	Family uses a public hand-pump for drinking which does not deplete in the dry season. Infants start drinking water from age 4 months	608 days drinking from public hand-pump
Scenario 3	Family uses a public hand-pump when groundwater is available (mid-June to February, 70% of the year), and resorts to an open unimproved well during the dry season (March to mid-June, 30% of the year).	608 days drinking water, of which 430 days from public-hand-pumps, and 178 days from open unimproved wells.
Pathway 2. Involuntary ingestion of water during bathing events at local streams		
Scenario 1	Family does not go to local streams for bathing	0 days exposed to bathing in local streams
Scenario 2	Mothers visit the local streams weekly for bathing and laundry, with infants joining from the age of 12 months onwards	52 days exposed to bathing in local streams
Scenario 3	Mothers visit the local streams weekly for bathing and laundry, but only when surface water such as streams are available (during monsoon season, Mid-June to end of September, or 16 weeks)	16 days exposed to bathing in local streams

To calculate the accumulated probability of infection when combining different exposures (for instance, when water is drunk from hand-pumps for a period of time, and from wells for another period of time) Equation 9 was followed[200], instead of Equation 8 which considered a single unique exposure pathway throughout the time period.

Equation 9 Two-year accumulated risk of enteric infection associated with combined exposures

$$P_{\mathrm{inf}(2years),combined} = 1 - \prod_{i=1}^{m} (1 - P_{\mathrm{inf,day,i}})^{n,i}$$

Where $P_{\mathrm{inf,day,i}}$ is the daily infection probability associated with each exposure (of a total of m exposures), occurring n, i times over the period (i.e., 2 years) for which the accumulated risk $P_{\mathrm{inf}(2years),combined}$ is calculated[200].

The model was developed following WHO guidelines on probabilistic QMRA models[200], and the code is available at www.github.com/juliavigu/QMRA_Montecarlo.

6.3.7 Sensitivity analysis

Two unique sensitivity analyses of the stochastic QMRA model were conducted. First, the model sensitivity to the faecal contamination loads in the local water sources was evaluated to examine the impact of contamination reductions on the annual infection risk. The EPA standard for drinking water suggests that risks of less than 1 in 10,000 infections per person-year are deemed acceptable (fewer than one in 10.000 people becoming infected from exposure to pathogens in water)[244]. Therefore, a series of interventions where the contamination loads in the different drinking water sources in Banswara decreased in Log_{10} decrements were simulated to evaluate the required reductions in faecal contamination to achieve the EPA standards for drinking water. The stochastic model was run while holding all the model parameters constant and reducing the *E. coli* concentration distributions in Log_{10} decrements until the tolerable annual risk of infection from drinking water was achieved. For simplicity and to avoid repetition, the risk was calculated only for infants 12-23 months and for the *E. coli* 0157:H7 pathogen, and the annual risk was calculated assuming 365 daily exposures (i.e., assuming an infant drinking from each water source every day of the year).

Secondly, the impact of changes in the ingestion intake volumes (which were extracted from the literature) on the daily enteric infection risk was examined. Since the faecal contamination levels were relatively high throughout, it was thought that the model could be highly sensitive to the levels of exposure to the environmental media, and thus, the model sensitivity was analysed. While holding all other model parameters constant, the water and soil volumes and hand-contact frequency input parameters were modified to simulate “high intakes” and “low intakes” and compare the daily enteric infection risk with the originally estimated risk. For water and soil intake, where a log-normal distribution was assumed, the log-mean input parameters were increased and decreased by 1 logarithmic-fold for the simulated high and low "intakes", respectively. Similarly, for hand-to-mouth contacts, which were modelled following a Weibull distribution, the Weibull scale was altered by a 10-fold increase and decrease. Once again, for simplicity, the sensitivity analysis was only carried out for infants aged 12-23 months and for the *E. coli* 0157:H7 pathogen.

6.4 Results

6.4.1 Faecal contamination of the village and household environment

Faecal bacteria were widespread and in high numbers across the infant's domestic and village environments in rural tribal Banswara.

6.4.1.1 Frequency of E. coli-positive samples

Almost 90% of all the environmental samples analysed were positive for *E. coli* bacteria (Table 6-11). Faecal indicator bacteria were present in all the courtyard floor soil samples (including both school and household courtyards) and surface water samples (including local streams). While over a quarter (26%) of domestic source waters (either hand-pumps or borewells) had no-detectable *E. coli* in 100mL samples, only 7% of domestic stored drinking water samples were free from detectable faecal contamination. Over 90% of hand-swabs were positive for *E. coli.*

Table 6-11 Frequency of faecal-positive environmental samples detected

Environmental samples	**Number of samples***	***E. coli* positive (%)**
Source water	82	74
Hand-pumps	68	75
Borewells	7	43
Open wells	7	100
Stored water	43	93
Stored water from hand-pump source	37	95
Stored water from borewell source	3	67
Stored water from open well source	3	100
Surface water	-	-
Local streams	24	100
Hand swabs	56	95
Infant's hand swabs	30	97
Caregiver's hand swabs	26	92
Soil samples	-	-
Courtyard floors	50	100
All samples	255	89

*Number of samples considered for analysis after excluding environmental samples for which colony enumeration was not possible (i.e., damaged sample or too dirty to count)

The frequency of samples in each logarithmic category of *E. coli* counts can be observed in Figure 6-3. While most source water samples appeared to have *E. coli* levels between 1 to 2 Log_{10} counts/100mL, samples collected from household drinking storage containers mostly fell in the 2-3 Log_{10} CFU/100mL category, and surface water samples mostly had 3-4 Log_{10} *E. coli* counts/100mL. Hand swabs from infants and their caregivers had relatively similar levels of faecal contamination, with most samples falling in the 2-3 Log_{10} CFU/hand-swab category. Soil samples had the highest levels of faecal contamination, with most samples over 4 Log_{10} *E. coli* counts/gram.

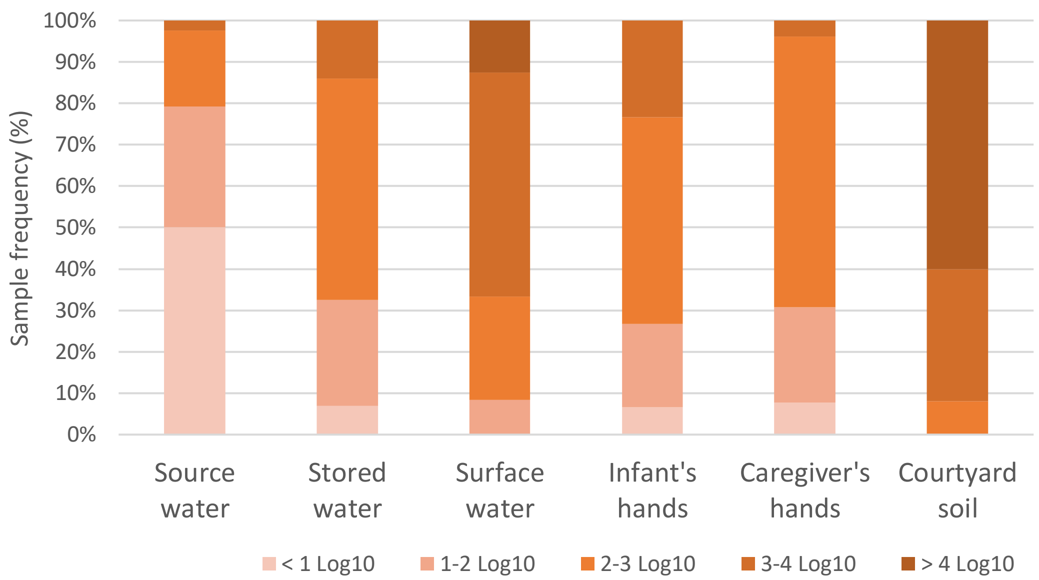


Figure 6-3 Frequency of environmental samples in ordinal categories of E. coli counts

From the 42 households visited across the study villages, 71% (n=30) used exclusively hand-pumps as their main source of drinking water, 12% (n=5) used hand-pumps as well as open wells, depending on the availability of groundwater, and 17% (n=7) used a private borewell. Given that the large majority of study households used hand-pumps as their domestic water source (Table 5-4), few samples from the other water sources were collected. Despite the small number of samples from wells and borewells, differences in the *E. coli* loads between hand-pumps, borewells and open wells were apparent (Figure 6-4). Open well water samples showed a higher frequency in higher *E. coli* count categories in comparison to hand-pumps and borewells, as was expected, since open wells are considered an unimproved water source[27]. For any of the three types of water sources, stored water samples invariably showed higher *E. coli* counts. From Figure 6-4, it can be inferred that the level of infants' exposure to faecal pathogens will be dependant to the type of domestic water source used in their household.

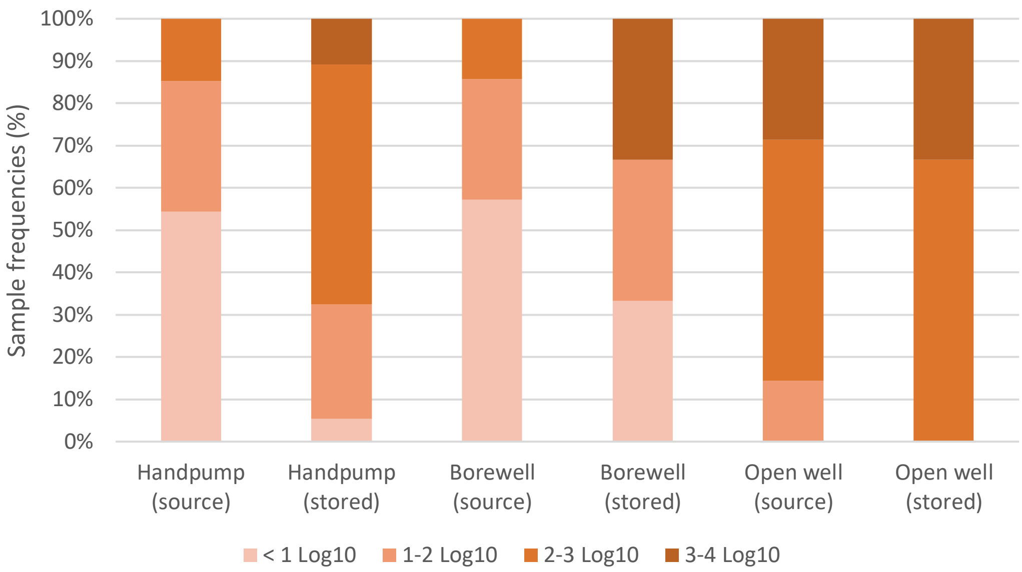


Figure 6-4 Frequency of water samples in ordinal categories of E. coli counts

6.4.1.2 Differences in the contamination levels between study villages and blocks

As explained previously in this thesis, the villages included in this study were distributed across two different administrative blocks in Banswara, Ghatol and Kushalgarh. As explained in Section 3.4, the two studied blocks differ in several geographic, socio-cultural, and economic characteristics. In brief, villages in the Ghatol block were closer to the district capital and are canal-fed, and villages in Kushalgarh were less well connected, not canal-fed, and faced further groundwater scarcity. Given this, differences in the contamination levels between the two blocks were assessed.

Hand-pump water samples in Ghatol had a geometric mean (geomean) of 1.17 (95% CI 0.849-1.48) *E. coli* Log_{10} CFU/100mL vs 1.15 (95% CI 0.84-1.45) in Kushalgarh (Table 6-12). Surface water samples (i.e., streams) also had similar geomeans of 3.49 and 3.17 *E. coli* Log_{10} CFU/100mL in Ghatol and Kushalgarh, respectively. The colour gradient scheme in Table 6-12 helps to visually capture differences in the mean contamination between villages and blocks. For instance, the groundwater *E. coli* loads in the KK village stand out from the rest, probably due to heavy rainfall that fell on that day in Kushalgarh, contributing to the percolation of pathogens to the groundwater aquifers. However, as it is visually apparent from the colour scheme and confirmed by the large p-values (>0.05), there were no significant differences in the mean contamination levels of groundwater nor surface waters between Ghatol and Kushalgarh blocks.

Table 6-12 E. coli concentrations in water samples across study villages and blocks

***E. coli* loads (Log10 CFU/100mL)**		**Groundwater (Hand-pump samples)**	**Surface water (Stream samples)**
Blocks	**Villages**	**Geomean, SD (N)**	**Geomean, SD (N)**
Ghatol	GU	1.37, 1.03 (14)	3.96, NA (1)
	GJ	1.24, 1.10 (3)	3.47, 0.04 (3)
	GK	1.00, 0.58 (3)	2.78, NA (1)
	GT	0.77, 0.48 (3)	3.11, 0.67 (3)
	GG	1.10, 0.81 (12)	3.79, 0.28 (2)
	Block total	**1.17, 0.92 (35)**	**3.49, 0.52 (12)**
Kushalgarh	KB	1.08, 0.78 (13)	2.58, 0.75 (3)
	KK	2.05, 0.74 (3)	3.60, 0.75 (3)
	KD	1.04, 0.85 (14)	3.37, 1.05 (5)
	KP	1.33, 0.89 (3)	3.67, 0.22 (3)
	Block total	**1.15, 0.87 (33)**	**3.17, 0.84 (12)**
Significant differences between blocks? (Wilcoxon test p-value)		0.63	0.54

Statistically significant differences between blocks on the school and Anganwadi's courtyard soil samples were also not detected (Table 6-13), with high geomean *E. coli* counts of around 4 Log_{10} per gram of soil detected throughout.

Table 6-13 E. coli concentrations (Log10 CFU/g) in soil samples across study blocks

***E. coli* loads (Log10 CFU/g)**	**School and Anganwadi's courtyard soil**
Block	**Geomean, SD (N)**
Ghatol	4.12, 0.66 (4)
Kushalgarh	3.74, 0.14 (5)
Significant differences between blocks? (Wilcoxon test p-value)	0.23

6.4.1.3 Differences in contamination levels between environmental medias

Despite the lack of apparent significant differences in the contamination levels by geographical area, differences in the contamination levels by type of environmental media can be observed in Figure 6-5. For instance, even though water, hands and soil samples' *E. coli* counts are expressed in different units (per 100 mL, per hand-swab, and per gram of soil, respectively), if 100 mL of water, a gram of soil, and a hand surface are considered as a single-unit of exposure, the contamination levels across different environmental media can be contrasted (Figure 6-5).

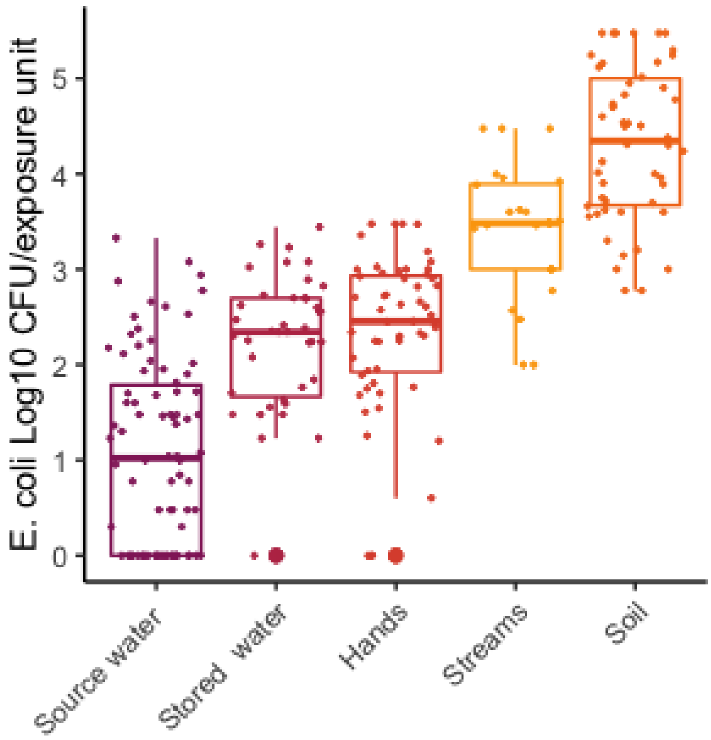


Figure 6-5 E. coli concentration (Log10 CFU per 100mL, per hand-swab, or per gram) in the different environmental sample sources. (Boxplot: 75th Percentile- Median-25th percentile. Whiskers: Maximum-Minimum)

In this way, domestic source water samples had a geomean *E. coli* Log_{10} count/100mL significantly lower than the geomean for stored water samples (p-value <0.01), and the mean contamination levels of local streams were significantly higher than both (p-value <0.01), domestic source and stored drinking waters (Table 6-14). Hand-swabs had moderate levels of faecal contamination, significantly lower than those found in a unit of soil, but higher than those found in domestic water samples. *E. coli* counts in soils were significantly higher than in any other environmental medium, as it has been seen in other studies[245].

Table 6-14 Statistical differences between the E. coli concentration geomeans (Log10 CFU per 100mL, per hand-swab, or per gram) in the different environment sample sources.

	Source water	Stored water	Hands	Streams	Soil
Source water	1.25, 0.98 (82)				
Stored water	<0.01	2.12, 0.82 (43)			
Hands	<0.01	0,08	2.26, 0.84 (56)		
Streams	<0.01	<0.01	<0.01	3.33, 0.70 (24)	
Soil	<0.01	<0.01	<0.01	<0.01	4.24, 0.81 (50)

Values in the diagonal correspond to the geomean, SD (N) for each sample type. Values across sample types express p-value for significant differences in geomeans.

The distribution of *E. coli* concentrations across the different domestic water types (i.e., hand-pumps, borewells and wells) and the respective stored drinking water samples from each different water source can be observed in Figure 6-6. The small number of samples from borewells and wells analysed led to large uncertainties in the mean concentration estimates from these sources. Nevertheless, most comparisons between the different types of domestic water samples resulted in significant statistical differences (Table 6-15). The geomean *E. coli* counts from well water were significantly higher than those of hand-pumps and borewells (p-value <0.01). Perhaps because none of the study households were observed to treat their drinking water other than by sieving it through a cloth (Section 5.4.2.2), stored drinking water *E. coli* loads were significantly higher than the contamination levels from water sources directly. Lastly, surface water samples from local streams had significantly higher *E. coli* levels than any other water sample type. The Wilcoxon test had no power to detect significant differences with stored borewell and stored open well water samples, given the small number of samples available.

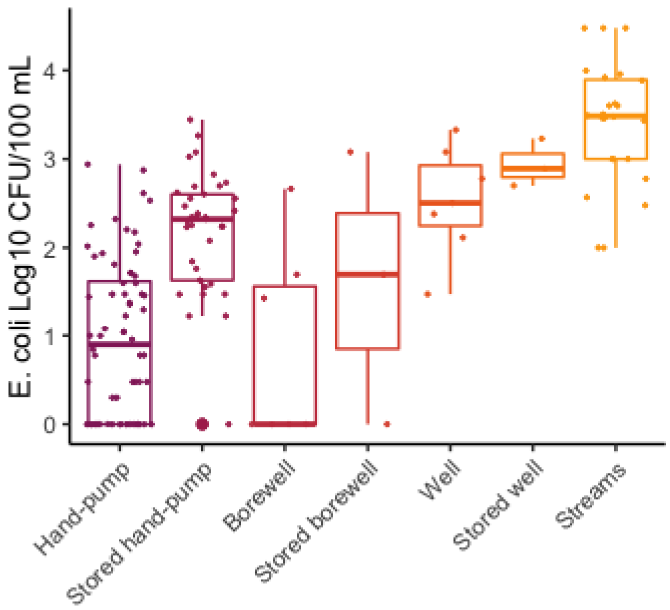


Figure 6-6 E. coli concentration (Log10 CFU/100mL) in the different water samples (Boxplot: 75th Percentile- Median-25th percentile. Whiskers: Maximum-Minimum)

Table 6-15 Statistical differences between the E. coli concentrations (Log10 CFU/100mL) in the different water samples

	Borewell	Hand-pump	Open well	Stored borewell	Stored hand-pump	Stored well	Streams
Borewell	1.31, 1.09 (7)						
Hand-pump	0.58	1.16, 0.89 (68)					
Open well	<0.01	<0.01	2.45, 0.62 (7)				
Stored borewell	-	-	-	1.74, 1.54 (3)			
Stored hand-pump	<0.01	<0.01	0.22	-	2.1, 0.76 (37)		
Stored well	-	-	-	-	-	2.93, 0.27 (3)	
Streams	<0.01	<0.01	<0.01	-	<0.01	-	3.33, 0.70 (24)

Values in the diagonal correspond to the geomean, SD (N) for each sample type. Values across sample types express p-value for significant differences in geomeans.

6.4.2 Daily risk of enteric infection from multiple exposure pathways

As explained in the methods of this chapter (Section 6.3.2), a probabilistic QMRA model was developed to assess the risk of enteric infection with three reference pathogens, *E. coli O157:H7*, *Campylobacter,* and Rotavirus, for infants in rural tribal Banswara exposed to 5 different potential faecal exposure pathways. The exposure pathways assessed included: (1) Drinking water from the household stored water containers; (2) Involuntary ingestion of water while bathing at the local streams; (3) Direct ingestion of soil while infants played and crawled around the household's earthen courtyard floors; (4) Mouthing of the infant's own hands; and (5) Mouthing of caregiver's hands during infant feeding episodes.

For practically all pathways, all enteric pathogens and all age groups, the median daily risks of infection were relatively high (Table 6-16). The direct ingestion of soil was the pathway that posed a consistently higher median risk of enteric infection with any of the reference pathogens, of more than 90% after every single day. Enteric infection risk estimates from soil ingestion remained persistently high even in the most optimistic scenario (10^{th} percentile) and even for <6 months old infants, who were assumed to have very low daily intakes of soil. This is likely due to the consistently high levels of faecal contamination found in household courtyard soils.

Drinking household stored water led to the lowest daily risks of enteric infection, relative to the other exposure pathways assessed. The estimated median daily infection risk with *E. coli* 0157:H7 ranged from 1.6% to 8.3% across age groups, however, bearing in mind the WHO guidelines for drinking water[246], any faecal contamination in domestic water sources and any infection risk from it, surpasses the international standards for drinking water safety (1 infection in 10.000 person-years).

Bathing in local streams, despite being quite an infrequent exposure only present for infants 12 months plus, led to an estimated 18% and 46% median probability of enteric infection with *E. coli* 0157:H7 and *Campylobacter,* respectively, after each single bathing instance.

Infant's mouthing of their own hands or caregiver's hands also led to significant daily infection risks, ranging from 34% to 61% for *Campylobacter* infection for instance. It is likely that the accumulated number of hand-mouthing events after a whole day largely contributed to the overall daily risk from this pathway. As expected, mouthing of caregiver's hands posed lower risks than mouthing of the infant's own hands, as caregiver's hand-mouthing was less frequent.

Across age groups, infants aged less than 6 months generally faced lower infection risks than infants 6 months and above, as they were less exposed to the environment, with lower volumes of water drunk or soil ingested. Infants aged 6-11 months and 12-23 months faced similar enteric infection risks, as their exploratory and mouthing behaviours increased their exposures to the environment.

Table 6-16 Estimated daily risk of enteric infection with E. coli O157:H7, Campylobacter and Rotavirus for infants aged 0-6 months, 6-11 months, and 12-23 month

Exposure pathways	**Estimated daily risk of enteric infection**								
Percentile	**10^{th} (%)**			**50^{th} (%)**			**90^{th} (%)**		
Age (months)	**< 6**	**6-11**	**12-23**	**< 6**	**6-11**	**12-23**	**< 6**	**6-11**	**12-23**
Drinking household stored water									
E. coli O157:H7	<0.1	0.3	0.2	1.6	8.3	4.8	29	45	38
Campylobacter	1.0	7.7	4.4	20	37	31	53	62	58
Rotavirus	<0.1	<0.1	<0.1	0.1	0.8	0.4	5.7	17	11
Bathing at local streams									
E. coli O157:H7	-	-	1.4	-	-	18	-	-	53
Campylobacter	-	-	19	-	-	46	-	-	66
Rotavirus	-	-	0.1	-	-	2.3	-	-	26
Direct soil ingestion									
E. coli O157:H7	88	91	91	94	96	96	97	98	98
Campylobacter	87	89	89	92	93	93	95	96	96
Rotavirus	84	89	89	93	95	95	97	98	98
Mouthing infant's own hands									
E. coli O157:H7	13	9.5	15	44	38	44	67	64	66
Campylobacter	43	39	44	61	58	61	73	71	73
Rotavirus	1.5	0.9	1.7	15	11	15	48	42	47
Mouthing caregiver's hands									
E. coli O157:H7	0.5	5.6	3.9	5.9	29	23	29	57	50
Campylobacter	11	33	29	34	54	50	54	68	64
Rotavirus	<0.1	0.5	0.3	0.5	5.8	3.5	5.8	31	22

Daily enteric risk estimates are also summarised Figure 6-7, which depicts the risk distributions for *E. coli* 0157:H7 infection across age groups and exposure pathways. It is visually apparent from Figure 6-7 that when taking into account the variability and uncertainty in exposure frequencies and pathogen concentrations, the daily infection risk estimates show a high variability as well. Nevertheless, soil ingestion and mouthing of hands show distributions with higher overall daily infection risk estimates in comparison to the risks posed by drinking water and bathing events.

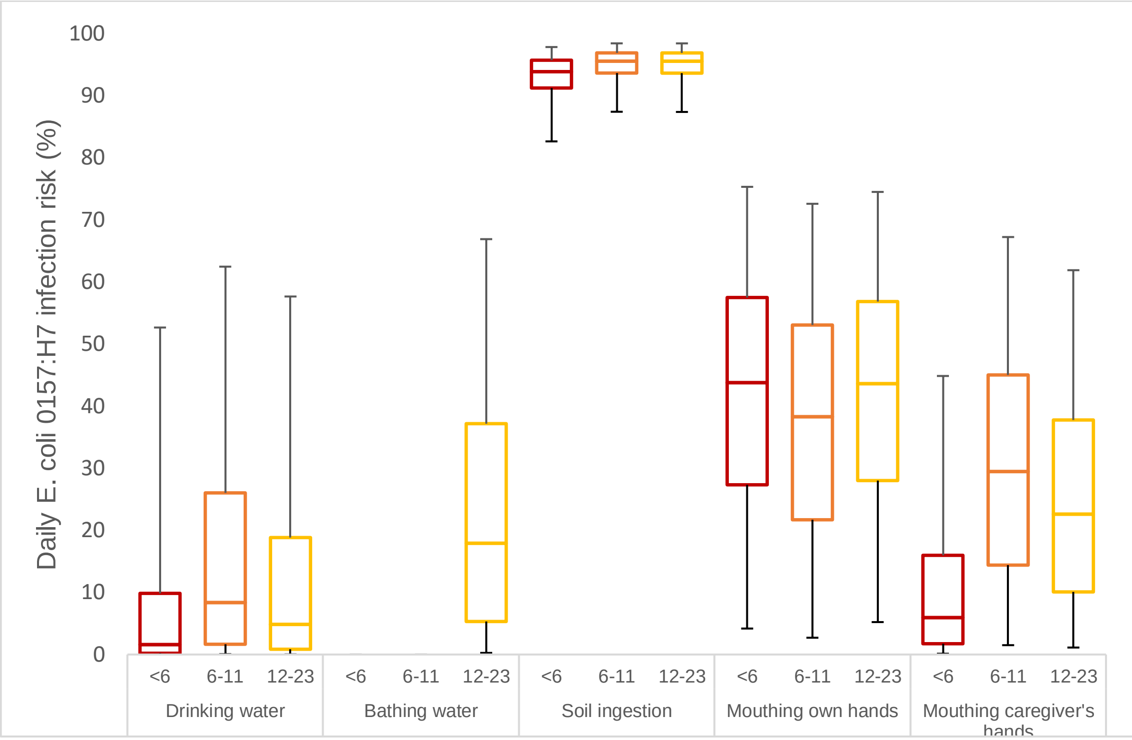


Figure 6-7 E. coli 0157:H7 infection daily risk distributions for different exposure pathways and age groups for infants 0-23 months. (Boxplots: 25th percentile-median-75th percentile. Whiskers: 5th and 95th percentiles. Outliers not shown in boxplots due to the large number of observations (10.000 simulations).

6.4.3 Risk of enteric infection during the first 2 years from multiple exposure pathways

Subsequently, the overall accumulated risk of infection after 2 years of daily exposures to the different pathways was calculated. For each exposure pathway, the number of daily exposures throughout the first 2 years of life was estimated, and the accumulated risk was assessed (Table 6-17). For all pathways, the median risk of enteric infection with either *E. coli* O157:H7, or *Campylobacter* after 2 years was 100%. Even in the most optimistic scenario, where infants are exposed to the lowest percentile of pathogenic doses, (2.5th percentile), the accumulated probability of suffering an enteric infection with *E. coli O157:H7* or *Campylobacter* during the first 2 years of life was 100% from mouthing their own hands or caregiver's hands, and from ingesting courtyard soil. In the most optimistic scenario (2.5th percentile), the risk of enteric infection with *E. coli O157:H7* from drinking household water or bathing at the local streams is 27% and 13%, respectively. Rotavirus risk estimates were lower throughout all pathways in comparison to the other reference pathogens, due to the lower *E. coli* to Rotavirus pathogen ratio assumed (Table 6-1). Nevertheless, even the median Rotavirus infection risk after 2 years was >99% for all pathways, except from bathing at the local streams (71%).

Table 6-17 Estimated risk of enteric infection with E. coli O157:H7, Campylobacter and Rotavirus after accumulated exposures to the different exposure pathways during the first 2 years of life

Exposure pathways	Estimated risk of enteric infection after the first 2 years of life			Days exposed*
Percentile	**2.5th (%)**	**50th (%)**	**97.5th (%)**	**(n)**
Drinking household stored water				608
E. coli O157:H7	27	100	100	
Campylobacter	100	100	100	
Rotavirus	2.3	99	100	
Bathing at local streams				52
E. coli O157:H7	13	100	100	
Campylobacter	97	100	100	
Rotavirus	1.0	71	100	
Direct soil ingestion				517
E. coli O157:H7	100	100	100	
Campylobacter	100	100	100	
Rotavirus	100	100	100	
Mouthing infant's hands				730
E. coli O157:H7	100	100	100	
Campylobacter	100	100	100	
Rotavirus	80	100	100	
Mouthing caregiver's hands				730
E. coli O157:H7	100	100	100	
Campylobacter	100	100	100	
Rotavirus	58	100	100	

*Number of days exposed to each pathway estimated (Table 6-9).

6.4.4 Daily risk of enteric infection in different domestic water scenarios

Additionally, the enteric infection risks from drinking water (Pathway 1) and bathing water (Pathway 2) were assessed for three different scenarios. Briefly, the three different scenarios included: (1) A family with a private electric borewell as a domestic water source; (2) A family that uses a public hand-pump as a water source and a local stream for bathing; and (3) A family that combines the use public hand-pumps and open wells as domestic water sources, depending on their availability, and also use local streams for bathing (more details on Section 6.3.3.3).

Figure 6-8 shows the risk distribution of daily *E. coli* O157:H7 infection from the 10,000 Monte Carlo simulations, per age group and for the different domestic drinking water sources. From Figure 6-8, the differences in the daily enteric infection risk according to the different drinking water sources (mechanical hand-pumps, electric borewells, or open wells) or household stored water sources can be observed. Drinking from stored drinking water containers repeatedly posed higher infection risks in comparison to drinking from domestic water sources directly, a pattern that can be observed for hand-pumps, borewells as well as open wells. Infants from families that relied on wells as a water source and drank from stored well water faced a median 8-26% daily *E. coli* O157:H7 infection risk, vs 0.5-3% if they drank from stored borewell water, or 1.5-8% if they drank from stored hand-pump water (Figure 6-8).

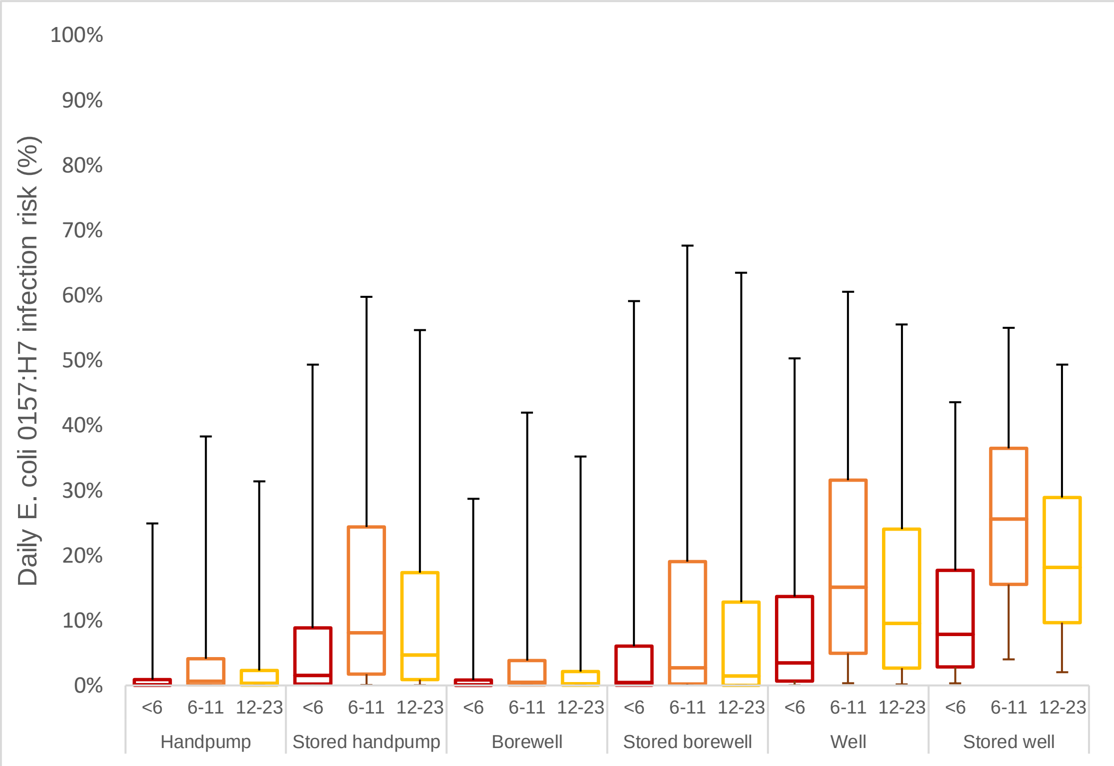


Figure 6-8 E. coli 0157:H7 infection daily risk distributions for different domestic water source scenarios and age groups for infants 0-23 months. (Boxplots: 25th percentile-median-75th percentile. Whiskers: 5th and 95th percentiles. Outliers not shown in boxplots due to the large number (10.000 simulations).

6.4.5 Risk of enteric infection during the first 2 years in different domestic water scenarios

Considering the three different scenarios in terms of the domestic water sources used by different families, the accumulated risk of enteric infection during the first 2 years of life from drinking water and bathing was assessed for Scenarios 1, 2 and 3 (Table 6-18). Once again, the median accumulated risk for *Campylobacter* and *E. coli* O157:H7 from drinking water and bathing after the first 2 years of life was estimated to be >95% for all the scenarios assessed. When looking at the Rotavirus infection risk though, Scenario 1, where the family had a private borewell, was the safest relative to the other two. Infants in Scenario 1 had a median Rotavirus infection risk from drinking water directly from the domestic source of 21%, rising to 74% when drinking from stored water. Instead, in Scenario 3, where the family temporarily used an open well as a domestic water source, the median Rotavirus infection risks from drinking water during the first 2 years of life were estimated at 97%. Scenarios 2 and 3, in which infants visited the local streams for bathing, introduced additional infection risks.

Table 6-18 Estimated risk of enteric infection with E. coli O157:H7, Campylobacter and Rotavirus after accumulated exposures under different domestic water source scenarios during the first 2 years of life

Exposure pathways	**Estimated risk of enteric infection after the first 2 years of life**								
Scenarios	**Scenario 1**			**Scenario 2**			**Scenario 3**		
Percentiles	**10th**	**50th**	**90th**	**10th**	**50th**	**90th**	**10th**	**50th**	**90th**
Drinking from the domestic water source									
E. coli O157:H7	5.0	95	100	9.7	98	100	93	100	100
Campylobacter	80	100	100	96	100	100	100	100	100
Rotavirus	0.4	21	100	0.8	27	100	19	97	100
Drinking from the domestic stored water containers									
E. coli O157:H7	14	100	100	90	100	100	93	100	100
Campylobacter	99	100	100	100	100	100	100	100	100
Rotavirus	0.1	74	100	16	99	100	19	97	100
Bathing at the local streams									
E. coli O157:H7	-	-	-	51	100	100	21	97	100
Campylobacter	-	-	-	100	100	100	68	100	100
Rotavirus	-	-	-	5.3	71	100	1.8	33	100

6.4.6 Sensitivity analysis

Sensitivity analysis of bacterial loads

The sensitivity of changes in the *E. coli* bacteria concentrations in water on the annual risk of enteric infection was analysed (Table 6-19). The faecal contamination loads in each drinking water source were decreased in Log_{10} decrements, simulating potential interventions that achieved Log_{10} reductions in the faecal contamination levels of local water sources. For any of the local water sources (i.e., public hand-pumps, private borewells, and open unimproved wells), at least a 4 Log_{10} reduction in the faecal contamination loads would be required to achieve annual infection risks below 0.01% (or 1 in 10,000 person-years), which is the level considered acceptable by the EPA[244]. A further logarithmic reduction (5 Log_{10}) in the *E. coli* contamination levels would be required in the household stored waters collected from hand-pumps and borewells, which posed even higher risks than when drinking directly from the water sources.

Table 6-19 Sensitivity analysis for the annual risk of enteric infection with E. coli O157:H7

	Annual *E. coli* O157:H7 infection risk for infants aged 12-23 months (median)*					
Log_{10} decrements in contamination loads	**Original risk**	**10^1**	**10^2**	**10^3**	**10^4**	**10^5**
Drinking water from hand-pumps	71%	12%	1.3%	0.1%	<0.01%	<0.01%
Drinking household stored water from hand-pump source	100%	86%	18%	1.9%	0.2%	<0.01%
Drinking water from borewells	61%	9%	0.9%	0.09%	<0.01%	<0.01%
Drinking household stored water from borewells	100%	42%	5.3%	0.6%	0.06%	<0.01%
Drinking water from wells	100%	99%	37%	4.6%	0.5%	<0.01%
Drinking household stored water from wells	100%	100%	70%	12%	1.2%	0.1%

**assuming 365 daily exposures*

Sensitivity analysis of exposure intakes

The model sensitivity to changes in the exposure intakes was assessed. When holding all other parameters constant and decreasing and increasing the mean daily intake of water and soil by 1 logarithmic count (log mean +/- 1 log count), and the frequency of hand-to-mouth contacts by 10 (Weibull scale +/- 10), the impact on the daily *E. coli* 0157:H7 infection risk was analysed (Table 6-20). The model appeared to be robust to the sensitivity analysis changes for the direct soil ingestion and mouthing of own and caregiver hands' frequency, where the input parameter changes led to small percentual variations (less than 3 percentual points) in the daily probability of infection. Instead, lower and higher intake water volumes led to larger variations in the daily risk of infection, with risks varying from 2 to 11% in the case of drinking household stored water. Despite this, interventions that aimed to reduce the water intake volumes for infants would not be feasible, and interventions that aim to reduce soil ingestion and hand-to-mouth contacts, in addition to potentially impairing the infant's exploratory and mouthing behaviours[74], do not appear that they would yield large benefits on enteric infection risk reduction.

Table 6-20 Sensitivity analysis for the daily risk of enteric infection with E. coli O157:H7 for infants aged 12-23 months

Exposure pathways	**Median daily risk**		
10-fold changes in intake volumes	**Low intake**	**Original risk**	**High intake**
Drinking household stored water	1.9%	4.8%	11%
Bathing at local streams	9.1%	18%	29%
Direct soil ingestion	95%	96%	96%
Mouthing infant's hands	41%	44%	45%
Mouthing caregiver's hands	20%	23%	24%

6.5 Discussion and conclusion

This chapter's results presented evidence of widespread faecal bacteria (*E. coli*) contamination across groundwater and surface water sources, household courtyard soils, as well as infant and caregiver's hands in rural tribal villages of Banswara, India. The infection risks from infant's ingestion of drinking water, infant's bathing at local streams, infant's direct ingestion of courtyard soil, and infant's mouthing of hands contaminated with enteric pathogens were high compared with normative tolerable risk levels associated with environmental exposures[244].

6.5.1 Faecal contamination loads

The *E. coli* counts found in household stored water samples, domestic water sources (i.e., public hand-pumps, open wells, and borewells) and local surface waters (i.e., streams and ponds) in this study were generally higher than in other studies in similar settings. For instance, 75% of the water samples collected from public hand-pumps were positive for *E. coli* in this study, while only 25% of public tube-wells were contaminated in rural Bangladesh[70], and 46% in Tanzania[247]. Similarly, 93% of the household stored drinking water samples were contaminated in Banswara (2.12 Log_{10} CFU/100mL), vs 77% in Bangladesh (0.96 Log_{10} CFU/100mL)[70], 59% in Tanzania (0.23 Log_{10} CFU/100mL)[247] or 63% in Zimbabwe (0.77 Log_{10} CFU/100mL)[248]. In rural Banswara, the lack of sanitation facilities and the unsafe management of livestock excreta are likely to contribute to surface water as well as to groundwater contamination, particularly during the monsoon season[249]. During the monsoon season is when the poor sanitation conditions are of higher concern, given the high groundwater tables (0.68 and 2.38 metres below ground in Ghatol and Kushalgarh, respectively[177]) that make it much easier for pathogens to percolate to the groundwater aquifers. The fact that samples were collected during the late and post-monsoon season only (September to December) may partly explain the higher *E. coli* detection rates found versus other studies. Climate factors such as temperature, soil moisture, and sunlight varying by seasons are strongly related to the survival and spread of enteric pathogens in the environment[233]. For instance, Ercumen *et al*[70] detected *E. coli* more frequently and at higher concentrations during the rainy season vs the dry in rural Nepal, with results more similar to the ones found in this study during the rains. Nevertheless, this study was consistent with results across several different settings[67,230,250,251] in that *E. coli* counts in household stored water were consistently higher compared with domestic water sources. In our study setting, point-of-use contamination during water storage may be partly attributed to the use of a cloth, which was commonly used for filtering drinking water before storing it, as it was reported to "make water safe to drink" (Section 5.4.2.2). Such cloths were often visibly dirty. In addition, child and caregivers' hands may also be responsible for the re-contamination of stored water, as hands were introduced into the storage vessels for the collection of water. An association between faecal contamination levels on mothers' and children's hands and those on stored drinking water has been previously reported[67,250,252].

Our findings revealed that open wells had an additional 1.3 Log_{10} CFU of *E. coli*/100 mL than the more commonly used public hand-pumps domestic water source. Equivalent to our findings, Machdar[230] found communal wells to be more highly contaminated than public tube-wells (i.e., public hand-pumps) and private yard taps (i.e., private borewells) in Ghana. In our study, all the local stream water samples were positive for *E. coli* (3.3 Log_{10} CFU/100mL). A study in rural Odisha, India, concurred that all surface water bodies such as ponds and streams were positive for faecal markers[43], and in rural Bangladesh local streams appeared to be even more highly contaminated than what was found in this study (3.7 Log_{10} CFU/100mL) [6].

E. coli counts found in the household courtyard soils in Banswara (4.2 Log_{10} CFU/gram) were, on average, higher than those found in urban domestic settings in Maputo, Mozambique (3.2 Log_{10} CFU/gram)[236], Harare, Zimbabwe (1.6 Log_{10} CFU/gram)[248] or Bagamoyo, Tanzania (2.1 Log_{10} CFU/gram)[69], but they were closer to the ones found in a more similar rural setting in Bangladesh (5.1 Log_{10} CFU/gram)[253]. Contextual factors such as the sanitation infrastructure, the presence of domestic animals or the infant's faeces and waste disposal practices contribute to soil contamination with faecal pathogens. In the rural study setting, domestic animals such as cows and goats were owned by practically all households (see Table 5-7), and fresh animal faeces such as cow dung were commonly used to pave the courtyard earthen floors, which may further contribute to the spread of faecal pathogens across the domestic soils. The ubiquitous presence of domestic animals in rural settings like the study villages is likely to play an important role in the overall infant's faecal exposure, as the mere presence of domestic animals has been estimated to increase soil contamination levels by an additional 0.54 Log_{10} *E. coli* CFU per gram of soil[70]. This highlights the need for One Health studies, that consider how human and animal health intertwine in shared environments.

Lastly, while hand contamination levels ranging around 1-3 Log_{10} *E. coli* CFU/hand have been found in other studies[70,247,248], similar to what our hand-swab samples revealed (2.26 Log_{10} *E. coli* CFU/hand), differences in the sampling methodologies used (sampling of one or two hands, hand-rinses vs hand-swabs, swabbing fingers or palms or nails…) may hinder comparisons. Regardless, most studies found that approximately half or more of the hands tested were positive for faecal markers[70,247,248].

6.5.2 Risk of infection

6.5.2.1 Enteric infection risks across 5 exposure pathways

Our risk assessment model estimated that infants in their first 2 years of life faced lower daily enteric infection risks from drinking household stored water and bathing at the local streams than from directly ingesting courtyard soil or mouthing their own hands. This is consistent with a few prior similar studies, where hand-to-mouth contacts resulted in greater ingestion of faecal pathogens in children than drinking water in Tanzania[235], or a study in Bangladesh where object mouthing, hand-mouthing and soil ingestion were identified as primary pathways of *E. coli* ingestion rather than drinking water or food ingestion for infants under-2[229]. These findings suggest that addressing the pathways that pose higher infection risks such as ingesting domestic soil and mouthing hands could potentially have a bigger impact on reducing overall infant infection than interventions that improve drinking water safety or exposure to contaminated streams, which have traditionally received much more attention. Instead, soil, mouthing of hands, and other infant-specific transmission routes remain under-researched. The infant-specificity of these exposure pathways, which are not relevant to the adult population, may partly explain the relative neglect in addressing them when compared to water and food safety measures[10,236,254]. WASH interventions may need to broaden and include other pathogen exposure risks within the domestic environment if they are to address the infant-specific pathways and see an effect on improving child growth during the first 1000 days of life[10].

Interventions that aim to reduce infant's risk of enteric infection from ingesting domestic soil, or mouthing soiled hands and objects, can take two distinct approaches; (1) either introduce control measures that tackle the faecal contamination levels in the infant's surroundings, such as interventions that improve latrine facilities and uptake, or the safe disposal of animal and babies' faeces[71,132,255] or (2) control measures that reduce infant's levels of exposure to faecal pathogens, such as interventions that provide safe child play spaces or improved household flooring[133,134,137]. Several control strategies to limit infants' exposures would be unfeasible. For instance, limiting drinking water intake would be unworkable, and limiting infant's opportunities for mouthing and exploratory behaviours, while it would protect them against environmental contaminants, it would hinder an essential part of their motor, perceptual and cognitive development, as infants explore their surroundings through touching and mouthing[74]. Nevertheless, while reductions in the level of faecal contamination would be ultimately more effective control strategies, they may require a more long-term and gradual approach[236], including transformative infrastructural (e.g. sanitation and drainage systems) and socio-cultural (i.e., open defecation and hygiene behaviours) shifts.

While the comparison of daily enteric infection risks across different pathways justified the need to prioritise soil ingestion and mouthing of soiled hands as critical transmission pathways, the accumulated enteric infection risks estimated after the first two years of continuous exposures were estimated to be as high as 100% for practically all exposure pathways, all infants' age-group and all enteric pathogens assessed. Other QMRA studies had actually found similarly high annual enteric infection risks for children. In Ghana, the annual risk of *E. coli* 0157:H7 and *Campylobacter* infection was also 100% from drinking household stored water or public tap water[230], and similar results were found in Uganda[256]. The median annual risk of enteric infection with *Giardia duodenalis* and *Shigella* from infants ingesting domestic soil found in Mozambique was slightly lower than what estimated for Banswara, ranging between 57-71% and 29-40%, respectively, however, these differences could be attributable to different pathogen infectivity[236]. The 2-year accumulated enteric infection risk estimates from our study indicate that prioritising *only* the most critical pathways will be most likely insufficient to prevent enteric infections in infants during their first 1000 days, given the ubiquitous high-level risks from multiple exposure pathways. As mentioned previously, the first two years of life are a well-recognised critical window for child development, where repeated enteric infections that impair gut function may have long-lasting consequences[8]. Therefore, our 2-year accumulated infection risk estimates suggest that drastic reductions in the overall faecal contamination levels of the infant's environment will need to be achieved to observe a significant reduction in enteric infections. For instance, the sensitivity analysis showed that 4 to 5 logarithmic reductions in the water *E. coli* counts would be required before meeting international guidelines of "acceptable" risk from drinking water[244].

6.5.2.2 Enteric infection risks across 3 domestic scenarios

The analysis of different domestic water source scenarios revealed that the scenario where families resorted to unimproved open wells for domestic water (Scenario 3) posed the highest risk of enteric infection to infants from drinking household stored water, and Scenario 1 where families used an electrical borewell as a source of domestic water, posed the lowest. Unfortunately, electrical borewells remained a private commodity still unaffordable for most. Across our study households, electrical borewells were mainly owned by the few non-tribal caste families (Section 5.4.2.4). Open wells were generally only used as a last resort when public groundwater sources were insufficient. Based on the household observations conducted, Scenario 2 was the most common scenario across the study villages, since 71% of households used hand-pumps as their only source of drinking water, with scenarios 1 and 3 being less common. However, increasing water scarcity pressures due to increased water needs for industrialization, population and agricultural growth[177] may lead to an increase of families in Scenario 3 that must resort to unimproved open wells temporarily. The need for groundwater development plans that meet the current demands may become increasingly pressing, particularly in the Kushalgarh block, which has been categorised under the Ministry of Water Resources as semi-critical[177].

Although monitoring of diarrhoeal prevalence in rural Banswara indicates that only 3% of children have diarrhoeal symptoms at one point in time[188], increasing evidence suggests that asymptomatic enteric infections may be nearly universal in some settings. For instance, the MAL-ED study found that enteropathogenic infection was common (65%) in non-diarrhoeal stool samples[257]. In Kolkata, India, 46% of the stool samples from children under-5 were positive for *Campylobacter* spp., and 58% for Enteroaggregative *E. coli*[77]. Similarly, the GEMS study found that up to 72% of children under-5 in South Asia and sub-Saharan Africa were infected with multiple enteropathogens despite not showing diarrhoeal symptoms[54]. It has been suggested that the high prevalence of faecal environmental contamination levels in low-resource settings may be the reason behind the limited success of current WASH interventions aiming to reduce diarrhoeal rates[22,258]. While national and international WASH development monitoring indicators report satisfactory statistics, such as the fact that 92% of rural households in Banswara have access to improved drinking water sources (as defined by the WHO)[19] or that it is declared open-defecation free[259], it is clear that these do not ensure microbiological safety in the domestic environment for infants during their critical period for development.

Results from this study make it evident that addressing the major contamination pathways *only* may not be enough to observe a change in child enteric disease burden if multiple other remnant pathways still pose such high infection risks. Tackling infants' multiple enteric infection risks will likely require infant-focused efforts across ministries and departments[29] to improve the hygiene of the domestic environments overall.

6.5.3 Strengths and limitations

The QMRA framework for risk analysis conducted in this chapter presents several strengths: it is an evidence-based, transparent, and objective approach that provides quantifiable conclusions that allow to compare and distinguish infection risks from different environmental exposures. The use of stochastic methods allowed to propagate the variability and uncertainty from the model parameters to capture the range of potential expected risks. However, the analysis was constrained by several limitations that need to be taken into account to interpret the findings.

First, context-specific ingestion data was not collected and thus the analysis relied on parameters from the literature. The use of assumptions from the literature for the intake values may have over or underestimated the risk of infants who ingest higher or lower volumes of water, soil and hand residue than what was assumed. However, this limitation is well recognised in risk assessment frameworks, that often need to rely on literature-based assumptions[200]. In addition, a sensitivity analysis of the intake values extracted from the literature revealed fairly robust results for soil ingestion and hand-to-mouth contacts, while changes in water intake volumes were seen to have a larger impact on risk estimates. Furthermore, the use of literature values is consistent with the screening-level purpose of this analysis, where an initial comparison of multiple exposure pathways was the objective of this chapter, enabling the identification of potential priority pathways and informing the need for further in-depth risk analyses of these.

Second, the analysis was limited by the reliance of *E. coli* as an indicator of faecal contamination and on the *E. coli* to pathogen ratios. However, *E. coli* to pathogen ratios have been widely used in other QMRA studies[230,260,261], and in the absence of pathogen surveillance, they have been accepted under the QMRA framework[200].

Overall, the use of assumptions and the inherent uncertainties associated with quantifying exposures are some of the biggest limitations for the quantification of the absolute infection risk in this chapter's analysis. Nevertheless, given that the focus of this analysis largely laid on the evaluation of relative risks between different exposure pathways and scenarios to identify the most critical pathways that limitation was less relevant. Thus, while the limitations of this chapter's analysis may affect the accuracy of the absolute risk estimates, the relative evaluation of risk trade-offs between different exposure pathways and the relative comparison between scenarios to determine the prioritisation of risk control measures, remains valid. Future work addressing this study's limitations could prove useful to improve risk estimates.

6.5.4 Conclusion

In a low-resource, rural, tribal setting in India, this study offers evidence that faecal contamination is high and widespread across the village and household environments, and that infants in these villages face a high daily risk of enteric infection from drinking water (from any of the different domestic water sources available in the setting), from occasionally bathing at the local streams, from directly ingesting soil while playing and crawling in their earthen household courtyards, and from the constant hand-mouthing contacts with their own hands or their caregiver's hands. While targeted efforts to reduce infants' faecal exposures should start by addressing infants' soil ingestion and hand-mouthing, since those were the exposure pathways that posed the highest daily risks of enteric infection, it is clear that transformative changes that reduce the overall widespread faecal contamination levels across the infant's environment are needed, as infants in rural Banswara persistently faced multiple enteric infection risks during their first two years of life, a critical period for development when constant exposures to faecal pathogens may entail long-lasting health consequences.

7 Chapter 7. Barriers to rural healthcare services

7.1 Chapter overview

The previous chapters of this thesis explored the risk factors and pathways to infant's enteric infections in rural Banswara: Chapter 5 looked at the conceptual pathways and interlinked network of physical-environmental, socio-cultural, socio-economic, and institutional factors contributing to infants' enteric infections. Chapter 6 explored the pathogenic loads in the environment and quantified the infection risks from different pathogen exposure pathways. To continue with the thesis' aim to comprehensively understand why and how infants in the study villages are contracting enteric infections, in this chapter I investigate what is currently being done to attempt to address enteric infection risks in terms of public health efforts, and the existing barriers to these efforts. The background chapter of this thesis introduced the key public health schemes that are currently in place to address the child health needs of rural areas in India (Section 1.6). The responsibilities of frontline health workers (ANMs, AWWs and ASHAs) in providing child healthcare services, including WASH promotion and education on infant enteric infection prevention practices, were also presented[262]. In this thesis chapter, I set to understand the existing barriers that hinder the delivery and uptake of WASH promotion and infant infection prevention services. Hence, this chapter addresses the third objective of this thesis:

> **Objective 3. To identify key barriers for the delivery and uptake of rural child healthcare services, particularly WASH promotion and infant enteric infection prevention services.**

Identifying the gaps in the public health programmes delivering services to improve child hygiene, nutrition, and growth outcomes in rural India, was already crucial when this PhD study was set up in 2018, given the national commitment and set targets to achieve significant stunting reductions under the POSHAN Mission[34], which had just been launched. However, throughout the course of the PhD, the additional shock of the COVID-19 pandemic has introduced delays and regression for the stunting reduction progress. Since the pandemic, the child stunting reduction trends have been observed to stagnate and even reverse in some states, further deviating from the marked progress targets[15,36]. Understanding the current bottlenecks in child hygiene and infection prevention services has now become even more urgent if the set development targets for child stunting are to be met. First, in this chapter, I explain how the data collected from key informant interviews with frontline health workers and focus group discussions with mothers of infants during fieldwork was analysed. I then present and discuss the findings in light of the current situation, offering some concluding remarks.

7.2 Data harnessed

Following the data collection fieldwork stage in the case study villages in Banswara, findings from this chapter are based on the analysis of the qualitative and observational data collected during the 12 KII with frontline health workers (ASHAs and ANMs) across the nine study villages, 4 FGDs with a total 27 mothers of infants, semi-structured observations of 4 community health events, and complemented with the information from unstructured observations and conversations with caregivers during the 42 household visits (Table 7-1). The FGDs, community health event observations, and household visits were conducted across 4 of the 9 study villages, those with which we, the fieldwork researchers, had developed the strongest community rapport. Further details on the sampling and recruitment process of the different data collection methods were provided in Sections 4.4.2, 4.4.3, 4.4.4, and 4.4.5.

Table 7-1 Data harnessed for analysis in this chapter

Data collection methods	Number of events
KII with ASHAs	10
KII with ANMs	2
FGD with mothers of young children	4
Unstructured conversations with caregivers of infants during household visits	42
VHND observations	4

7.3 Data analysis

7.3.1 Data processing

All KII and FGDs were audio-recorded, transcribed verbatim and translated into English. The English transcripts were imported into the NVivo software. Textual data from field memos containing descriptive and reflective notes that I collected during the 4 community health event observations and the unstructured conversations with caregivers during the 42 household visits, were transcribed from the paper field notes to text files, and then imported into NVivo for analysis. Thus, qualitative data from interview transcripts and from field memos were brought together into NVivo for analysis to provide a richer and more complete pool of information to perform the analysis from.

7.3.2 Thematic analysis

The thematic analysis was guided by this chapter's objective: to identify barriers for the delivery and uptake of current rural child healthcare services, with a focus on WASH promotion and enteric infection prevention services. An inductive approach for analysis of the data was adopted, where social phenomena and core themes were derived from the data[193]. The first analysis stages involved a process of familiarisation and search of repeating ideas across the data where all textual information was repeatedly read through. Following, statements that were perceived to contain relevant information describing potential barriers and difficulties for the delivery or uptake of health services were coded using preliminary codes. Figure 7-1 shows an example of the preliminary codes that were extracted from the textual data using NVivo. Preliminary codes were then conceptually pooled into appropriate categories forming analytical themes. After an iterative process of discussion and validation with the experienced social researcher and Indian public health policy expert in the study team (RD), the final themes were defined. Lastly, themes were organised under two higher-level core themes: 1-Barriers to the delivery of services, and 2-Barriers to the uptake of health services. A final review of the original raw data was carried out to ensure reliability and fidelity of the analytical categories and interpretation.

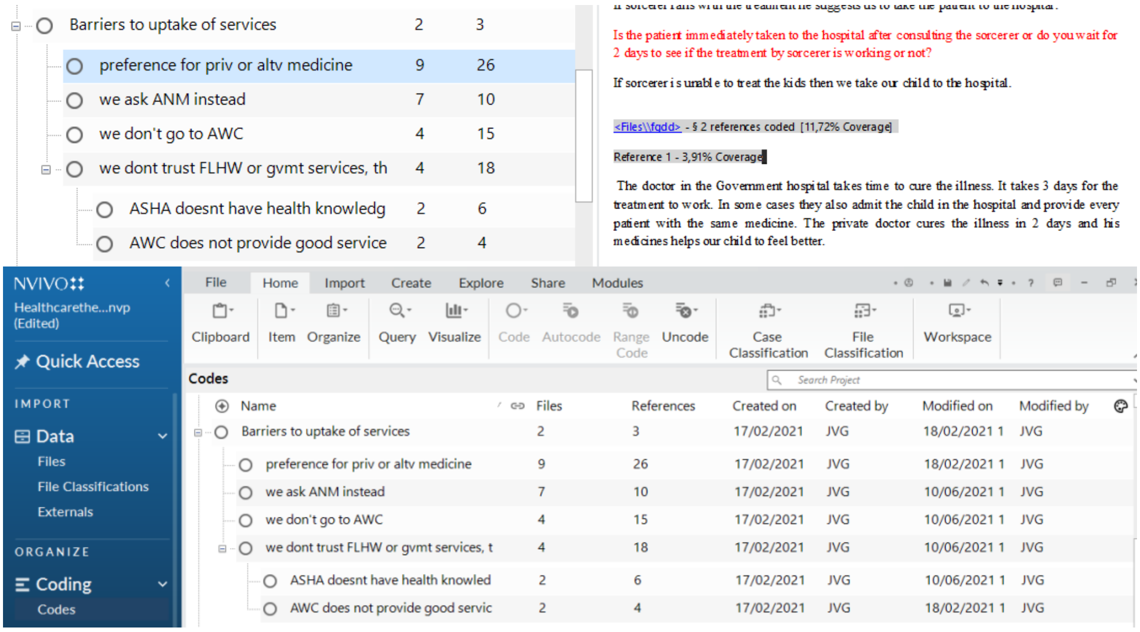


Figure 7-1 Example of preliminary coding of qualitative data in the NVivo Software

7.4 Results

Thematic analysis uncovered two core themes hindering current WASH promotion and infant infection risk awareness services. ASHAs prioritising their link-worker roles over their health activist roles was identified as the core theme under barriers constraining the delivery of health

& hygiene promotion services. On the other hand, caregivers lacking trust in the public child health services and having a preference for private or tribal healthcare options was identified as the core theme under barriers constraining the uptake of such services. Several sub-themes were found that elaborated and substantiated the concepts captured by the two core themes (Table 7-2).

These results, along with the participant's quotes presented below, were published at the Indian Pediatrics Journal[263], but permission was obtained to reproduce them in this thesis.

Table 7-2 Emerging themes constraining WASH promotion and infant diarrhoea prevention services

	Barriers to services' delivery	**Barriers to services' uptake**
Core themes	ASHAs prioritise their link-worker roles over their health activist roles	Caregivers lack trust in public child health services and have a preference for private or tribal healthcare options
Sub-themes	ASHAs have… (1) **Multiple responsibilities** compel ASHAs to prioritise some tasks over others. (2) **Limited community engagement ability** by ASHAs, who struggle to engage communities in social change, despite efforts to "educate" people on health and hygiene. (3) **Lack of clarity on how to use the resources available for health and WASH promotion during VHND/VHNSC,** as ASHA's are unclear on how to use funds for village health planning or health and hygiene awareness activities. (4) **Lack of monitoring and accountability** for ASHA's health activist roles including health promotion activities.	Caregivers have… (1) **Preference for private healthcare providers** since they are thought to provide quicker, more easily accessible, and more effective treatment than government facilities, despite sometimes being unlicensed and more expensive. (2) **Tribal traditional beliefs on illness and health** play an important role in healthcare-seeking behaviours among tribal communities where myths, superstitions and spiritual healers are still widely present. (3) **Lack of trust in ASHAs health knowledge** due to ASHA's lack of higher education or formal health training. (4) **Locational factors hindering access to ASHAs** due to the scattered geography and lack of transport across tribal villages.

7.4.1 Health promotion and prevention service delivery barriers

Several aspects were found to hinder the delivery of WASH promotion and infection risk awareness by ASHAs.

7.4.1.1 Theme: ASHA's multiple responsibilities

ASHAs accounts of their own roles and responsibilities emphasised the multiplicity of activities they were engaged in, compelling them to prioritise some tasks over others. From the range of responsibilities, ASHAs particularly highlighted that most of their time was spent conducting home visits to pregnant and lactating mothers, assisting in the organisation of Village Health and Nutrition Day (VHND) events, and making sure that all required infants attended their immunisation and growth monitoring appointments. On the contrary, ASHAs seldomly mentioned their "health activist" roles or performing activities to raise awareness on WASH practices and infant infection risks.

> *"We were trained to do the registration of every pregnant lady from 3 months and provide accurate vaccination to them (…), to get the regular weight checks done of women and teach them how to breastfeed. (…) I have an array of works starting from reporting, visiting 10 houses [of pregnant women and newborns], checking the growth of newborn children, seeing if the child is having diarrhoea, keeping tabs on their weight". ASHA, Ghatol.*

7.4.1.2 Theme: ASHA's limited community engagement ability

ASHAs acknowledged their responsibility to provide health education to raise awareness on safe WASH practices and infant infection risks. They recognised and pointed out numerous poor hygiene habits and infection risks to infants present across the village environments, which they reported informing caregivers and the wider community about, either during home visits or VHND events. However, ASHAs unanimously reported struggling to provide health and hygiene advice. For instance, ASHAs claimed that sometimes villagers do not understand, do not listen, or do not believe and reject the health and hygiene advice they provide. Engaging communities has been defined as the power to tap on social networks to build groups where there is meaningful participation that leads to empowered decision-making on the community's own agenda for change[264]. It was apparent that despite ASHAs efforts to raise awareness about safe WASH practices and infant infection risks, ASHAs ability to engage communities to stir social change towards safer child hygiene practices was limited.

On the other hand, a contrasting perspective was offered by mothers and caregivers of infants, that claimed often not being aware of some unsafe hygiene habits and infant infection risks and not being informed about them by ASHAs or doctors, evidencing the gap between health workers and caregivers in health education. Table 7-3 provides representative quotes that substantiate the fact ASHAs struggled to engage communities for change towards healthy and hygienic habits.

Table 7-3 Representative quotes for the theme "ASHAs limited community engagement ability"

Code	Representative quote

People do not understand hygiene risks	*"The educated crowd understands but the uneducated ones just nod their heads. (…) I don't know if they really understand [about proper hygiene habits] as when we say they often nod head and say yes to everything"* [ASHA, Ghatol]
People do not listen to the hygiene and health advice	*"We were trained to educate about how to keep the child neat and tidy, proper feeding habits and proper bathroom habits. (…) We tell about vomiting, diarrhoea and educate about the benefits of the ORS solution (…) Some villagers follow [advice], and some others don't follow".* [ASHA, Kushalgarh]
People do not believe the hygiene and health advice	*"We tell [that drinking river water is not good] but people reply by saying that we have been drinking this water from years and nothing has or will happen. I have even spoken to my family about it, that this is the same water from where an animal drinks and if we consume then we are bound to fall ill. (…) They drink river water without understanding the harm".* [ASHA, Ghatol]
People reject hygiene and health advice	*"I sometimes give advice, support and suggestion but some people from the community tell me bad words. Some people say that the Anganwadi centre also belongs to them and they also want to use it for personal functions or meetings".* [ANM, Kushalgarh]
People do not know or receive information on hygiene and health risks	*"We don't know why [child gets diarrhoea]. On consulting the doctor, he provides treatment to our kids. He gives us medicine and we pay them. He assures us that our child will heal. He doesn't brief us on the cause of illness. If the treatment doesn't work, we take our child back to the doctor. (…). We just came to know that water can also be contaminated like this. Whenever kids ask for water, we put our hands inside the pot and fetch it to them we didn't know that we were polluting our drinking water".* [Mother, Kushalgarh]

7.4.1.3 Theme: ASHA's lack of clarity on how to use the resources available for health and WASH promotion during VHND & VHNSC

Observations of ASHAs activities at VHND events revealed that there was a lack of clarity on how to raise awareness on the health determinants such as WASH and infection risks. VHND events, the monthly village-level meetings designated for the delivery of child health education, including child nutrition, WASH promotion, were observed to focus exclusively on other child health services such as immunizations. VHND events were observed to be poorly attended, with only 2-4 mothers observed at a time in each observed event. Mothers and infants were observed to briefly visit the Anganwadi centres on VHND, to receive the child vaccinations and child growth monitoring services. However, no further activities or discussions on child health, sanitation & hygiene, or nutrition were observed to happen during the VHND. During the VHND events observed, ASHAs appeared to be mainly in charge of providing logistical support fetching mothers from their houses when they needed to be appointed. When asked, ASHAs were unclear on what activities to conduct at the village level to raise awareness on WASH practices and other health determinants. When asked about the activities conducted under the Village Health, Sanitation & Nutrition Committee (VHSNC), ASHAs were also unclear on how to use budget funds intended for these. There was no clarity on how to utilise the village WASH and development funds, neither there was clarity on what the funds available were since these were managed by the Panchayat and given to frontline health workers intermittently and sometimes with varying amounts. Moreover, awareness of the existence or purpose of VHNSC, the committees in charge of identifying community health needs and utilising public funds for the WASH and village development, was low. Some ASHAs reported that the VHNSC only existed "on paper records", but that no actual meetings or community actions were being carried out (Table 7-4).

Table 7-4 Representative quotes for the theme "ASHAs lack of clarity and focus on health and WASH promotion during VHND & VHNSC

Representative quotes
"We don't know what the budget is [for the VHND], 5000 rupees a year are delivered, of which 200 are given to us to work around the Anganwadi. Earlier we received some money we bought some chairs, and we need to buy some more articles".[ASHA, Ghatol]
"We have money in our bank accounts, but we have not yet used it. 5000 rupees were deposited in our account which is unused as of now. If money is given to the [VHSNC] committee or to us we may use but if money is given to the village panchayat then it won't be used" [ASHA, Ghatol]
"The VHNSC Committee is only on the paper records, because no one comes. The village Sarpanch leaves everything on us" [ASHA, Ghatol]
" [Interviewer] Have you heard of the VHNSC, is there a committee for this here? No, no such thing is here"[ASHA, Ghatol]

7.4.1.4 Theme: Lack of monitoring and accountability for ASHA's health activist roles

Daily visits to the case study villages revealed that many Anganwadi centres often remained closed during their opening hours and their attendance of pre-school children was low. In more than one instance, neighbours from some of the villages reported on ASHAs absenteeism and Anganwadi centres remaining closed for long periods of time. Contrary to the monitoring systems in place to keep track of births and institutional deliveries, child vaccination schedules, pre-and post-natal home visits, which were recorded and monitored by ASHA supervisors and other government functionaries, ASHA's health activist services to raise awareness on child health, sanitation, and hygiene had no formal systems of monitoring and evaluation. In one VHND event, it was observed that records of the VHND event were populated *a posteriori* with fabricated accounts of health awareness discussions after mothers had added their signature to record their attendance. The acceptance of inaccurate "paper records", as well as the lack of formal monitoring systems for the ASHAs health awareness services facilitated non-compliance of ASHAs to carry out their health activist role.

In summary, ASHAs appeared to place an unequal emphasis on their link-worker role (which involved providing logistical support to healthcare systems by ensuring child vaccination, and health support around births) in detriment to their health activist role (which involved raising awareness on health, WASH practices, and infant infection risks). Their link-worker role involves more mechanistic tasks such as carrying out antenatal and postnatal checks, accompanying mothers for institutional birth deliveries, and helping to ensure child vaccinations. Tasks that are, in addition, further incentivised by monetary compensations based on performance. Instead, the ASHAs' health activist role involves delivering more intricate and elaborate activities to successfully raise awareness and engage communities towards healthy habits, safe WASH practices and infant infection risk prevention, which ASHAs struggled more to do. Overall, ASHAs with multiple responsibilities, a lack of clarity and ability to perform health activism and raise awareness on the health and hygiene risks, and a lack of monitoring and accountability of such activities hindered the delivery of WASH promotion and infant infection risk awareness services by them.

7.4.2 Health promotion and prevention service uptake barriers

In addition to factors constraining the delivery of WASH promotion and infant infection risk awareness services, which mostly related to ASHAs, factors relating to the beneficiaries of the services, the caregivers of infants, were also captured. That is, factors constraining the uptake of child health services in the rural study villages.

7.4.2.1 Theme: Preference for private healthcare providers

Parents recurrently reported having a preference for private healthcare providers, even with the added expenditures that they involved, rather than public and government healthcare services in the instance of needing healthcare or advice relating to children's infections. Despite the fact that ASHAs were envisaged to be the first port of call for infant health ailments in rural villages, and they were equipped with first-aid treatment such as ORS and prepared to monitor diarrhoeal events and refer cases when needed, most parents did not seek her help. Reasons for this reported by parents were that ASHAs often did not have the necessary medication or knowledge, and that when referred to government hospitals they would not provide the most effective treatment. Instead, when their children had symptoms such as diarrhoea, parents most commonly sought treatment from what were locally known as "Bengali doctors". "Bengali doctors", as referred to locally, were men who provided medical treatment despite not being registered medical doctors or not having a legal medical license. Despite being more expensive, "Bengali doctors" were perceived to provide better, quicker, and more effective treatment than public hospitals, and they were also preferred due to the easier access, as they were available across the rural areas, had more flexible service hours, and patients were not required to provide their paperwork and vaccination cards, which was described by some caregivers as an inconvenient hassle in public healthcare facilities. "Bengali doctors" were perceived to provide higher-quality treatment due to the fact that they provided treatments via drips, rather than treatments such as pills, syrups, ORS powder, or diets, which were more often prescribed in government healthcare facilities, and perceived as less effective. This medicalised idea of what high-quality treatment entailed, hindered the uptake of public child health services (Table 7-5).

Table 7-5 Representative quotes for the theme "Preference for private healthcare providers"

Code	Representative quotes
Private healthcare is thought to be quicker and better	*"The doctor in the Government hospital takes time to cure the illness. It takes 3 days for the treatment to work. (…) the private doctor cures the illness in 2 days and his medicines helps our child to feel better. In private hospital you just have to pay, and they treat you, no hassle".* [Mother]
There is a medicalised idea of high-quality treatment	*"[People] at times they go to the Bengali doctor only because he gives saline drip (…). The Bengali doctor prescribes a heavy dose of medicine which has resulted in fatal deaths".* [ASHA]

7.4.2.2 Theme: Traditional tribal beliefs on illness and health

In addition to "Bengali doctors", traditional tribal beliefs on illness and health also played a role in the healthcare-seeking behaviours of infant caregivers. Tribal beliefs among *Bhils* (the tribal ethnic group present in the Banswara district) were dominated by spirits and deities thought to be responsible for much of the diseases[180]. According to these tribal beliefs, young children are particularly vulnerable to the "evil eye" from this supernatural forces[265], and therefore caregivers followed a series of practices to protect and appease infants from them. For instance, infants were often seen to be wearing a black thread on their neck and have their eyes smeared in black, which was thought to protect them from the evil spirits[265]. The belief that infants and young children were particularly vulnerable prompted parents to take swift action when they detected symptoms such as child diarrhoea, leading to a quick healthcare-seeking response. This contrasted to the healthcare-seeking action taken in response to adult disease, for which home remedies were sometimes reported to be thought of as sufficient to deal with diarrhoeal symptoms.

> *"Interviewer: What is your line of action when a child suffers from diarrhoea?*
>
> *Mothers: We take our child to the hospital.*
>
> *Interviewer: Do you take your child straight away to the doctor or do you first do something else?*
>
> *Mothers: When the child is very young we prefer to take them to the doctor (…) We take our child immediately to the doctor with the fear of it worsening". -Mothers, Kushalgarh*

> *"Interviewer: What measures do you take when a child suffers from diarrhoea?*
>
> *Mothers: We take our child immediately to the hospital for medication. If it affects an adult then we feed him butter milk [fermented dairy drink], but in the case of younger child we have to treat them with medicines, so we take them to the hospital straight away"- Mothers, Ghatol*

Upon seeing disease symptoms in infants, in addition to frontline health workers, public hospitals or private healthcare providers such as those provided by "Bengali doctors", caregivers also sometimes sought help from spiritual healers (known as *bhopas*), which were still prevalent across the tribal communities, providing healing rituals for different child afflictions. Group discussions with mothers revealed that *bhopas* were still commonly sought for child health ailments in the study villages. For instance, at a group discussion, one mother reported that "*everyone present here has visited the bhopa*". While the timing and type of child illnesses for visiting *bhopas* varied across parents' reports, there seemed to be agreement amongst parents that diarrhoea symptoms required a visit to either a public or a private hospital, and that it was not treatable by spiritual healings.

> *"Mothers: Yes, we visit the bhopa [spiritual healer]. First, we visit the bhopa and after that, if it doesn't work, we take our child to the hospital for consultation. Everyone present here have visited the bhopa. We see the*

bhopa in the event of chicken-pox or if a child unnecessarily cries while going to someone's place. We then assume that the child has been attacked by some negative energy.

Interviewer: Where do you take the child if he suffers from diarrhoea?

Mothers: Then we consult the doctor"- Mothers, Ghatol

"Herbs don't work against diarrhoea. No one believes in such things anymore. Those who trust these things end up losing their child after roaming around for several days. (…) When medicines don't work, we take our child to the bhopa. If the bhopa fails with the treatment, he then suggests us to take the patient to the hospital. (…) But we only take our child there (to the bhopa) while he is suffering from fever or vomiting, but not during diarrhoea"- Mothers, Kushalgarh

"We visit them [bhopas] for our child. We see them in case of fever, injury, etc. He reads mantras and carries out incantations. (…) But not for diarrhoea, he cures only fevers."- Mothers, Kushalgarh

Among all the healthcare options (i.e., frontline health workers like ASHAs, private healthcare providers either registered or not like Bengali doctors, or government healthcare facilities such as sub-health centres or larger district hospitals), reports on the parents' preferences were mixed. It appeared that caregivers sought child healthcare from the different available alternatives depending on preference based on prior experiences or social norms, based on the types of illness, or based on convenience aspects such as distance to the place or links with the doctor, health worker or healer. As expressed by a mother: "*From whichever doctor's treatment our child gets relieved, we visit him*"- Mother, Ghatol. However, ASHA's role as a first line advisor and referral for child health issues remained limited as parents seldomly reported turning to her in such instances.

7.4.2.3 Theme: Lack of trust in ASHAs health knowledge

Parents of infants seldomly sought ASHA's support when their children fell ill or showed any symptoms of enteric infections such as diarrhoea, arguing that they did not see the point as they did not trust that ASHAs were knowledgeable enough to provide child health advice or first aid treatment (i.e., ORS). Parents pointed out the fact that ASHAs were local women that, like most of them, had not received higher education, and that the relatively short training modules that ASHAs had received were not thought to confer them enough knowledge or skills on child health to be trusted as the first port of call for child health concerns. On the contrary, parents did recognise ASHA's link-worker roles, and they mostly appreciated ASHAs support during childbirth and for child immunisation, but their role as health advocates was not recognised. Consistent with this attitudes that were captured from caregivers, ASHAs reported struggling to give advice on infant infection prevention and monitor and keep records on children's diarrhoeal cases, as it was asked of them by their supervisors, since caregivers seldomly reached out to them in those cases.

> *"[Diarrhoea cases] do not come to us, they [parents] rather go to the ANM sister directly or hospital. Rarely someone comes, when they do we give ORS to them". ASHA, Ghatol*

> *"We keep notes of the number of cases of diarrhoea and we have to fill a form, but if it counts to 0 then we are scolded by Sir". ASHA, Ghatol*

7.4.2.4 Theme: Locational factors hindering access to ASHAs

As it was previously explained, the rural tribal villages of Banswara are characterised by their hilly and scattered geography, with groups of households generally clustered in *phalas.* Even though ASHAs serve populations of 800-1000[159] in these tribal areas, the lack of transport means and limited mobility across the villages impacted the accessibility to ASHAs. For instance, one ASHA mentioned that the 30-minute walk to the Anganwadi centre made it difficult for her to attend the Anganwadi daily and juggle her domestic and agricultural workload with her ASHA responsibilities. It was observed that the place of residence of the ASHA within each village strongly influenced whether families benefited from her support. For instance, the caregivers of a family living within the same *phala* as the ASHA reported often reaching out for her advice on child health or for the provision of essential medicines like ORS and paracetamol etc. Families within each *phala* generally shared many domestic living aspects, including childcare. By contrast, parents who lived relatively far from the ASHAs domicile or the Anganwadi centre from the village often reported not having regular contact with either the ASHA nor the AWW and only interacting with them when it was required such as at the time of child vaccination.

> *"ASHA only provided support during delivery time and for injections. She does not provide support for diarrhoea or child health. People go straight to hospital for that. She also lives far away, so even if she has some ORS treatment available, people don't bother and also she doesn't provide support for that". Mother, Kushalgarh*

In addition to the problem of difficult access to ASHAs within each village due to the scattered nature of the tribal villages, it was observed that in some cases ASHAs did not reside in the villages they served, which defeated the point of them acting as a first port of call for rural villages. The reason that some ASHAs had been selected from outside of the pool of local village residents was that some ASHAs had been selected by the Panchayat leaders thanks to their political connections, despite not being female residents and active community members. In the instances in which ASHAs had been selected thanks to their political favouritism, parents of infants reported not finding ASHAs commonly available, nor seeking or receiving support from them for child health ailments.

7.5 Discussion and conclusion

7.5.1 Interpretation of findings

The thematic results presented in this chapter uncovered several factors hindering the delivery and uptake of rural child health services in the study villages, particularly regarding the WASH promotion and child infection risk awareness advice provided by ASHAs.

7.5.1.1 Barriers to the delivery of child health services by ASHAs

ASHAs placed an unequal emphasis on their link-worker roles (including logistical support to mothers during childbirth, or child immunisation programmes) to the detriment of their health activist roles (including promotion of healthy habits and awareness on the health determinants), hence impairing the delivery of WASH promotion and infection risks awareness. ASHA's multiple responsibilities, their limited ability to engage communities in health behaviours, the lack of clear guidelines on how to deliver health activism activities using the current resources and platforms in place, the lack of monitoring and accountability systems for such activities, and the lack of specific incentives for ASHAs to deliver these, further impaired the successful delivery of activities that promote and raise awareness on sanitation, hygiene and infection risks for infants.

ASHAs focus on their link-worker role versus their health activist role had also been captured in previous studies. For instance, Kawade *et al.*, interestingly noticed that ASHAs in Maharashtra consistently referred to themselves as "ASHA workers", instead of health activists as their name indicates, which Kawade interpreted as a reflection of how they perceived their ASHA identities as link-workers rather than health activists[262].

It has been suggested that ASHAs lag in their health activism roles is largely due to the poor training on counselling and health promotion skills that ASHAs receive[266]. In accordance with this, a report evaluating the ASHA programme in Banswara in 2011[267] stressed the fact that, in the Banswara district in particular, ASHAs' roles as community mobilisers were "extremely weak". It appears that block-level officials in Banswara did not believe ASHAs' health activist role needed to be prioritised either, arguing that ASHAs' role was *"primarily as a link worker"* and that "*she has no time to devote to community mobilisation".* It is likely that the block-level officials take on the ASHAs roles may have influenced the training they received, partially explaining the particular lack of community engagement and mobilisation ability captured in ASHAs in Banswara district[267], as it has been seen to happen in other states[268].

Nevertheless, findings from this study differed from those of another study in the same state of Rajasthan[266], which found that ASHAs often had conflicts and unfriendly relationships with their co-workers ANMs and AWW, hindering the delivery of joint services. Instead, in this study villages, ASHAs were observed to provide support to ANMs during VHNDs and have a cordial relationship.

7.5.1.2 Barriers to the uptake of child health services by caregivers of infants

While several studies had explored factors affecting ASHAs performance[269], fewer studies had contrasted them with the perspectives of the service beneficiaries: mainly the mothers, infants, and their caregivers, particularly in a tribal setting. The caregivers' perspectives revealed additional barriers to the uptake of the ASHA's services on sanitation, hygiene, and infection risk awareness.

Caregivers of infants in the tribal study villages did not acknowledge ASHAs' role in providing information, advice, or first-aid for child health-related issues, as they did not trust that she was knowledgeable enough on child health. A study in a tribal area in the nearby state of Maharashtra similarly found that while most beneficiaries were satisfied with ASHAs antenatal, postnatal, delivery time, child immunisations and family planning support services, but only 10% of the beneficiaries reported seeking ASHAs support or advice for minor illnesses as they did not consider her qualified on health knowledge[270].

Additionally, aspects particular of the tribal setting such as the hilly and scattered distribution of the villages, and the traditional tribal beliefs about health and disease also hindered the uptake of ASHAs' services, as similarly found in another study in the same Rajasthan state that compared tribal and non-tribal villages[266]. While this other study similarly noted that ASHAs that were non-residents of the village they served lacked an involvement and rapport with the villagers[266], how the specific location of the ASHAs domicile in the different *phalas* within a village may affect the support beneficiaries receive had not been highlighted yet.

Regardless of the perceptions and access to ASHAs, opportunities to intervene through public health functionaries and facilities competed with private healthcare providers such as Bengali doctors, or spiritual healers such as *Bhopas,* available throughout the study villages. The long-established cultural beliefs on tribal health and disease still had a profound impact on the *Bhil*'s healthcare seeking behaviours. For instance, a study on the *Bhil*'s perceptions of illness revealed that, according to tribal beliefs, physical factors such as weather events, supernatural forces such as past sins or breach of taboos, and lifestyle habits such as diet, unclean water, eating hot or cold food, or lax/casual/promiscuous sexual practices were all attributed to being potential causes of diseases[265].

While these traditional beliefs may be hindering the caregiver's perception of infection risks by shifting health concerns from poor sanitation and hygiene to other perceived causes of disease, parents of infants in this study appeared to agree that tribal healing practices only worked to an extent and that *bhopas* were not able to heal all child health ailments. Enteric disease symptoms such as diarrhoeas were regarded with concern. Hence, in the study villages, the different healthcare options (public, private and traditional healthcare practices) co-existed.

7.5.2 Implications for policy and practice

7.5.2.1 Implications for the ASHA programme

Results in this chapter highlight the ASHAs lack of emphasis on their health activist roles, and how this may particularly impair the delivery of WASH promotion and infant infection risk awareness services across tribal villages. Since poor WASH and enteric diseases are increasingly recognised as primary causal factors of child stunting[143], and ASHAs are the main nationwide public functionary that delivers these type of services at the village level, these findings could offer some explanation as to why stunting reduction rates in children in India are stagnating[34].

Based on results from this study and lessons learnt from other published studies[262,266], it is clear that ASHA's health activist roles to engage communities on health promotion is largely neglected in relation to the ASHAs link-worker responsibilities. The ASHA programme needs to reinforce this crucial aspect that is core to the programme, as the name itself indicates (Accredited Social "Health Activist")[262]. Reinforcements of the ASHAs' health activist role may need to happen not only among ASHAs but also among the block and district-level management and governance spheres, given their views on prioritising link-worker over health activist tasks[267]. Conducting health promotion and community engagement activities that successfully mobilise communities towards social and behaviour change is no easy task, often more complex to implement than other link-worker role tasks such as keeping records on children's growth[271].

However, improving ASHAs training and role clarity on how to conduct health activism and WASH promotion is needed. Frameworks[116,218,272] and evidence-based approaches[273,274] to successful health promotion & hygiene behaviour change are increasingly recognised, but they necessarily need to be backed by a strong policy framework[271]. Putting monitoring and evaluation systems in place to monitor health promotion activities and the provision of monetary incentives to ASHAs for these activities will also be required to revalorise and upgrade ASHAs health activist's role to par with her other responsibilities.

Additionally, ASHAs serving tribal communities may require particular considerations. The tribal communities still strongly rely on local unlicensed doctors (*Bengali doctors*) and spiritual healers (*bhopas*). The opportunity for ASHAs and other government frontline health workers to work together with local health practitioners that already have the trust of the community in these tribal areas needs to be better acknowledged.

In addition, revamping the recognition given to ASHAs health knowledge, for instance, by providing certificates of ASHAs health module training completions could prove useful to improve ASHA's assertiveness and the community's trust in ASHA's health advice[270]. Examples could be taken from the successful *Mitanin Programme* first introduced in Chhattisgarh state, a community-based programme that specifically focused on the empowerment of local females as "agents of social change", who delivered intensive behaviour change activities for the promotion of safe child feeding practices[273].

7.5.2.2 Implications for the wider health system in India

Findings and reflections from this analysis suggest there may be a larger-scale mismatch between India's nationwide policy shifts, which are seeing increased attention and funds diverted towards WASH and child stunting determinants, and how they have translated into shifting village-level realities.

For instance, while the central government has emphasised WASH and child stunting efforts in the recent years under flagship programmes such as the *Swachh Bharat* Mission or the POSHAN Mission, a similar emphasis was not seen among block-level officials or village-level frontline health workers' realities in Banswara. This suggests that there is a disconnect between the policy-level guidelines for WASH and child health and nutrition promotion and the delivery of these services at the village level, which may be part of a larger crisis of care where the delivery of health promotion remains a major gap.

A study by Gaitonde *et al.*[161], highlights the dissonances and disconnects in policy implementation, specifically under the NHM that need to be overcome for the successful implementation of interventions. Similarly, Dasgupta *et al*.[34], highlighted the "uphill task" that remains for the implementation of national policies under the POSHAN Mission if the child stunting reduction targets are to be met.

7.5.3 Strengths and limitations

This chapter's analysis' strength relied on the fact that it drew from in-depth qualitative data from different community members (i.e., frontline health workers, mothers of infants), and was complemented with extensive unstructured households' observations and natural conversations infant caregivers during over 40 household visits. The observational and qualitative data from multiple community stakeholders enabled a more comprehensive understanding of the different perspectives across the community on the child healthcare services.

A limitation of this chapter's analysis is that while most of the ASHAs from the case-study villages were interviewed, the sample size for key informant interviews remained relatively small (N=12), and the views of the ASHAs from the case-study villages may not be representative of other villages. Given that a particular characteristic of the study villages is that they were inhabited by a majority of tribal families, it is likely that results from this chapter on the healthcare perspectives are more generalisable to other rural and tribal villages in north India.

Another limitation is that the focus group discussions were carried out with a sample of self-selected mothers. It is likely that the sample of mothers in the FGD was biased towards those mothers that lived close to or had stronger links to the Anganwadi centres and who were able and willing to attend the activity despite their domestic responsibilities. In the study tribal villages, some households remained particularly geographically isolated and inaccessible, and while infants from these households are likely to face the largest barriers for the delivery and uptake of child health services, it is less likely that I was able to capture their concerns.

Similarly, while efforts were made to provide all mothers with the opportunity to participate in focus groups, intrinsic power dynamics within communities made some people's voices heard more than others. However, the household visits provided the opportunity to hold unstructured conversations with additional caregivers from each family, capturing individual perspectives that complemented and confirmed the views expressed during the focus group discussions.

7.5.4 Conclusion

ASHAs' unequal emphasis on their health activist roles in comparison to their link-worker roles, and the lack of trust on public healthcare by tribal families, hindered the delivery and uptake of WASH promotion and infection risk awareness services provided by frontline health workers in rural tribal Banswara. Strengthening ASHAs' health activists' role and improving the tribal communities' trust in frontline health workers will be crucial to improve the delivery and uptake of public health schemes in WASH promotion, infection prevention, and child health, accelerating progress towards achieving the national targets for stunting reduction under the POSHAN Mission and the Sustainable Development Goals.

8 Chapter 8: Co-developing recommendations for local programming to enhance infant hygiene and enteric infection prevention practices

8.1 Chapter overview

The results presented in this thesis have so far delved into the risk factors and pathways to enteric infections in infants in rural Banswara, uncovering drivers across the physical environment, microbial, socio-cultural, socio-economic, and institutional dimensions. The barriers faced by the public health services and frontline health workers for hygiene promotion and infection prevention were also explored. Having developed a comprehensive understanding of how infants may end up afflicted by enteric infections in these communities, it pertinently followed to use these findings to develop a set of tailored recommendations to inform local programming and intervention design.

To develop a set of recommendations that were relevant and tailored to the study context, it was appropriate to do it in conjunction with relevant local stakeholders and experts, following a co-development process. Moreover, to co-develop recommendations that were based on the evidence gathered in this study, the results and conclusions from this study (Chapters 5, 6, 7) needed to be brought together and synthesised so that they could be efficiently communicated and discussed with the relevant stakeholders, before recommendations were identified. Thus, this chapter deals with the process of co-developing a set of tailored recommendations to inform interventions and programmes in rural Banswara to enhance infant hygiene and enteric infection prevention practices. To do so, I followed a series of methodological steps, including: (1) integrating the evidence collected throughout this study to synthesise the overall key findings on factors driving enteric infections in infants, (2) discussing the key factors with local stakeholders and experts to brainstorm recommendations relevant to the study setting, and finally (3) co-developing a set of recommendations aimed at local programmers and interventions. In this chapter, I present the process and final output of co-developing recommendations, which addresses the 4th and last objective of this thesis:

Objective 4. To co-develop a set of tailored recommendations to inform local policy and programming for enhancing infant hygiene and enteric infection prevention practices.

8.2 Fieldwork adjustments due to COVID-19 restrictions

To co-develop recommendations, the initial plan was to conduct follow-up visits to the study communities in Banswara so that face-to-face workshops could be organised with relevant community members to discuss the results obtained and identify recommendations for local programming. More specifically, the plan was to conduct community workshops to brainstorm ideas on how to best address the key factors driving infant infections identified in this study and based on those discussions, co-develop recommendations with the community. However, due to pandemic-related restrictions on travel and fieldwork research, a follow-up trip to the field site was not possible. Online communication via calls with village community members themselves was also discarded as an option, as they did not have access to the technological resources required. Given the situation, alternative ways were considered to involve local perspectives in the process of co-developing recommendations as much as possible. It was decided that conducting online consultations with relevant experts and stakeholders from local NGOs and government organisations in charge of implementing child health and WASH programmes in rural India, would be the next best thing. Experts with experience in working with the rural tribal populations in Banswara, or delivering programmes and interventions for WASH and child health in the Rajasthan State, or other similar contexts in India, could provide valuable insights on how to address the infection risks identified, drawing from their own experiences. It was decided that to co-develop tailored recommendations that could inform local programming on infant hygiene and enteric infection prevention practices, evidence would be drawn from the data collected during fieldwork, as well as from online consultations with local experts and stakeholders that would be carried out. The specific methodological steps that were followed for this process are explained below.

8.3 Methodological steps for co-development

Firstly, it is worth describing what is meant by undertaking a process of co-development. Co-development, co-design, co-creation, or co-production are terms that have sometimes been used interchangeably in the literature with ambiguous meanings. Co-design is an approach that emerged from the product design sector, and that it focuses on understanding the experiences of users to find design solutions to improve the usability of products[275]. Co-production, on the other hand, has been defined as an approach in which people across organisations (researchers, practitioners, business, and the public) work together, sharing power and responsibility from the start to the end of the project, including the generation of knowledge[276]. Instead, the term of co-development is understood as a broader approach that underlines the importance of collaboration and participation across organisations within a network, particularly with the users and frontline workers of the service that is being conceptualised and developed[277]. While there are small, nuanced differences, the practice of collaborative development is at the core of all these terms[277]. Thus, for this thesis' chapter, the purpose of co-development was to collaborate with stakeholders that have a frontline role in designing or implementing WASH and health promotion programmes in Banswara, or more broadly in rural India, and seek their participation in the process of developing evidence-based recommendations for programming. With this approach in mind, a series of methodological steps were defined to guide the process of co-developing recommendations to improve infant hygiene and enteric infection prevention practices in rural Banswara (Figure 8-1).

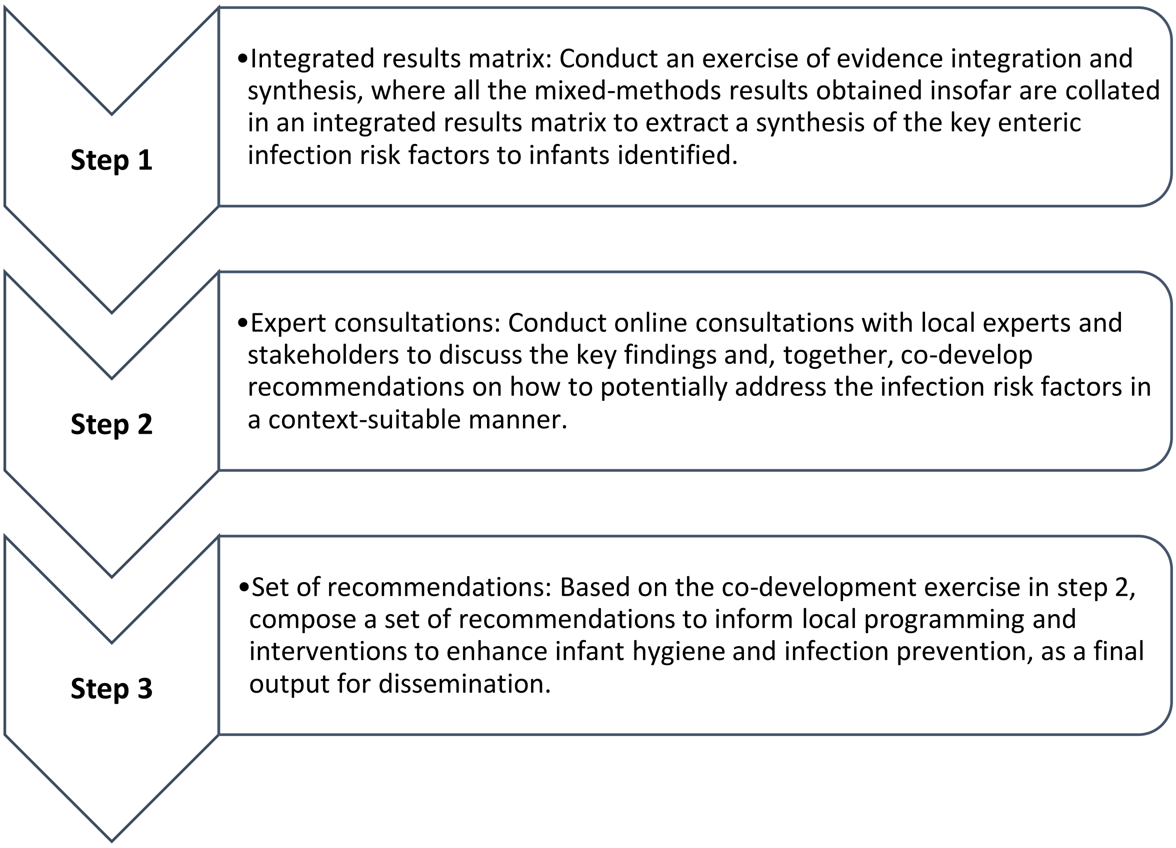


Figure 8-1 Methodological steps to co-develop a set of recommendations to inform local programming and interventions

8.3.1 Step 1. Integrated results matrix

Step 1 involved the integration of results obtained during this thesis to extract a synthesis of the key factors driving enteric infections in infants. The purpose of integrating the results obtained from mixed methods across this thesis' chapters was to interpret them "as a whole, greater than the sum of its parts"[278] and extract a holistic synthesis of the key findings. The literature on mixed-methods integration was scoped to identify a strategy to integrate findings. To interpret qualitative and quantitative results in an integrated manner, O'Cathain proposes different strategies to do so, one of them the mixed-methods matrix[279]. In a mixed-methods matrix, findings from each case-study can be summarised in a row, and each column displays the data collected using the different qualitative and quantitative methods. Comparing columns of the matrix allows researchers to look out for discrepant, convergent or complementary information obtained using the different methods[279]. Based on the mixed-methods matrix approach proposed by O'Cathain, a similar, but slightly modified exercise was conducted to integrate the mixed methods findings in this thesis. I decided to embed the integration exercise in the socio-ecological model, as the socio-ecological model has underpinned the research conducted throughout this thesis. In this manner, a mixed-methods matrix was drawn, where each row of the matrix referred to a factor driving infant infections across the different levels of agency in the socio-ecological model (individual, household, community, and societal levels), and each column referred to factors in different domains (environmental factors, socio-cultural factors, institutional & economic factors). Colour codes were used to differentiate and contrast results obtained through the different qualitative and quantitative methods (Table 8-1).

To populate the mixed-methods matrix, I went back to the results presented in Chapters 5, 6 and 7 in this thesis. Each finding presented (be it qualitative themes, observations, summary statistics, microbial concentration levels, infection risk estimates, etc) was summarised in the corresponding socio-ecological framework cell, according to whether it referred to an individual, household, community, or societal-level factor and whether it related to environmental, socio-cultural, or institutional-economic factors. Findings from qualitative observations were coded in red. Qualitative reports from interviews or group discussions were coded in blue. Quantitative information from structured observations was coded in green, and results from the microbial analysis were coded in yellow (Table 8-1). The display of mixed-methods findings in colour codes but altogether in the same framework allowed to assess whether the information regarding one particular factor converged, conflicted or complemented, as captured through observations, reports, summary statistics or via sample analyses. The integrated results matrix enabled a birds-eye integrated view of all the findings from this thesis, allowing a synthesis of the key findings to be extracted from it.

Table 8-1 Colour codes used in the mixed-methods matrix

As qualitatively observed (from unstructured observations)
As qualitatively reported (from interviews & group discussions)
As quantitatively measured (from structured observations)
As quantitatively analysed (from microbial sampling)

8.3.2 Step 2. Online expert consultations

Based on the key findings extracted from the results' integration exercise in Step 1, the next step was to discuss the key factors driving infant infections with relevant local experts to brainstorm and co-develop recommendations on how to potentially address them. Since the goal was to capture the diverse range of opinions of relevant local experts and stakeholders with different levels of knowledge (block-level knowledge, district-level, state-level and national-level), purposive sampling was carried out. While block and district-level stakeholders would be more aware of the rural tribal setting in Banswara and the *Bhil* community, state and national-level experts were thought to be more knowledgeable on the policy aspects and development sector considerations. For each level, relevant stakeholders that were knowledgeable on designing, implementing, or delivering child health, hygiene and nutrition interventions or programmes were sought out using the local contacts and networks that I developed during the fieldwork stage. Finally, ten online discussions were carried out from October to December 2020, lasting between 30 minutes to 1 hour each. Table 8-2 summarises the expertise of the stakeholders with whom discussions were carried out.

Table 8-2 Summary of local experts and stakeholders recruited for online consultations

Level	Local experts and stakeholders' expertise
Block	1) Local NGO fieldwork officer with extensive experience in development programme implementation across rural Banswara. 2) Local NGO fieldwork officer with comprehensive knowledge of study communities in the Ghatol and Kushalgarh blocks.
District	3) Programme leader at a district-level NGO, responsible for implementing child health programmes. 4) District programme coordinator for a government child health and development programme.
State	5) Deputy director of state-wide child health NGO 6) Programme leader at NGO, responsible for state-wide child health programmes
National	7) Expert in WASH programme design, with particular experience in Indian government flagship programmes and service delivery 8) Director of health & nutrition department at a nation-wide NGO in India. 9) Water and sanitation expert, with extensive knowledge of the WASH NGO sector in India 10) Hygiene intervention design expert, with experience at the Public Health Foundation of India.

As explained in Section 4.5, ethical approval was sought from both the UK and India ethics boards for the post-covid amendments that were necessary to reflect the change from face-to-face to online interviews and its implications for data management. The online consultations were audio-recorded, and informed signed consent was obtained.

In order to ensure that the discussions with local experts and stakeholders had a clear focus on developing tailored recommendations on how to address the identified infant enteric infection risk factors, a brief Summary of Research document was put together. The Summary of Research summarised the key factors driving infant enteric infections identified as a result of the integration exercise carried out previously. The Summary of Research for online consultations can be found in Appendix O. It was shared with the local experts and stakeholders in advance of the discussions, and it was also used to guide them. Each key factor driving infections summarised in the Summary of Research triggered a discussion on how it could potentially be addressed, and recommendations for possible interventions, target audiences, and communication channels that could work in the local context were identified. Therefore, recommendations were co-developed in conversation with local experts and stakeholders, based on several different inputs of information. On the one hand, recommendations were based on the findings and evidence collected during fieldwork, summarised in the Summary of Research, on the other hand, local experts and stakeholders provided suggestions based on their local knowledge of the community and of the local policies and programmes, finally, I provided a third cadre of information based on my own knowledge of the community and knowledge of the literature. While information saturation was not reached (stakeholders' opinions and recommendations were very diverse), recommendations and suggestions for all the identified key factors driving infections were captured, and the information was deemed sufficient.

Online consultations were carried out in English and audio recorded. Once they were concluded, the audio files were re-played and detailed notes on the expert's comments and recommendations were taken. Notes extracted from the expert consultations were then critically reviewed, and notable remarks were categorised according to which key factor they were referring to. The results from the online consultations presented below in this chapter (Section 8.4.2) outline the concluding remarks and recommendations that were reached on how to best address the key factors driving infant enteric infections.

8.3.3 Step 3. Set of recommendations to inform local programming on infant hygiene and infection prevention

Once recommendations on how to address each key factor driving enteric infections had been brainstormed together with stakeholders during online consultations, they were structured into a concise set of recommendations that could be used as a final output for dissemination. The purpose of the set of recommendations was to inform local programmes and interventions aiming to enhance infant hygiene and infection prevention, ultimately to improve child nutrition and development. Since the research done during this PhD built on the PANChSHEEEL project, the recommendations developed in this chapter also aimed to inform the PANChSHEEEL intervention package[49]. The PANChSHEEEL intervention package proposed intervention activities across 5 levels of intervention, including those targeting mothers, households, village communities, frontline health workers, and district-level officials. To be able to inform the PANChSHEEEL intervention package and other potential programmes, the set of recommendations was structured using the same framework as in PANChSHEEEL (Figure 8-2). Therefore, the set of recommendations was structured into the different target audiences that potential interventions and programmes could reach: Mothers, Households, Village communities, Frontline health workers, and District-level officials.

Levels of intervention				
Mothers	**Family households**	**Village communities**	**Frontline health workers**	**District-level officials**

Figure 8-2 Levels of intervention in the PANChSHEEEL intervention package

8.4 Results

8.4.1 Key enteric infection risk factors resulting from the integration exercise

The mixed-methods results integration matrix (Table 8-3) summarises all the factors driving enteric infections in infants in rural tribal Banswara, identified via the qualitative and quantitative methods in this study. Thus, it includes the infection risk factors (Chapter 5), the dominant transmission pathways (Chapter 6), and the barriers to infection prevention and hygiene promotion captured in this case study (Chapter 7).

Table 8-3 Mixed-methods matrix of key factors contributing to infant's enteric infections in rural tribal Banswara. In blue, factors captured from qualitative reports. In red, from qualitative observations. In green, from quantitative observations. In yellow, from quantitative microbial analyses.

Levels	Environmental factors	Socio-cultural factors	Institutional & economic factors
Societal	· The geographical area is water scarce, qualified as "semi-critical". 86% of households in Kushalgarh faced water supply disruptions from their main water source. · Modern-day pressures including rising population, increasing water demands and land fragmentation are worsening water scarcity and threatening the traditional tribal agricultural livelihoods. Alternative job opportunities remained very limited and inaccessible from the villages.	· Weak and unregulated local governance and corruption hindered the delivery of public services and eroded trust in political leadership and health & development programmes. · Tribal castes continued to be perceived as marginalised and disadvantaged. The stigma contributed to reduced access to job opportunities, improved education, and household infrastructure. · Tribal identity is characterised by their traditional and independent way of living, but the historical state-dependency for health & development programmes in tribal culture contributed to a perceived lack of self-efficacy to improve infant hygiene and child health.	· The public funds provided to build latrines under the Swachh Bharat Abhiyaan (SBA) were reported to be insufficient, and the monitoring of latrine coverage under SBA, inaccurate. · Government and district-level officials placed an unequal emphasis on the health and hygiene promotion services to be delivered at the village-level by frontline health workers, hindering resources towards these activities, such as providing health promotion training to frontline health workers, implementing monitoring and accountability systems, and giving monetary incentives.
Community	· Most families had access to a public hand-pump as a source of domestic water. 76% of households used hand-pumps, while 5% did not and resorted to unimproved open wells. 75% of the hand-pump water samples analysed were faecally contaminated, but to significantly lower levels than open well water samples.	· Tribal families often preferred traditional healers or informal non-registered doctors when seeking treatment for child health issues. Parents reported often not trusting health advice provided by frontline health workers or treatment from public health facilities and resorting to alternative private providers.	· Frontline health workers struggled to deliver health and hygiene promotion services because they were reported being overburdened with multiple responsibilities and facing difficulties to reach all the dispersed rural houses under their village catchment area.
Household	· Kacha households made of mud impeded the cleaning of child play surfaces like the earthen floors. 86% of study households were Kacha. 100% of the household soil samples analysed were positive for faecal bacteria, with high contamination levels (4.2 Log_{10} *E. coli* CFU/gr). · Animals and animal faeces were widely present around the household surroundings and child play areas. 98% of study households owned domestic animals but only 19% had a designated shed to separate animals.	· The use of local streams for bathing was preferred to the use of hand-pumps, but surface water samples were 2 logs more contaminated than groundwater samples (3.33 vs 1.25 Log10 E. coli CFU/100mL). · Filtering drinking water through a cloth was perceived as a hygienic practice thought to make drinking water safe, both by frontline health workers as well as parents, but water filtering-cloths were observed to be visibly dirty. · Social norms made poultry increasingly undesirable domestic animals, reducing infant's exposures to chicken faeces. Only 30% of households owned chickens.	· People reported starting household latrine constructions to cash in the government financial aid provided, but then latrines were left unfinished and unused. While 40% of the households had initiated the construction of a latrine, only 12% were finished and being used. Financial constraints were reported as the main limitation to building latrines and improving household WASH facilities. · Grandparents and older siblings played a prominent role in childcare during the first 2 years, since parents were busy with agriculture.
Individual	· As infants gained mobility during the first 2 years of life, opportunities for faecal exposures increased. For instance, over 70% of infants aged 6-24 months mouthed their soiled hands, but not infants under 6-months. 97% of infants' hand swab samples were positive for *E. coli*. Infants 0-2 yr. faced a 38-44% median daily risk of infection from enteric pathogens such as E. coli 0157:H7 from mouthing their own contaminated hands. · Infant's exploratory and mouthing behaviours continuously exposed them to faecal pathogens in their surroundings via mouthing of dirt, dirty hands and fomites. For instance, 0%, 15%, and 39% of infants aged 0-5, 6-11, and 12-24 months were observed to directly ingest soil. Infants faced an estimated daily infection risk of 94-96% from direct soil ingestion, a risk higher than that from mouthing contaminated hands and drinking water.	· Animals were described to be like friends to children, and animal faeces such as cow dung had multiple local uses, hence close contact with animals and animal faeces was not perceived as a potential infection threat. · Mothers reported feeling unable to prevent infant's exposures to dirt given the farming environments where they lived and the fact that they were often busy tending the fields and relied on others for childcare. · Use of soap for handwashing and washing utensils was not habitual, and it was not observed to be used prior to any of the 30 cooking and 21 feeding events captured. 92% of the caregiver's hand swab samples were positive for faecal indicator bacteria. · The habit of open defecation and the disposal of infant's faeces in the environment remained widespread.	· People often preferred resorting to open wells when water from public hand-pumps became depleted, or they were far away and had to be shared with the community, but well water was significantly more contaminated than hand-pump water samples (2.45 CFU/100 ml vs 1.16) · Soap was perceived as cheap. · The lack of in-house piped water meant that all households stored water at home, both for drinking as well as for other domestic tasks. Household stored water was invariably more highly contaminated than water from the sources (2-3 Log10 *E.coli* CFU/100mL vs 1-2). Drinking stored water daily posed an estimated risk of infection with *E. coli* 0157:H7 of 3-22% to infants.

Reading through the mixed-methods matrix (Table 8-3) where the multiple factors driving enteric infections identified in this thesis are presented in an integrated manner, some overarching key issues can be identified across the individual, household, and community-levels and across the environmental, socio-cultural, and institutional domains. The key factors driving infant infections identified from the mixed-methods' results integrated matrix can be summarised in the following ten bullet points:

1. **Infant-specific risks:** Particular characteristics of infants in their first 2 years such as their exploratory behaviours which involve crawling around the household floors and continuously mouthing their hands and objects, repeatedly exposed them to the faecal pathogens in their surroundings.
2. **House cleanliness obstacles:** The typical *Kacha* houses made with earthen floors and walls impeded the cleaning and sanitising of domestic surfaces, contributing to infants' constant exposures to soil. There was limited awareness of the infection risks to infants from soil exposures, and mothers reported not knowing how to avoid infants' exposures to soil given the farming and earthen built environment in which they lived.
3. **Contact with domestic animals:** The many local uses of domestic animals and their faeces (cow dung in particular), meant that animals and animal faeces were often present in the domestic living environments, bringing faecal pathogens into the infants' surroundings. There was low infection risk awareness from contact with animal faeces.
4. **Water issues:** Domestic water resources were scarce and widely contaminated with faecal matter, introducing faecal exposures to infants while drinking water and bathing. Moreover, safe water handling and treatment practices were unclear and uncommon.
5. **Handwashing constraints:** The use of soap for handwashing or washing kitchen utensils was not habitual, even though soap was thought to be cheap and accessible.
6. **Sanitation constraints:** The use of toilets for defecation and faeces disposal was also not habitual, although in this case constrained by the reported financial difficulties to build latrines and the water scarcity issues to use toilets.
7. **Health promotion barriers:** The district-level implementation of government health schemes often neglected health activism efforts in favour of other health services, meaning that WASH promotion and infection prevention programmes delivered by frontline health workers often did not reach the ground-level.
8. **Traditional healthcare-seeking behaviours:** Healthcare-seeking behaviours were shaped by a traditional reliance on healers and non-registered private health

practitioners, and a lack of trust in the frontline health workers' health knowledge, which hindered the opportunities to deliver WASH promotion and infection risk awareness programmes to infant caregivers at the ground-level.

9. **Governance hindrances:** Unregulated local governance was reported to lead to the misuse of public funds for village development, hindering improvements in village-level WASH infrastructure such as hand-pumps and school toilets, and therefore contributing to infants' infection risks.
10. **Tribal cultural identity:** Tribal communities are characterised by their traditional and independent way of living. This also means that tribal communities have often been considered outcasts and discriminated against, hindering their opportunities for improved education and employment, even when their agrarian livelihoods are being threatened by modern-day pressures such as climate change. Tribal groups have also historically been the passive recipients of several government development programmes, which may have contributed to the tribal attitudes of resignation and perceived lack of self-efficacy to drive health & WASH progress in their communities. These tribal attitudes may be limiting their opportunities for WASH improvements and child health.

Briefly summarised, the key factors contributing to enteric infections in infants were (1) the fact that infant's exploratory behaviours continuously exposed them to faecal pathogens through crawling and mouthing, (2) the fact that houses made of mud were difficult to keep clean, (3) and domestic animals brought faeces into the homes, with parents not recognising some of these infection risks and not knowing how to avoid them, (4) that water was scarce and mostly contaminated and there was a lack of knowledge on how to make it safe, (5) that the use of soap for handwashing and (6) the use of toilets for defecation was not habitual, (7) that health and hygiene promotion programmes often did not reach the ground due to poor institutional emphasis on delivering these services, (8) and due to a lack of trust on the frontline health workers' health advice, (9) that unregulated governance impaired the delivery of public development funds at the village-level, and lastly, (10) the historical discrimination against tribal castes influenced the tribal attitudes of poor self-efficacy and mobility, limiting their opportunities for improved socio-economic status and living conditions.

In addition to identifying the overarching key factors, the mixed-methods matrix allowed to explore and compare patterns between the different columns and rows. The first column of the mixed-methods matrix (Table 8-3) captured the environmental and contextual factors, which arose mainly from the infant's inherent behaviours or from the inherent characteristics of the natural and built environment in rural Banswara. Such contextual factors would be difficult to modify, and therefore it was important that during the expert consultations in the following step of the co-development process, recommendations would rather focus on identifying alternative coping strategies or support mechanisms to address them. Secondly, the socio-cultural factors column captured issues arising from the engrained tribal habits, social norms, and cultural values. While some of these factors, such as tribal caste discrimination, would require long-term large-scale societal shifts on how tribal communities are perceived, other factors could prove to be more easily modifiable. It was determined that during expert consultations it would be important to focus on identifying recommendations to improve hygiene practices such as the use of soap for handwashing and cleaning kitchen utensils, the separation from animal faeces, or the use of a cloth to filter drinking water, that were not perceived as infection threats. Thirdly, institutional and economic factors mainly related to problems with financing, maintaining and accessing water and toilet infrastructures, as well as accessing and benefiting from the public health and WASH promotion services. Potential ways of strengthening the governance system to ensure that such services that support basic needs are available and accessible would also need to be discussed when co-developing recommendations with experts.

Findings resulting from the different methods (colour-coded in Table 8-3) mostly complemented each other, providing a more complete picture of each specific factor, rather than contradicting each other. Some contradictions between mixed-methods results were captured. For instance, while parents and frontline health workers reported that filtering drinking water through a cloth was a good practice to make drinking water safe, it was later observed that the cloths used were often dirty, and environmental sampling results revealed that household stored water was consistently more highly contaminated than that at the source. However, much more often information collected via different methods, converged. For instance, the lack of soap use for handwashing was observed during household observations, and it was confirmed by subsequent reports from parents that expressed that handwashing with soap was not habitual. Similarly, reports from parents stating that they did not seek out frontline health workers' help for child health ailments were in agreement with what was reported by the frontline health workers themselves, who admitted that parents seldomly asked them for first-aid treatment or hospital referral advice.

8.4.2 Tailored recommendations for local programming resulting from expert consultations

Once the integrated key findings had been distilled and synthesised into ten bullet points, they were discussed with the relevant experts during online consultations. The discussions with local experts and stakeholders led to the brainstorming of several potential recommendations for local programming and interventions on how to address each of the key factors driving infections in infants that had been captured during the results integration exercise (Section 8.4.1). Different types of recommendations arose during expert consultations. Suggestions on which key factors would need to be highlighted to the different audiences, what feasible strategies could be proposed to parents and caregivers to enhance their infant hygiene and infection prevention practices, which strategies could be adopted to enhance frontline health workers' services, and which channels of communication would be most appropriate for engaging with the different relevant audiences, were all discussed. This results' section presents all the brainstormed thoughts and suggestions that were discussed during expert consultations, and the following results' section (Section 8.4.3) presents the concise set of final recommendations, curated from the discussions with experts.

1. **Recommendations to address infant-specific risks:** Local stakeholders highlighted the fact that relatively little attention was being paid to the role of infant hygiene and infections and their impact on malnutrition and stunting in district-level child health government programmes and meetings. Stakeholders mentioned that while several national flagship programmes being implemented in Banswara bring attention to enhancing sanitation practices by promoting latrine construction or reducing child malnutrition by promoting better diets and nutrition, much less attention is given to the influence of poor WASH and infections on child health and malnutrition. The links between WASH, enteric infections, malnutrition, and stunting and the criticality of the first 1000 days of life are not so clearly understood, and it is often the case that district-level officials are unaware of village-level realities. It was suggested that district-level government officials would benefit from being briefed about the key infection risks specific to infants, highlighting their consequences for child health and development, and the challenges faced by tribal villages at the ground-level. Local stakeholders and experts also emphasised that government officials and implementation programmers would likely want to be briefed about what the top most prominent "problems" are in regards to child infections, and what easily implementable "solutions" are there to tackle them. Therefore, recommendations for the key factors

driving infections below focused on highlighting the key issues and possible ways to address them, with the aim to inform future programming to enhance hygiene behaviours and infection prevention.

2. **Recommendations to address house cleanliness obstacles:** House cleanliness obstacles were mainly rooted in the fact that the built infrastructure of *Kacha* houses were made of soil. Recommending parents to modify housing materials would be unfeasible due to the costly expenditures required. However, the Government of India already has ongoing initiatives such as the *Pradhan Mantri Awaas Yojana* that provides financial support for the rural population to construct *Pucca* houses. While such initiatives are gradually being rolled out, local stakeholders suggested proposing some other more easily implementable solutions to separate infants from the dirt in the domestic environment and raise awareness about the soil exposure infection risks. For instance, stakeholders suggested promoting the use of *tatipats* (i.e. floor mats), which were already widely available across the study village households (as seen in Image 8-1), to separate infants from the dirt floors. This would need to be paired with explanations to parents about the infection risks for infants associated with soil exposures, and with an emphasis on the need to keep play mats and child play spaces clean.

Image 8-1 Example of a floor mat available in one of the houses

Alternatively, parents could be shown examples of other child play mats and play yards that are used in other settings to separate children from earthen floors, which could provide an example for them to aspire or imitate it. Examples of locally designed play yards in rural Ethiopia[133] and rural Zambia[134], have resulted in positive feedback from mothers, who reported that the play yards helped them keep infants clean and helped them perform domestic tasks while caring for the infants. Therefore, it was suggested that explaining the risks associated with soil exposures and presenting different potential solutions on how to separate infants from dirt to parents and caregivers may motivate them to adopt these practices, which would contribute to enhancing infant hygiene and infection prevention.

3. **Recommendations to address close contact with domestic animals:** During discussions with local stakeholders there was agreement about respecting the importance of the role that domestic animals play in tribal culture and their livelihoods. However, it was clear that there was a need to explain why it is important to separate infants from animal faeces, given the current lack of awareness of this infection risk amongst parents. Particularly, it was suggested that promoting the separation of animals from the infant's sleeping quarters would be important, as this has been associated with child stunting and enteric dysfunction[70], and the separation of animals from child play areas as much as possible. Most rural households had vast space surrounding the house to allow for a fair separation of livestock from the main courtyard and child play area, and while animals in most households were scattered around the courtyard (Image 8-2), in some other households, rudimentary animal sheds were also observed. Image 8-3 shows some examples of the animal corrals observed across the study households. The materials and know-how on building animal sheds for corralling domestic animals were already present, and it would be a matter of explaining to parents and caregivers why it would be beneficial for infants to avoid contacts with animal faeces to potentially contribute to the reduction of infants' infection risks through this exposure pathway.

Image 8-2 Example of a household courtyard where animals are kept

Image 8-3 Example of a local animal corral space

4. **Recommendations to address water issues:** While water-related constraints were often rooted in the lack of adequate water supply infrastructure, local stakeholders suggested that recommendations aimed at the district-level government officials should refrain from proposing infrastructural changes that would require large expenditures since infrastructural changes requiring large budgets would only be considered following a different chain of decision-making authority. Instead, it was suggested that recommendations to address water-related issues should focus on raising awareness about water contamination risks among village communities and proposing easy solutions to improve water handling and treatment practices, given the lack of knowledge on how water becomes contaminated and what to do about it. Based on the findings that household

stored water was consistently more highly contaminated than source water, several recommendations were proposed to reduce the contamination levels of household stored drinking water. Firstly, it was suggested that developing an understanding about the potential sources of water re-contamination at home would be needed in the village communities, including explaining the risks of water contamination when water storage containers are not cleaned, when drinking water is filtered through a cloth that has not been properly cleaned, or re-contaminating household stored water by introducing dirty hands onto the water containers to collect a glass of water. Secondly, recommending the use of *dandivalas* (i.e., ladles) for collecting water from the drinking water storage containers was proposed as a possible solution to avoid re-contamination of stored water by dirty hands. *Dandivalas* were widely available across the study villages (Image 8-4) as they were used for cooking, so their adoption by families would be relatively easy. While *dandivalas* could prove helpful at reducing stored water re-contamination by dirty hands, they were also sometimes observed to be visibly dirty (Image 8-4) and therefore potentially introducing pathogens anyway, so it was noted that it was equally important to emphasise the need to regularly wash utensils with soap. Thirdly, recommending the boiling of water as a treatment strategy whenever possible could prove useful. Local stakeholders pointed out that boiling drinking water is time-consuming, and not feasible to do all the time. Therefore, it was suggested that the need to boil drinking water should be emphasised in the following particularly high-risk instances: a) when a family needs to rely on open well water, b) when water from the hand-pump being used appears mixed with mud, c) when preparing drinking water for infants in their first years of life, given the critical developmental age and impact of enteric infections.

Image 8-4 Example of a local ladle for scooping water from the storage containers

Lastly, based on the findings that surface water from local streams were significantly more highly contaminated than water from hand-pumps, it was suggested that the risks of infection to infants from involuntary ingesting water from local streams while bathing should also be highlighted to parents. Recommending to avoid the use of local streams for bathing infants, at least during the first years of life when the volumes of involuntary ingested water are larger[102], could help reduce infants' faecal exposures.

While raising awareness about water contamination risks amongst parents was recommended to improve their water handling practices, it was also suggested that these village-level challenges should be highlighted to government officials. National reports suggest that 92% of the households in Banswara have access to an improved water source[188], but this fails to recognise the seasonal variations in water access that were reported or the risks from faecal contamination. It was suggested that it is important that government officials are aware of the village realities and that these do not remain hidden behind the national statistics.

5. **Recommendations to address handwashing constraints**: Findings revealed that while soap was considered cheap and used in other instances, handwashing with soap before or after cooking, or to wash the kitchen utensils was simply not habitual. As explained by the hygiene intervention design experts, there are three key aspects required to drive the uptake of soap and latrine use behaviours. Briefly, these include 1) for people to be capable of carrying it out, for instance having access to the necessary infrastructure, 2) for people to have the opportunity of carrying it out, such as having enough water or the social acceptance to do it, and 3) having the motivation to do it[133], so that the behaviours become engrained habits. In the case of handwashing with soap in the rural Banswara, people seemed to have the capabilities and opportunities but lack the motivation. Hygiene intervention design experts suggested during expert consultations that developing creative materials containing cues and nudges may prove useful in this case to trigger a change in the engrained handwashing habits of people. It was suggested that visual materials including images that associate positive feelings with handwashing with soap and washing kitchen utensils with soap, and negative feelings with the lack of it could prove useful to reinforce handwashing behaviours. Moreover, current coronavirus information dissemination platforms could be used to engrain this handwashing with soap promotion materials providing cues, and nudges as suggested by hygiene intervention design experts.

6. **Recommendations to address sanitation constraints**: Findings from this study suggested that most families still lacked access to a latrine facility and that financial constraints and water scarcity were the main deterrents for building one, as parents and young adults mostly reported a willingness to modernise and use latrines. It was also observed that official reports of latrine coverage[188] did not match ground-level realities. Therefore, it was agreed together with stakeholders that additional steps were still required to drive latrine uptake in rural Banswara, and that perhaps it would be beneficial to start by recommending that accurate monitoring and reporting of the ground-level latrine coverage realities is undertaken so that the remaining challenges are recognised.

7. **Recommendations to overcome health promotion barriers:** As captured in Chapter 7, ASHAs did not prioritise their "health activist" role, partly due to a perceived lack of ability to act as community mobilisers and deliver health and hygiene advice. It was suggested that informative sessions on germ theory could be provided to frontline health workers to improve their understanding of infection risks and safe hygiene practices and contribute to them feeling more confident to provide health and hygiene advice to parents of infants and mobilise communities. Germ theory sessions could include explanations on how germs and diseases spread, and empirical demonstrations including tests for microbial contamination. For instance, dip-slides (Image 8-5) could be used to engage frontline health workers in testing surfaces and liquids in their surroundings for faecal contamination, as this tool already proved useful to spark the villager's curiosity on germs when it was tested during the formative fieldtrip. A previous study that used germ theory to develop an accurate understanding of the causes, transmission, and prevention of enteric infections was successful at improving hygiene behaviours and reducing diarrhoeal incidence[133]. ASHAs' lack of emphasis on health activism was also likely shaped by the lack of institutional emphasis on health promotion programmes (i.e., no training, no formal monitoring, no incentives for frontline health workers to carry them out). Therefore, it is recommended that the need to strengthen health promotion services delivered by frontline health workers' training is emphasised to local district-level officials and that additional training (such as germ theory sessions) is given to frontline health workers to improve their understanding of infections and hygiene practices, enhancing their ability to provide health & hygiene advice and act as health activists.

Image 8-5 Dip-slides as an environmental sampling method to engage with the community

8. **Recommendations to enhance healthcare-seeking behaviours:** In addition to improving the frontline health workers' ability to act as health activists and deliver health and hygiene promotion services, improving the parents' trust in the frontline health workers' health advice would be needed, given that traditional healthcare-seeking behaviours relied mainly on private practitioners. Firstly, it was apparent that involving spiritual healers (i.e., Bhopas) and non-registered practitioners (i.e., *Bengali* doctors) to deliver health promotion services would be important, as they have the trust of the community in regard to healthcare practices. Perhaps frontline health workers could be encouraged to invite private practitioners and healers to attend health promotion events and ask them to aid in promoting safe health & hygiene practices. Secondly, it was suggested that a strategy to improve parent's trust in the frontline health workers health & hygiene advice could include the provision of certificates that certified the knowledge and hours of training completed by frontline health workers, as the lack of health education and training was a prominent concern amongst parents.

In addition to these recommendations, strengthening the institutional governance systems was discussed to be key to ultimately ensure an accurate monitoring and delivery of WASH and child health development programmes and funds that reach the ground-level[280]. Better monitoring of village-level political leadership would be required given the common reports of misused funds captured, but local stakeholders argued that this obstacle to WASH development and infection prevention was out of scope for a set of recommendations focused on addressing infant hygiene and infections. Similar arguments were given when discussing the factors relating to tribal cultural identity and caste discrimination. Factors engrained in the tribal culture such as the traditional self-sufficient way of living, the traditional reliance on non-registered practitioners for healthcare, the persistent caste inequalities, the historical dependency on state programmes for development, or the modern-day threats on their agricultural livelihoods, all have potentially significant trickle-down effects on the day-to-day hygiene and childcare practices. However relevant, it was discussed that these remained out of scope in the context of recommendations for infant hygiene & infection prevention programming.

In summary, the recommendations presented above identified; (1) The key topics that need to be brought to the attention of district-level government officials, including the need to enhance infant hygiene and infections to reduce child malnutrition and stunting, and the need to better report the remaining village-level challenges and coverage of safe domestic water sources that are free from contamination and improved latrine facilities. (2) Recommendations also identified possible strategies to improve the delivery and uptake of health and hygiene promotion programmes by frontline health workers, and (3) identified the key infection risk factors to infants for which awareness needs to be raised amongst parents and village communities, and possible strategies that could be locally easily adopted by them to improve their hygiene and infection prevention practices.

Expert consultations also centred around the specific communication channels that could be most useful to reach the different relevant target audiences (i.e. mothers, fathers, grandparents and siblings of infants, frontline health workers, and district-level officials). Practically all stakeholders and experts strongly emphasised the need to focus on visual forms of communication, with any of the target audiences. At the village-level, due to the literacy levels, visual or oral communication would be the obvious choice, but even for district-level officials, it was suggested that information should be presented in the briefest and most visual format (i.e., diagrams, infographics…). The suggested communication channels to reach the different target audiences in the study setting were:

- **Recommended communication channels to reach mothers of infants:** If an infection risk awareness & infant hygiene promotion programme needs to be delivered to mothers of infants, the PUKKAR and the VHND events at the Anganwadi centres provide the perfect platforms to do so. The PUKKAR and VHND events are already established periodic meetups with groups of pregnant and lactating women, for the purpose of delivering different maternal and child health services (platforms explained in detail in Section 1.6). To deliver an infection risk awareness & infant hygiene promotion programme, it was suggested that visual materials such as posters with pictures and drawings could prove useful to engage with mothers, highlight the infection risks from water, soil, animal faeces etc, and propose possible strategies to enhance infection prevention practices. These meeting platforms would allow for the visual materials to be disseminated by frontline health workers and prompt further discussions between mothers of infants.

- **Recommended communication channels to reach fathers, grandparents, and siblings of infants:** Findings revealed that young adults at the parenting age were often busy tending to the fields, which inevitably placed childcaring responsibilities to grandparents and siblings, even though they were seldomly targeted by childcare interventions. During expert consultations, it was discussed that Anganwadi centres are often underexploited platforms for programme delivery, contrary to schools, which are more often included in programmes and interventions. Some villagers had even complained that Anganwadi centres were exclusively used by frontline health workers for maternal and child health services, and that other villagers would also like to make use of the installations. It was therefore suggested that events at the Anganwadi centres involving not only mothers, but the rest of the family members as well, should be organised to deliver the infection risk awareness & infant hygiene promotion programme. It was suggested that rather than only posters and visual materials, other more creative approaches were used to deliver an infection risk awareness & infant hygiene promotion programme that engaged other family members to the Anganwadi centres. Some ideas included developing a storybook to communicate the infant infection risks, a picture card game to promote safe hygiene practices vs unsafe hygiene practices, or even conducting experimental demonstrations of the efficacy of soap at removing dirt during handwashing, using colouring powder to exemplify hand residue.
- **Recommended communication channels to reach whole village communities:** Reaching whole village communities, including the population groups that are not infants' family members or caregivers at the time is important to shift collective perceptions of infection risks and social norms regarding hygiene practices. It was therefore also important that key messages in an infection risk awareness & infant hygiene promotion programme reached whole village communities. Local stakeholders suggested that one of the most widely used media channels around the rural tribal villages was the radio, and that audio stories could delivered via radio channels, where awareness on the top infection risks and safe hygiene practices could be disseminated.

The fact that radio programmes for the dissemination of health-related topics are already in place and managed by local NGOs enhanced the feasibility of this recommendation.

- **Recommended communication channels to reach frontline health workers:** Using the frontline health workers' block-level training events was suggested to be the best approach to communicate and engage with them, as this is a time where all block-level ASHAs gather in one place. Therefore, the block-level ASHA training sessions could be used to deliver the germ theory sessions to enhance the frontline health workers' infections understanding and agency to do health promotion at the village-level.
- **Recommended communication channels to reach district-level government officials:** It was suggested that delivering brief presentations at meetings would be the best approach to communicating with district-level officials. Local stakeholders emphasised the need to keep the information very visual, including graphs, diagrams, or infographics to communicate findings and recommendations, since long text documents would rarely be read. An ideal opportunity for conducting these meetings where key findings and recommendations for infection prevention and child health could be shared and discussed with relevant district-level officials are the POSHAN *Abhiyaan* District converge meetings. The POSHAN convergence meetings are periodically occurring meetings where all the district-level officials involved in the POSHAN Mission meet specifically to unite efforts and direct targeted interventions to address child malnutrition. POSHAN convergence meetings were conceptualised to ensure convergence between various programmes such as the National Health Mission, the *Swachh Bharat* Mission, the Department of Food & Public Distribution, Mahatma Gandhi National Rural Employment Guarantee Scheme, Ministry of Drinking Water & Sanitation, and others[34]. Thus, POSHAN convergence meetings bring together the whole range of district-level officers that play a role in addressing the multiple determinants of child malnutrition and stunting.

8.4.3 Set of recommendations to enhance infant hygiene and infection prevention

Based on the suggestions co-developed in conjunction with local experts and stakeholders regarding the possible ways of improving infant hygiene and infection prevention practices and the best communication channels to engage with the different population groups, a set of tailored recommendations was developed. This set of recommendations is directed at local programmers that want to develop or deliver interventions to enhance infant hygiene and enteric infection prevention practices in rural tribal Banswara, with the ultimate goal of improving the child nutrition and development status of the region.

The set of recommendations is presented in Table 8-4, and it is organised by the different relevant target population groups (mothers, families, village communities, frontline health workers, and government officials) that future programmes and interventions may want to work and engage with. The structure of this set of recommendations (organised by the 5 target audience groups) is akin to the PANChSHEEEL intervention framework[49], since it was envisioned that these recommendations would inform potential future stages of the PANChSHEEEL project, where a holistic tailored intervention to address child malnutrition and stunting is delivered in rural tribal Banswara.

Table 8-4 Recommendations set to inform local programming and interventions to enhance infant hygiene and enteric infection prevention practices in rural tribal Banswara

Target audience	Recommendations	Communication channels
District level government officials	· The impact of poor WASH and enteric infections during the first 2 years of the infants' life on child malnutrition, stunting, and impaired development needs to be highlighted to the relevant district-level government officials. · The mismatch between official records and village realities regarding improved domestic water and sanitation facilities coverage needs to be highlighted, alongside the need for accurate reporting. · Efforts to deliver child health & hygiene promotion programmes across tribal villages need to be revamped to raise awareness about key infection risks and infection prevention practices amongst infant caregivers. This package provides recommendations on how to do so.	These recommendations for district-level officials could be shared via a briefing or presentation at the POSHAN convergence meetings where all the relevant district-level department representatives come together
Frontline health workers	· The frontline health workers' perceived ability to provide health & hygiene advice and act as health activists needs to be strengthened. Germ theory sessions where the pathogen transmission pathways are explained could be delivered to improve ASHA's understanding of infection risks and safe hygiene practices. Easy-to-use microbial tests to analyse faecal contamination levels of the environment such as dip-slides could further capacitate frontline health workers to provide trusted health & hygiene advice. · Providing official certificates of completion after each ASHA health training module could prove useful to increase parents' trust in ASHAs health knowledge.	These recommendations could be delivered at the block-level ASHA training events, where all ASHAs from each block gather together routinely

Mothers	· Delivering an infection risk awareness & infant hygiene promotion programme could persuade mothers to adopt hygiene practices that enhance infant infection prevention. It is recommended that such a programme includes: · The infection risks to infants from exposures to the floor soil, soiled objects, soiled hands, and animals' faeces around the house during child play are explained. Using floor mats, child play yards, or animal corrals and fences should be proposed as possible locally feasible strategies to for infant infection prevention. · The sources of water contamination need to be explained to mothers together with strategies to reduce water contamination risks such as using ladles to collect water, boiling water, or avoiding bathing infants in streams. · Motivation to use soap for handwashing at key times and for washing kitchen utensils needs to be enhanced. Creative materials such as illustrative pictures with cues and nudges could prove useful to trigger an uptake of the soap use habits.	These recommendations for mothers could be delivered by frontline health workers using visual materials such as posters, and discussed at existing womens' group meetings such as PUKKAR and VHND
Family households	Given the role of fathers, grandparents, siblings, and other caregivers in childcare, it is recommended that an infection risk awareness & infant hygiene promotion programme also reaches them. Such a programme could include: · A storybook explaining the key infant enteric infection risks (from exposures to soil, soiled objects, and animal faeces during child play, as well as exposures to contaminated water, food, and dirty hands). · A picture card game to propose infection prevention strategies (for water handling and treatment, and for infants' separation from soil and animal faeces) and promote the adoption of hygiene practices (soap use for handwashing and washing utensils). · A handwashing with soap effectiveness demonstration using hand colouring powder is delivered.	Recommendations that reach fathers, grandparents and siblings of infants could be delivered at events organised at the Anganwadi centres by frontline health workers through engaging activities such as story books, picture card games, and demonstrations
Village communities	It is recommended that for key messages of an infection risk awareness and infant hygiene promotion programme to reach whole village communities: · Audio story books could be delivered via radio channels, highlighting the key infection risks (from exposures to soil, soiled objects, animal faeces, contaminated water, food, and dirty hands), proposing infection prevention strategies (for water handling and treatment and for soil and animal faeces separation), and promoting the adoption of hygiene practices (soap use for handwashing and washing utensils).	Recommendations that reach whole village communities could be delivered via the local radio channels through podcasts and audio stories

Developing the materials for the delivery of interventions or programmes remained out of scope for this study. However, an initial pilot illustration was developed to serve as a basis for the materials to be used to raise awareness about the several infection risks to infants across the village communities. I conceptualised and designed an illustration that was able to visually convey all the potential risks to faecal exposures that infants could face in the study villages, as had been captured during data collection. Once the design had been defined, a professional illustrator was tasked with drawing it. After discussions with the fieldwork team colleagues from Save the Children, the illustration was refined to ensure that it was locally relevant and relatable to the tribal people of Banswara. Figure 8-3 presents the pilot illustration depicting Infant's enteric infection risks in rural Banswara. The purpose of the illustration was to serve as a possible prototype to build from and develop the recommended materials to raise awareness about infant's enteric infection risks.

Figure 8-3 Illustration of infant's enteric infection risks in rural tribal Banswara

8.5 Discussion and conclusion

This chapter dealt with the process of co-developing tailored recommendations based on the key findings obtained in this thesis. Integrating all the mixed-methods results in a matrix allowed me to observe discrepancies and convergences, but most importantly allowed me to have a whole picture of the findings and see patterns emerging about what the key factors driving enteric infections in infants in the study setting were. Based on the integrated findings and by means of online consultations with local experts and stakeholders, I was able to co-develop a set of recommendations to address the key infection factors through engaging with the different population groups that play a role in infant hygiene and infections.

8.5.1 Integrated findings on key barriers to infant hygiene

Some of the key factors identified in the mixed-methods results integration exercise, such as the challenges with accessing clean water, the uptake of toilets and handwashing with soap at key times, were already well recognised infection risk factors. In fact, these factors (i.e. water, toilets, handwashing) have formed the core of most WASH interventions up until now[281] and are the key indicators for WASH progress worldwide[19]. Nevertheless, the focus on infants and the first 1000 days of life in this study shed a light on some other not-so-well recognised infant-specific infection risk factors such as the role of poor domestic hygiene. The infants' exposures to earthen floors in *Kacha* households and the close contact with domestic animals' faeces, coupled with the infants' exploratory and mouthing behaviours, made these factors of high-relevance as potential infection risks, while they had been traditionally ignored in more adult-centred WASH studies[10]. The involuntary ingestion of water from local streams while bathing was also identified as an important infection risk factor to infants that, to my knowledge, has not yet been yet included in any WASH intervention.

The socio-ecological approach adopted throughout this thesis prompted me to look at the most proximal, as well as at the most distal factors hindering progress in infant hygiene. Using these multi-level lenses led me to recognise the role of some deeply rooted characteristics of tribal culture that inevitably shaped infant hygiene practices. For instance, the fact that tribal communities had traditionally entrusted spiritual and non-registered practitioners with child healthcare[282] posed a barrier to the uptake of government healthcare schemes, as parents seldomly sought the government's frontline health workers help. Similarly, the fact that tribal communities have been the passive recipients of government development schemes[191] was also thought to influence the perceived lack of self-efficacy among tribal parents to drive WASH progress. It is evident that the tribal community's cultural background has shaped many aspects of their daily lives, ultimately influencing several infant hygiene-related practices as well. While these factors may be out of scope for an infant hygiene and nutrition intervention, it is essential they are accounted for and were considered when co-developing recommendations.

8.5.2 Co-developed recommendations

Discussions with local experts and stakeholders were essential to identify locally suitable ways for parents to enhance their hygiene and infection prevention practices. During expert consultations, while there was a tendency to move away from recommendations that would require lengthy governance involvement, there was a particular focus on trying to identify easy and simple "hacks" that could be adopted using local materials and local knowledge that would help reinforce safe infant hygiene practices. These simple "life-hacks" or creative "work-arounds" were colloquially referred to as *jugaad (जुगाड़)*[283]. *Jugaad* was a concept that was commonly alluded to, not only during expert consultations, but also by villagers, that prided themselves on being able to come up with frugal solutions. The emphasis on identifying local *jugaads* exemplified the willingness of the tribal population as well as local stakeholders to find their own solutions to the problems and live autonomously.

The set of recommendations (Table 8-4) was conceptualised as an integrated package. Throughout this thesis, it has been repeatedly observed that the determinants of infant enteric infections are intertwined. As it was argued from the beginning and further confirmed by recent large WASH RCTs[23], standalone WASH intervention activities "*are not effective enough in reducing faecal-oral transmission of pathogens to support child growth and optimal health*"[23]. It is important that the set of recommendations is considered as a bundle of integrated activities to be delivered conjunctly. While the proposed recommendations are complementary to each other, the challenge of complex multifaceted package also lays in defining under which public sector's responsibilities they fall. The proposed set of recommendations touches on several different topics that have traditionally been broken up into different ministerial responsibilities (i.e., water, houses, animals, toilets, healthcare…). As it can be seen in Figure 8-4, there are multiple government schemes from several different ministries that are currently in place with relevant responsibilities for the different key infection factors identified. It is obvious that a coordinated effort is required to bring together all the different schemes and ministries and integrate efforts to enhance infant hygiene and ultimately child malnutrition and stunting. Luckily, this is the specific purpose of the POSHAN *Abhiyaan* District Convergence Committees, which were set up as part of the POSHAN Mission[35]. Therefore, while aligning all the different sectors (i.e., water, housing, toilets, health promotion, healthcare, child development…) is a significant challenge, the POSHAN Mission provides the ideal platform for the delivery of complex multifaceted intervention packages as the one proposed in this chapter.

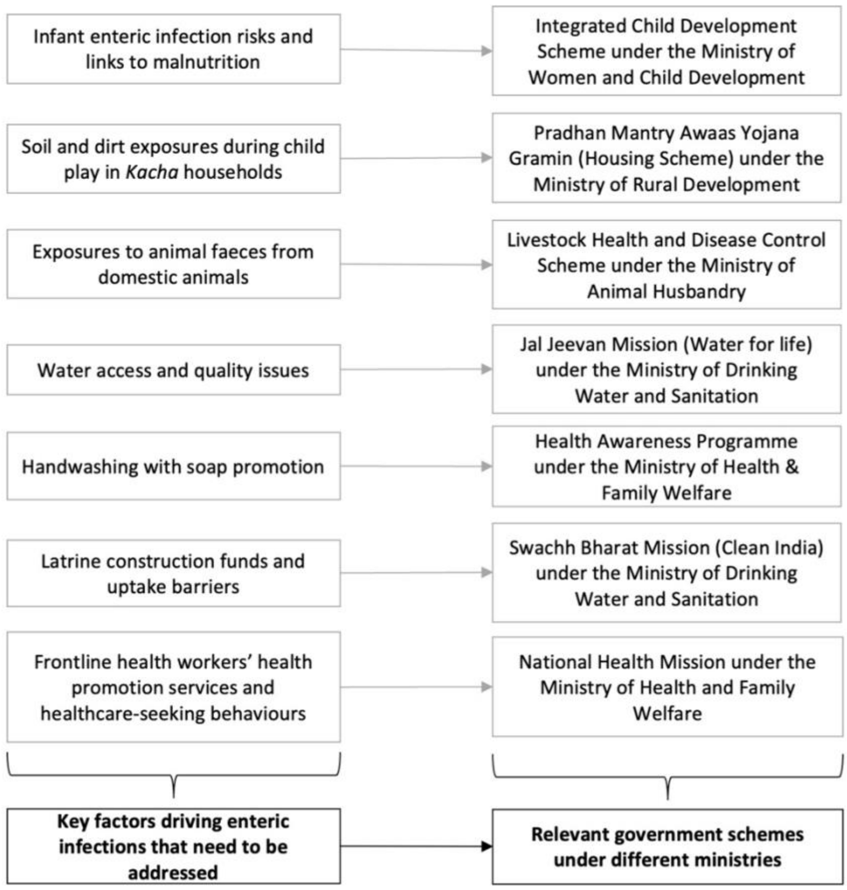


Figure 8-4 Government schemes and ministries with relevant responsibilities for infant enteric infections

8.5.3 Strengths and limitations

The main limitation of this chapter was not having been able to conduct meetings with the community members themselves to co-develop recommendations, nor having been able to deploy and test them to obtain feedback. Local perspectives are crucial to develop recommendations that lead to feasible and sustainable interventions. Unfortunately, due to the COVID-19 restrictions, it was not possible to go back to the rural villages of Banswara to discuss the study findings and develop recommendations with the community. Bringing the set of recommendations back to the study communities to refine and implement them remains a potential line of future work. Nevertheless, this limitation was partially addressed by engaging with a range of local experts and stakeholders with different levels of knowledge. Some local stakeholders had a comprehensive knowledge of the tribal study communities, having worked with them for several years. Some other local experts were knowledgeable about the institutional and policy aspects of programme implementation in Banswara, Rajasthan and India, which proved very useful when discussing potential programmatic recommendations.

Despite these limitations, the strengths of this chapter lay on the fact that the process of co-developing recommendations was grounded on extensive field-based research and a comprehensive understanding of the village-level realities. Moreover, the process of co-developing recommendations followed a series of methodological steps, presenting a traceable conceptual path to how they have been developed. Rather than having emerged from a single researcher's thinking process, the recommendations were the result of the integrated conclusions among a group of relevant experts. As argued by Professor Chambers, a deep understanding of the grounding local realities and complex contexts, a focus on engagement and dialogue, and reflexivity on what is really important, is what enhances rigour in participatory research[129], and it is here where the strengths of this research chapter lay.

8.5.4 Conclusion

Based on the integrated findings captured in this thesis and in conjunction with local experts and stakeholders, a set of recommendations to enhance infant hygiene and enteric infection prevention practices among rural tribal communities in Banswara was developed. The recommendations, targeted to local programmers and interventions, include suggestions on the key issues that need to be brought to the attention of the relevant district-level government officials, suggestions on how current health and hygiene promotion programmes delivered by frontline health workers could be enhanced, and recommendations on how to deliver an infection risk awareness and infant hygiene promotion programme that persuades parents and infant caregivers to adopt infant infection prevention practices. Harnessing local opportunities, simple, frugal, and locally available strategies (i.e., *jugaads*) to reinforce infant infection prevention practices were identified. Ultimately, tribal communities have been self-sufficient for centuries. A simple fresh pair of eyes and attentive pair of ears may prove helpful to nudge them to recognise the perhaps overlooked risks and local opportunities to enhance and reinforce hygiene behaviours that will protect infants from faecal exposures and enteric infections.

9 Chapter 9. Implications of findings and concluding remarks

9.1 Chapter overview

In this final chapter of the thesis, I summarise the key findings and their methodological and empirical contributions. I discuss the implications of the findings for policy and programming in India and reflect on the way forward. I finish by providing concluding remarks.

9.2 Key findings and contributions from this thesis

9.2.1 Key findings addressing the study's aim and objectives

This thesis investigated the risk factors and transmission pathways contributing to enteric infections in infants, focusing on a few rural villages in tribal India. The thesis started with a review of the literature, where it was apparent that the issue of enteric infections during the early years of life and the associated consequences for child health and development, are a persistent challenge in rural India, and globally. It was also clear that traditional approaches for improving WASH and interrupting infants' exposures to faecal pathogens have been overly simplistic and with only limited success at improving child health and growth outcomes. A need to develop a more comprehensive understanding that considered a broader range of interdisciplinary factors contributing to infants' enteric infections, was identified. Consequently, this thesis' aim was to develop a holistic understanding of the multiple risk factors and transmission pathways to enteric infections in infants in rural tribal India and develop tailored recommendations for local programming.

Through conducting a period of fieldwork in selected case study villages in rural India, data was collected using a range of mixed methods. Qualitative data was thematically analysed, descriptive summary statistics were drawn from quantitative data, and a risk assessment was performed with environmental microbial data to address the first three study objectives. Further online interviews were conducted with local experts and stakeholders to address the fourth and last objective of the study, to develop recommendations for local programming. The key findings addressing each of the study objectives are summarised in Table 9-1.

Table 9-1 Summary of key findings addressing each of the four study objectives

Objective 1. To holistically explore the multiple and multifaceted risk factors at the individual, household and village-level contributing to infant enteric infections.
An arid geographical climate, limited livelihood opportunities, unreliable local governance, social caste discrimination, poor housing conditions and WASH facilities, feelings of inability to interrupt infection risks, and unsafe domestic and hygiene practices were several of the multiple factors that were observed to contribute to infant's faecal exposures and enteric infection risks in rural tribal Banswara. These findings suggested that future interventions need to look beyond infection risk factors as currently defined and recognise the impact of broader interdisciplinary factors across the physical environment, the socio-cultural, socio-economic, and institutional domains. For instance, restoring the tribal attitudes of perceived self-efficacy may be key to drive improvements in WASH and child health.
Objective 2. To assess the faecal contamination levels in the infants' environment and evaluate the risks of enteric infection from multiple transmission pathways.
The faecal contamination levels were high and widespread across the study villages in rural tribal Banswara. Infants faced considerably high daily risks of enteric infection from drinking water, from bathing at the local streams, from ingesting soil while playing and crawling on the household earthen floors, and from the constant hand-mouthing contacts. While soil ingestion and hand-mouthing contacts were the exposure pathways that posed the highest risks of enteric infection, all the pathways analysed posed high accumulated risks throughout the infants' first two years of life. These findings suggested that substantial reductions in faecal contamination across the infants' domestic environments need to be achieved before any changes in the infant enteric infection burden are seen.
Objective 3. To identify key barriers for the delivery and uptake of rural child healthcare services, particularly WASH promotion and infant enteric infection prevention services.
The frontline health workers' multiple responsibilities and lack of emphasis on their health activism and hygiene promotion roles hindered the delivery of WASH and infection risk awareness services in rural Banswara. On the other hand, the traditional beliefs about health and disease among tribal communities meant they often relied on unregulated private practitioners for healthcare and advise, which hindered the uptake of public health services. These findings suggested that strengthening the frontline health workers' health promotion roles and strengthening the tribal communities' trust in public health services will be crucial to improve delivery and uptake of public health schemes in WASH promotion, infection prevention, and child health.
Objective 4. To co-develop a set of tailored recommendations to inform local policy and programming for enhancing infant hygiene and enteric infection prevention practices.

Based on the integrated findings captured in this thesis and in conjunction with local experts and stakeholders, a set of tailored recommendations to enhance infant hygiene and enteric infection prevention practices among rural tribal communities in Banswara was developed. Through recognising overlooked risks and harnessing local opportunities, simple, frugal, and locally feasible strategies to reinforce infant hygiene and infection prevention practices amongst caregivers were identified. The set of tailored recommendations will prove useful to local programmes and interventions aiming to enhance infant hygiene and enteric infection prevention practices, to ultimately improve child health, nutritional and development indicators in rural tribal Banswara.

9.2.2 Methodological contributions to community-based research in rural tribal India

Learnings from preliminary testing of the mixed methodologies during the formative fieldtrip (Section 4.3) and reflections from the fieldwork stage (Section 4.6) contributed to identifying several important challenges and opportunities for conducting fieldwork-based research with a rural tribal community in India. These learnings may inform and be relevant to a wider range of studies working with rural or indigenous communities in similar settings.

The tribal populations of India, like other indigenous populations, continue to carry a disproportionately high burden of disease that warrants further research into these communities. However, at the same time, the material deprivation and history of cultural oppression put tribal communities in a vulnerable position that warrants for caution on how research is conducted[220]. Reading about the historical and socio-political past of the *Bhil* study communities was essential for me to understand their background and where their customs and beliefs might be coming from, and to be able to conduct culturally sensitive research. For instance, learning about the fact that religious beliefs in tribal communities were not rooted in Hinduism, but modern pressures to become integrated into mainstream culture means that they increasingly self-describe as Hindus[180,191], helped me understand some of the subtleties that arose when discussing religion-influenced topics, such as their diets, and be culturally sensitive about these topics. During fieldwork, the extensive ground-level observations across villages and households proved crucial to generate rich and in-depth data about the day-to-day realities of the tribal communities, revealing nuances that could not have been captured through other methods. The observation periods also proved insightful because they fostered numerous naturally occurring interactions with community members, which allowed villagers to voice their own concerns and priorities. Village residents often took the chance of having researchers ask about their lives to emphasise the predicaments in which they found themselves. While these unstructured conversations often diverged from the topic of study, they allowed me to connect with the people and form a more comprehensive picture of the broader factors influencing their habits and beliefs. It has been argued that participatory research methods reduce the power imbalances and allow tribal communities to address their own health needs[220].

Adopting a holistic approach in which the elements of the system were considered as an integrated network of interconnected elements, was a key aspect of this study. There were several features of this PhD study that embedded this holistic approach and that may guide other studies aiming to adopt similar systems-thinking. To begin with, the fact that the supervisory team was formed of four experts with distinct backgrounds (i.e., paediatrics, engineering, microbiology, and social health) encouraged me to approach the study objectives from different perspectives from the outset and consider a range of mixed methods to investigate the topic of concern. The use of mixed methods enabled me to appreciate the diversity of factors influencing infection risks across disciplines and how they influenced each other (i.e., health-related, built environment, microbiological, and socio-cultural). In addition, the socio-ecological model that underpinned this study throughout forced me to look at the different hierarchal levels each time, and consider how individual, family, community and societal-level factors interacted. Finally, the use of concept mapping as a tool enabled me to visualise the complex system and interdisciplinary factors and in an integrated manner. These methodological considerations enabled me to continuously ground the project into a holistic perspective.

The reflections on my own positionality and the ways in which it challenged, facilitated, and overall influenced the research could also prove useful to other researchers that are seeking to conduct cross-cultural research. Being a foreigner presented significant challenges to understanding the true inner workings of the communities' lives given the wide cross-cultural gap that divided me from the study communities. However, acquiring a conversational level of the Hindi language and working in close partnership with local researchers proved crucial to bridge many of such cultural gaps and enabled more harmonious and fruitful interactions with participants. On the other hand, being a foreigner provided the chance to ask naïve questions without being perceived as inquisitorial. When researchers have been perceived as "insiders" to the study communities, participants have sometimes presumed that they should know the answers to what they are asking them[284]. Being a foreigner also provided the opportunity to hold exciting cross-cultural interactions, which appeared to be engaging not only for myself but also for the study participants, who were often equally intrigued to learn about each other. My cross-cultural interactions did not only occur at the field site with the study participants but continuously throughout the PhD project. A regular rapport with the team of local fieldwork researchers was maintained throughout the project, who became regular advisors on the feasibility of fieldwork to be conducted at the field site, and the appropriateness of the results and conclusions drawn. In addition, having a supervisor from the Indian academic sector who was knowledgeable in the national-level policies and health systems provided invaluable insights for conducting this research based in India, while at UCL. Based on my own experience of fieldwork in a community culturally distant from my native one, I would suggest to any researcher preparing to conduct similar cross-cultural research to leverage the opportunities of being an "outsider"[208], such as the ability to ask naïve questions and to foster engaging cross-cultural interactions, while ensuring that a minimum level of communicability is acquired to be able to directly interact with participants, and that a continuous rapport is maintained with local partners so that there is a constant engagement with the study context.

9.2.3 Empirical contributions to *transformative* BabyWASH interventions

This thesis has contributed to advancing knowledge towards *transformative* BabyWASH interventions by improving the understanding of what the multiple risk factors and transmission pathways to enteric infections in infants are, using a few rural tribal villages in India as an exemplary case study. As explained in Section 1.5.2, the BabyWASH sector is concerned with understanding and addressing the multiple factors that contribute to poor child health and nutritional outcomes during the child's first two years of life, ultimately leading to impaired physical and cognitive child development[65]. The empirical contributions of this thesis respond to the call that was made by the WHO/UNICEF at the start of 2019[21] (Section 1.5.4), a call that highlighted the knowledge gaps in BabyWASH, and that asked for efforts towards identifying what *transformative* interventions would require. While it was not entirely clear what these would entail, it was agreed from the outset that they would need to be **context-specific, risk-based,** acknowledging of the **multiple infection risks** across disciplines, including **infant-specific exposure** pathways, reaching a **high community coverage**, strengthening the **governance systems**, and finally considering **the sustainability of the programmes** implemented[21].

- This thesis investigated the **multiple enteric infection risks** with a focus on those **particular to infants** in their first 2 years of life in a **specific context** of study. Findings suggested that future *transformative* BabyWASH interventions will need to consider a broader range of interdisciplinary factors that ultimately contribute to infant's infection risks. In rural Banswara for instance, the tribal communities' history of discrimination and cultural oppression, and the modern-day pressures such as climate change that are contributing to the displacement from the communities' agrarian livelihoods, have shaped the tribal identities and attitudes. These broader-level factors may be contributing to the attitudes of resignation and feelings of inability to improve their living conditions, reducing their opportunities to take advantage of public health schemes for child health available to them.

- This thesis also included a **risk-based** study, in which an important feature was the discovery that the infants' exposure to soil from crawling in earthen household floors was a critical pathway to enteric infection. Future BabyWASH interventions will need to address traditionally neglected infection risks such as infant's soil exposures in earthen households while acknowledging that sizeable reductions in environmental faecal contamination need to be achieved in rural settings, particularly where infants live in close contact with animal faeces.
- The exploration of the frontline health workers' roles and child health services available across the rural villages revealed a mismatch between the government policies and programmes and how they were actually delivered and perceived in the rural communities, which highlighted several pitfalls of the **governance systems**. Findings suggested that "a transformation" is required in the implementation field, but particularly in the implementation of health promotion programmes, which continued to be obliterated by other more mechanistic and better monitored programmes. These findings may also apply to the wider global public health sector, which while consistently getting better at lifesaving and reducing mortality, its shortcomings continue to be in health promotion and preventive measures, as shown by the persistent high levels of morbidity.
- Finally, the co-developed recommendations in this thesis will contribute to future local programmes and interventions in Banswara by providing suggestions on how to address some of the key infant enteric infection risks using local resources that would be **sustainable** in the local community. Particularly, the set of recommendations will directly contribute to the larger programme of research by informing the PANChSHEEEL intervention package.

9.2.4 Contributions to the larger programme of research

As explained previously, this PhD project stemmed from a larger programme of work initiated by the PANChSHEEEL Project in 2017[24], which aimed to develop an intervention package to address malnutrition and stunting in children under-2 in rural India. Under the PANCHShEEEL Project, a package of intervention activities to enhance infant and young children's feeding practices in the rural tribal district of Banswara was developed[49]. This PhD project stemmed from the fieldwork research done during PANChSHEEEL, in which a knowledge gap to further explore the multiple infection risk factors to infants was recognised. Partly, the purpose of this PhD project was to complement the findings from PANChSHEEEL and get a more complete picture of the multiple infant malnutrition drivers in rural Banswara. Hence, the findings and recommendations developed during this PhD contribute to the larger programme of research under PANChSHEEEL, and the tailored recommendations developed (Section 8.4.3) inform its intervention package and its future plans to be deployed. Figure 9-1 shows a cyclical diagram of how this PhD stemmed from the PANChSHEEEL project and was motivated by an identified knowledge gap, and ultimately how it complements and informs the larger programme of research towards addressing infant malnutrition and stunting in rural India.

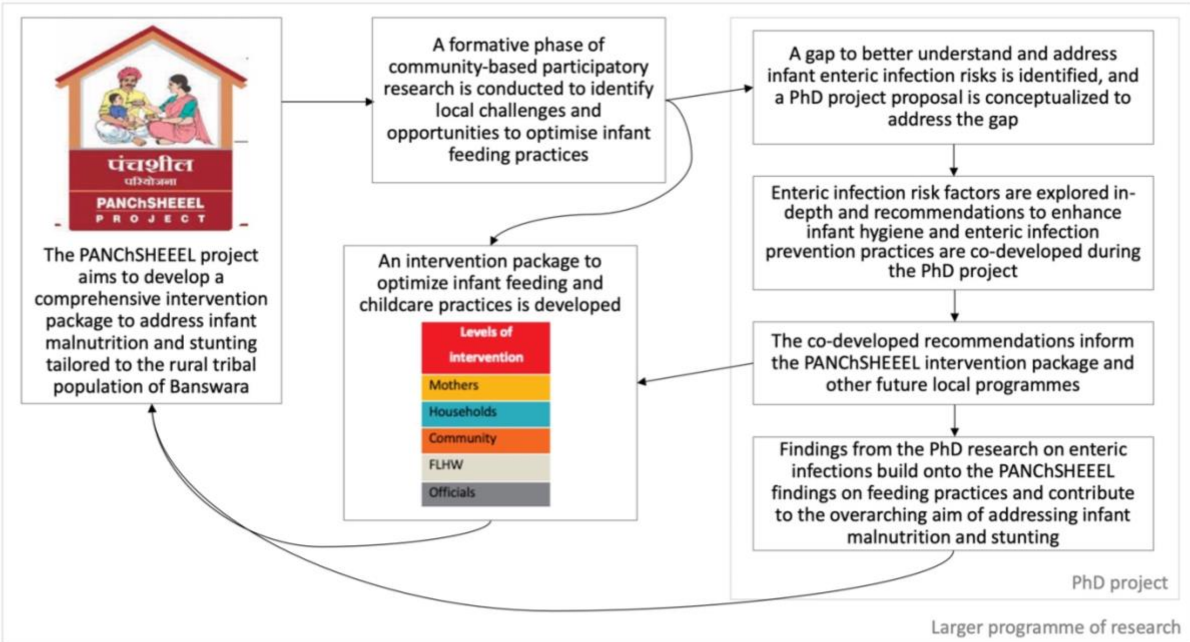


Figure 9-1 Cyclical diagram of how this PhD stemmed from and feeds back into a larger programme of research

9.3 Implications for future policy and programming

At the start of this PhD, in 2018, India was already saddled with high burdens of child malnutrition and stunting. According to the India national health survey NFHS-4 conducted in 2016/2017, 35.5% of all children under-5 were underweight, and 38.4% were stunted[285]. India's target to meet the SDG 2 of ending hunger and malnutrition and SDG 6 of achieving safe water and sanitation for all by 2030 was already a significant challenge. However, motivated by the commitment to meet the SDG Agenda, efforts to reduce child malnutrition and stunting in India were being revamped. For instance, the launch of the POSHAN Mission in March 2018, which set to achieve a 2% annual reduction in child stunting by fostering inter-sectoral convergent action brought a renewed focus to battle child stunting[34]. From the start of this PhD in 2018, to now, start of 2022, communities worldwide have gone through unprecedented times marked by the COVID-19 pandemic, which have inevitably shaped the progress towards the SDG Agenda in 2030. Since March 2020, the infants in the study communities have likely been affected by the disruptions in the economic activity and supply chains that impacted the agricultural practices and gains from their families, by the border closures that barred their parents from practising temporary migration and who lost job opportunities and incomes, by the school lockdowns that left almost 2 billion students unschooled for months leading to numerous other issues such as food insecurity from lost school meals, by the excess deaths that left orphaned children[185], and more. The pandemic has made people plunge deeper into poverty, particularly affecting the most vulnerable such as the rural tribal communities in Banswara. Moreover, while COVID-19 placed the spotlight on the elderly population due to their higher mortality rates, children were the "unaffected", so it is important that post-covid programmes do not forget about children.

Throughout this same time period of the PhD, the time has run out for the POSHAN Mission, which set to revise its target to reduce child stunting by 10 percentage points in 2022 (from 2017). We are now at the start of 2022. The nationwide stunting rates have decreased 3 percentage points, from 38.4% to 35.5%. Similarly, underweight rates have reduced from 35.8% to 32.1% of children under-5[15]. These results are far from the envisioned targets, and could even worsen once the impact of the COVID-19 disruptions is captured in the data[286]. Overall, the current situation does not paint a pretty picture for the issue of child malnutrition and stunting, and the POSHAN target for 2022 appears to be unattainable. If there was a need to address enteric infections as key determinants of child malnutrition and stunting, this need is even more urgent now. Findings from this thesis provide timely and relevant learnings for policy and programmes in India targeting malnutrition and stunting, such as future revamped efforts under the POSHAN Mission.

On the one hand, findings from this thesis have made it clear that interdisciplinary efforts are required to tackle enteric infection factors, which were identified across different dimensions. Therefore, the vision of the POSHAN Mission to bring together the different ministries to deliver convergent action to tackle child malnutrition and stunting is a commendable effort from the Government of India. However, on the other hand, the fieldwork done in this study highlighted the mismatch between what the national-level programmes aim and claim to do, and what the realities at the village level were. Several examples of this disconnect were captured in this study. For instance, while the *Swachh Bharat* Mission claimed to have achieved an open-defecation free district in Banswara, with 95% coverage of households with improved latrines[189], the ground-level realities in the villages were quite different. Most households had unfinished latrine constructions without a pit, that were reported to have been built only for "namesake" in the official records. Another example of such a mismatch was captured when looking at the frontline health worker's roles. While someone who reads about the frontline health workers' roles and responsibilities, as described in the official programme guidelines, may think that rural tribal communities are receiving a comprehensive range of maternal and child health services, including WASH and health promotion, infection risk awareness, nutrition education, complementary feeding, and others, this thesis captured the multiple barriers that frontline health workers faced in delivering these services.

This gap in the delivery of health and development schemes led me to reflect on how programmes such as the POSHAN Mission are touching the lives of these rural communities. I wondered: Are those who need them, really appreciating the benefits of these programmes? Quotes such as *"The major problem is of water. From where do we get water for everyone?" "There is no water here for drinking purpose, so how will the people here use it for toilets?"* by village residents very clearly stated what their main problems were. Instead, programmes such as the POSHAN Mission are essentially devoted to enhancing the governance and management aspects of improving child health and nutrition, rather than directly targeting the main problems voiced by the villagers. While *transformative* BabyWASH interventions addressing the multiple interdisciplinary factors and fostering convergent action across the governance systems may be needed to comprehensively improve child health and nutrition, as emphasised by this study, it is important to remember that very basic needs still need to be covered. If plates remain empty and water taps dry, it is unlikely that real progress is realised.

The findings and recommendations in this thesis bear relevant implications for policy makers and programmers defining future schemes under the POSHAN Mission or other programmes that aim to tackle infants' infections and nutrition in India, particularly in the Banswara district. This thesis suggests that future programmes to tackle child malnutrition and stunting will need to integrate multiple components to improve infants' hygiene and infections, and their diets, for which intersectoral convergent action will be essential. However, before these future programmes are implemented, a real strengthening of the delivery mechanisms will be needed to ensure that the public schemes reach the ground. Accurate and reliable monitoring and evaluation of the ground-level realities will be vital for the "messy truth" to not remain hidden underneath the data, and therefore unaddressed. The pandemic has elevated the relevance of hygiene as a key aspect of good health. Hopefully, this will boost efforts to develop and implement BabyWASH programmes that deliver integrated child health, nutrition, and hygiene services during the first 1000 days of life, bringing India closer to SDG 2 (zero hunger) and SDG 6 (clean water and sanitation).

9.4 Conclusion

This study found that the first two years of an infant's life in the rural tribal villages of Banswara are impacted by continuous exposures to faecal pathogens present in their domestic environment via multiple pathways. These continuous exposures lead to repeated enteric infections with possible long-term morbidities including child malnutrition and stunting. Given the widespread faecal contamination levels and the numerous and multifaceted infection risks identified, transformational changes across multiple dimensions will be required before meaningful impacts on the contamination levels and the infant enteric infection burden are realised. Integrated efforts to improve the public water supply, sanitation facilities, housing conditions, infection risk awareness, hygiene behaviours, frontline health promotion services, and attitudes towards public health systems, are all needed. Notably, incorporating the tribal communities' views in future public health programmes to promote their self-efficacy and mobilisation will be essential to drive improvements in their living conditions and child health and hygiene. Moreover, focusing on addressing infants' exposures to contaminated soil in rural, earthen, farming households will be crucial to reduce their overall risk of enteric infection.

Government efforts for convergent intersectoral action across different ministries to tackle child infections, malnutrition, and stunting are a step in the right direction. However, this thesis painted a detailed picture of the daily village-level realities that emphasised the disconnect between the institutional-level public health programmes and the delivery and uptake of them at the village level. Future work will need to ensure that these integrated programmes that are set to address child infections and stunting actually reach the ground-level communities, for all infants to have a safe and clean environment to develop and reach their potential.

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Appendices

Appendix A. Career development activities and doctoral training

Type of activity	Description	Date
Doctoral skills course	Introduction to Doctoral Skills Development and the Research Student Log	17/10/2018
Doctoral skills course	Managing your PhD: How to Solve problems and boost your creativity	25/10/2018
Doctoral skills course	Training on bullying and harassment specifically to support students at ICH	27/10/2018
Risk assessment application	Completed Risk Assessment application for fieldwork and occupational health hazards training and forms	01/11/2018
Doctoral skills course	Introduction to qualitative research: In-depth interviewing	12/11/2018
Doctoral skills course	Introduction to Qualitative Research: Thematic Analysis	13/11/2018
Conference-Attendance	International Society for Neglected Tropical Diseases conference (ISNTD Water 2018)	15/11/2018
Doctoral skills course	Multilevel data analysis with R by CASC training	04/12/2018
Doctoral skills course	Tips for conducting Research	18/01/2019
Doctoral skills course	Your PhD Part 1 - Reading for a PhD - The First Important Steps	22/01/2019
Doctoral skills course	Your PhD Part 2 - Management Skills for Researchers	23/01/2019
Doctoral skills course	Ethical issues when conducting research in developing countries	13/02/2019
Fieldwork abroad for data collection	First preliminary fieldwork trip to Banswara, India (3 weeks), to conduct a recce visit and preliminary fieldwork tasks in preparation for data collection	28/02/2019
Conference-Attendance	Attended the PANChSHEEEL Dissemination Conference in Jaipur, India	28/02/2019
Fellowship application	Successfully applied to the Chadwick Trust Travelling Fellowship, to cover fieldwork costs overseas. I was named Jeroen Ensink Fellow 2018-2019 in recognition of the relevance of the PhD project for the field of WASH.	01/03/2019
Ethics Application	Submitted an ethics review application to the UCL Ethics Committee	25/03/2019
Ethics Application	Submitted an ethics review application to the Institutional Review Board at IIHMR University in Jaipur	01/04/2019
Language acquisition	Enrolled in Hindi language classes at the Mary Ward Centre. Completed levels: Year 1 A,B,C, Year 2 A,B,C, Year 3 A,B,C and Year 4, A.	29/04/2019
Doctoral skills course	Research Integrity Workshop	14/05/2019

Conference-Attendance	Attended the PANChSHEEEL Dissemination Conference in London, UK	18/06/2019
Laboratory skills training	Conducted lab sessions at the UCL Dept Civil and Environmental Engineering for training on the membrane filtration technique, culture incubation and culture count, to test for faecal contamination levels in environmental samples.	01/08/2019
Conference - Poster Presentation	Presented a poster at the 3rd ECR WASH Conference at Cranfield University	05/09/2019
Research Assistance	Research assistant for fieldwork data collection with Aceso Global Health Ltd. Assisted during fieldwork for data collection in Jaipur slums, as part of the feasibility phase of the CHIP (Childhood Infections and Pollution) research project.	15/09/2019
Fieldwork abroad for data collection	Fieldwork trip (3 months) for data collection. Designed and organised the fieldwork logistics, schedules, data collection protocols and tools. Managed and led the team through the data collection and microbial analysis procedures. Worked in partnership with the local branch from the Save the Children NGO.	09/09/2019
Poster Presentation	Presented poster at the UCL GOS ICH Poster Competition	01/10/2019
Doctoral skills course	Writing to Engage: the Art and Craft of Good Writing	29/01/2020
Competition - Hackathon	1 day Hackathon to design WASH solutions for an NGO in Bangladesh, led by the UCL Engineers Without Borders (Designathon)	08/02/2020
Viva presentation	MPhil to PhD Upgrade Session for Research Students	20/02/2020
Doctoral skills course	Public Engagement Skills: Train and Engage Session 1: Practical Public Engagement	10/03/2020
Doctoral skills course	Public Engagement Skills: Train and Engage Session 2: Learning from Public Engagement	11/03/2020
Doctoral skills course	Public Engagement Skills: Train and Engage session 3: Project Management and Finding Funding	18/03/2020
Doctoral skills course	Editing your own work *Cancelled*	26/03/2020
Conference-Oral Presentation	Cranfield WASH ECR 4th Conference. *Abstract for oral presentation accepted but conference was cancelled due to Covid*	01/04/2020
Training course	Attendance at the Global Environmental Health Course (a 2-week intensive training programme) at Institute Salut Global, Barcelona, Spain. *Cancelled*	15/04/2020
Teaching assistance	Teaching assistant for the Environmental Engineering module (led by Dr Ilan Adler) from CEGE, UCL. Tasks: marking final year projects	20/04/2020
Doctoral skills course	Data Science foundations in R. Online course by Coursera	01/05/2020
Conference-Oral Presentation	IAS QMUL South Asia Conference *Abstract for oral presentation accepted but conference was cancelled due to Covid*	01/06/2020

Internship	Accepted as an intern to conduct a 3-week internship at UNICEF Malawi, training with the WASH (Water, Sanitation, Hygiene) team. *Internship cancelled*	01/06/2020
Journal article submission	Submitted article manuscript to the Journal of Water and Health	21/08/2021
Internship	Internship with the ISGlobal research institute to help with the data collection phase for a large cohort study in Barcelona, Spain, studying the impacts of COVID in the population.	01/09/2020
Journal club	Led and participated in a weekly journal club with other PhD Candidates where we critically analysed epidemiology papers and reviewed key epi topics during 9 months.	01/10/2020
Journal article submission	Submitted an article manuscript to the Journal of Water, Sanitation and Hygiene for Development	12/10/2020
Conference-Attendance	Attended the UNC Water and Health Conference 2020 (5 days long). Virtual attendance	20/10/2020
Public Engagement event	Accepted as a speaker at the SoapBox Science Event 2020, an outreach platform for promoting women scientists. Received training on how to make engaging videos for dissemination and presented my research in a live online youtube event, where over 300 viewers from the general public were present.	05/11/2020
Doctoral skills course	Presentation storytelling techniques course	20/11/2020
Journal article submission	Submitted an article manuscript to the BMC Public Health Journal	04/12/2020
Doctoral skills course	Introduction to rapid ethnography course	26/02/2021
Public Engagement event	Submitted a visual illustration of my research to the Virtual Art & Science Exhibition titled "The Early Years- A window of Opportunity: A Global Art & Science Exhibition", showcasing selected artwork about Child, Maternal and Family Health.	26/03/2021
Journal article submission	Submitted an article manuscript to the Journal of Indian Pediatrics	20/04/2021
Public Engagement event	Participated in the 3 Minute Thesis (3MT) competition and was awarded the joint winner “People’s Choice” Award of the 2021 GOS ICH 3MT competition	20/04/2021
Conference-Poster presentation	Poster presented at the RCPCH Singapore 2021 virtual conference. Poster abstract peer-reviewed and published in the BMJ Paediatrics Open journal.	03/06/2021
Peer-reviewed journal article publication	Published a peer-reviewed article at the BMC Public Health Journal	07/06/2021
Peer-reviewed journal article publication	Published a peer-reviewed article at the Journal of Indian Pediatrics	07/08/2021
Conference-Attendance	SIWI Conference 2021. Virtual attendance	23/08/2021
Conference-Attendance	WEDC Conference 2021. Virtual Attendance	14/09/2021

Conference-Oral presentation	Presented at the 42nd WEDC Conference, and the conference abstract was peer-reviewed and published in the conference proceedings.	15/09/2021
Conference-Attendance	UNC Water and Health Conference 2021. Virtual attendance	04/10/2021
Review of a journal article	Reviewed a paper for the SAGE Open Medicine Journal	10/10/2021

Appendix B. Village spot-checks data collection tool

SPOT-CHECK OF VILLAGE WASH-RELEVANT RESOURCES		
VILLAGE ID:		
DATE AND TIME OF START AND END:		
TEAM:		
ADDITIONAL INFORMATION: Observations should be an evaluation of the situation at one point in time and should therefore take no more than a few minutes per site. The aim of this tool is to be able to capture the details of the state of the WASH resources at the village level and understand how they are used for drinking, washing, agriculture and livestock. WASH resources at the village level will impact sanitation and hygiene practices and help us understand those better. Answers are to be complemented with remarks from the community champions accompanying us during the transect walk.		
CANAL		Answer
1	Is there water in the canal?	
2	Is the water clear/transparent?	
3	Is the canal free of visible solid waste?	
4	Is the canal free of visible animal or human excreta?	
5	Is the canal odourless?	
6	Q-What do people use the canal's water for? Cleaning clothes? Crops? *Log nehar ke pani ka upaiog kis lie kya karte hai? Kapre saf karna? Fasal?*	
7	Q- Do children play in the canal? *Kya bacce neher me khelte hai?*	
8	Is the canal in close proximity to households (<100m)?	
Notes Take picture		
DRAIN (NALA)		Answer
9	Is there water?	
10	Is the water clear/transparent?	
11	Is there visible solid waste?	
12	Is there visible animal or human excreta?	
13	Does the nala smell?	
14	Q-What do people use the drain's water for? Cleaning clothes? Crops? *Log nehar ke pani ka upaiog kis lie kya karte hai? Kapre saf karna? Fasal?*	
15	Q- Do children play in the drain? *Kya bacce neher me khelte hai?*	
16	Is the nala in close proximity of the households (<100m)?	
Notes Take picture		
PONDS / WELLS		Answer
17	Is there water?	
18	Is the water clear/transparent?	

19	Is there visible solid waste?	
20	Is there visible animal or human excreta?	
21	Is the well odourless?	
22	**Q**-What do people use the well's water for? Crops? Animals? *Log kuna ke pani ka upaiog kis lie kya karte hai? Fasal? Janvar ke lie?*	
Notes Take picture		

RO SYSTEM		Answer
23	Is there an RO system in the village?	
24	Is the RO system functioning right now?	
25	Does water flow from the drinking water tap of the RO system?	
26	Does water flow from the washing water tap of the RO system?	
27	Is each tap (drinking/washing) clearly indicated by words and colours?	
28	Is the water flow remarkably small (i.e. it would take more than 5s to fill a glass of water)?	
29	Is there a cloth wrapped around the tap outlet?	
30	Are there water puddles around the RO system?	
31	Are there insects (mosquitos, flies) around the water tap?	
32	Is there a man-made ally for the water to drain from the tap?	
33	Is there soap nearby?	
	Q-Who uses the RO system in the village and for what? *RO ka upaiog kaun karte hai?*	
Notes Take picture		

PRIMARY SCHOOLS		Answer
	Is there electricity available? *(bijalee)*	
	Are there latrines?	
	Do latrines have a pit?	
	Are there latrines for boys/girls?	
	Is there a handwashing station?	
	Is there soap in the school?	
	Is the school floor improved?	
	Is the courtyard floor improved?	
Notes Take picture		

ANGANWADI CENTRES		Answer
	Is there electricity?	
	Are there latrines?	
	Is there a handwashing station?	
	Is there soap in the anganwadi centre?	
	Is the school floor improved?	
	Is the courtyard floor improved?	
Notes Take picture		

Appendix C. Household visual survey data collection tool

HOUSEHOLD VISITS- GUIDED VISUAL SURVEY		
HOUSEHOLD ID: VILLAGE ID: DATE AND TIME OF START: TEAM: ADDITIONAL INFORMATION: Tool used to be able to capture household-level infrastructural & material factors and how they could potentially correlate with higher levels of faecal contamination in the house and infection risks. Observations to be captured in the moment and questions to be asked either to the household head or parents of the child.		
KITCHEN		Answer
HOB		
1	Does the household have an LPG hob?	
2	**Q-**Where is the food cooked? *Aap kaha khana banate hai? LPG/ Chulha/ Dusera*	
3	Where in the house is the main cooking place?	
4	**Q-** What is it used to fuel the cooking source? Agricultural waste (wood/straw/shrub/grass) / animal dung / electricity / other *Aap kis indhan ka upaiog karte hai? (lakri, ghass, upla, bijali, kerosene, dusera)*	
5	Are there flies around the cooking place?	
6	Are there animal faeces around the cooking place?	
UTENSILS		
7	Where in the house are the cooking utensils stored?	
8	Do the cooking utensils appear visibly clean?	
STORED DRINKING WATER		
9	Is there stored drinking water in the house compound?	
10	Where in the house is the water stored?	
11	Which type of container is used to store the water? Metal jar / ceramics / plastic / other	
12	Is the water container covered?	
13	Is there a ladle or cup used to scoop the water from the container next to it?	
14	Do the water storage containers and cups appear visibly clean?	
15	**Q-** How do they treat the water to make it safer to drink? Boil/ Chlorine tablets/ cloth/ water filter/ let it stand to settle/ other *Kya aap jal upachar karte hai? Pani nerapad banate hai? Kuch nahi/Foda/chlorine/filter/dusera?*	
STORED FOOD		
16	Is there any dry food stored in the house compound?	
17	Is there any fresh food stored in the house compound? (fruit, veg, eggs, meat/fish)	
18	Is there any milk stored in the house compound?	
19	Is the food stored in a separate closed room where animals cannot access?	
20	Is the food stored in covered storage units?	
21	Are there flies around the stored food?	
LIVING ROOM		Answer
BUILT ENVIRONMENT AND CLEANLINESS		
22	Type of indoor flooring Natural (mud/clay/earth/sand/dung) / rudimentary (wood planks, brick, stone) / finished (parquet, asphalt, ceramic, tiles, polished, marble)	

23	Type of outdoor flooring Natural (mud/clay/earth/sand/dung) / rudimentary (wood planks, brick, stone) / finished (parquet, asphalt, ceramic, tiles, polished, marble)	
24	Type of roofing Natural (no roof, grass or leafs, mud, soil, or plastic), rudimentary (rustic mat, wood planks, unburnt brick or loosely packed stone), finished (metal, wood, cement, concrete, tiles, burnt brick)	
25	Is the indoor floor free of visible faeces?	
26	Is there an off-ground sleeping area indoors?	
27	Is the sleeping area (beds and cloths) visibly dirty?	
28	Is there an off-ground surface for the child to sleep/rest (i.e. hammock or hanging sari)?	
28	Is the child bed (hammock or hanging saree) visibly dirty?	
30	Is the household compound free of solid waste?	
31	**Q-**Does the household have access to working electricity at least a few hours a day? *Kya aapke pas kam karne ki bijli hai?*	
32	Are there mosquito nets in the child sleeping area?	
COURTYARD		Answer
LATRINE		
33	**Q**-How far away from the house is the closest latrine? (in approximate meters) *Toilet kitne duur hai?*	
34	Type of roofing None / bricks / aluminium / ceramic / other	
35	Type of flooring None / PVC / Earth, mud or bare / concrete / tiled / other	
36	Does the latrine have a door?	
37	Does the door have a closing mechanisms (i.e. handle/lock)?	
38	Does the latrine have a ventilation system?	
39	Does the latrine have a light for night time use?	
40	Does the latrine have a concrete/slab?	
41	How far is the water source for handwashing after latrine use? (in approximate meters)	
42	Can spillages be observed around the latrine? Excreta / urine / none	
43	Is smell apparent in the latrine?	
44	Are there flies in the latrine?	
45	**Q-** Does the latrine appear to be regularly used? *(if observed, justify indicators)* Dry / brick in the latrine slab / object blocking access to latrine / others *Log toilet me aate hai?*	
46	How many households share the latrine facility?	
HAND-PUMP OR DOMESTIC WATER SOURCE		
47	Is the household's main water source a hand-pump at the time? And if not, which water source is used? (electric borewell, well)	
48	How far away from the house is the water source (in approximate meters)?	
49	When pumped, does water flow from the tap?	
50	Is the water flow very small (i.e. it would take more than 5s to fill a glass of water)?	
51	Is there a cloth wrapped around the tap outlet?	
52	Are there water puddles around the water source?	
53	Are there insects (mosquitos, flies) around the water source?	

54	How does the water drain? Earth/mud drain/ cemented drain / underground drain / other	
55	Is soap for handwashing observed?	
56	**Q-**What is the hand-pump water used for? Drinking / bathing / clothes washing / animal care *Yehe pani pine, sharir dhona, kapre dhona, janvaran ke lie hai?*	
57	**Q-** Are other water sources used for other uses? If yes, which and for what? Canal / Nala / RO / bottled water / other *Pani ke any srot?*	
58	**Q-** Where are young children washed/bathed? Hand-pump water / canal / nala *Bacce kaha dhoya jata hai?*	
59	**Q-** During the last year, has the main water source ever gone dry?	
60	**Q-** During the dry season or other times of the year, do you use other sources of water?	
ANIMALS		
61	Does the household have animals?	
62	If yes, which animals and how many?	
63	Are the animals corralled/tied/fenced?	
64	Where are the animals now? Indoors / Courtyard / Separate from the dwelling / moving free / other	
65	How far are they from the house? (in approximate meters)	
66	**Q-** Where do animals sleep? indoors in same room as people / indoors different room from people / different building / courtyard / other *Janvar kaha sote hai?*	
67	Are there visible animal faeces in the animal space? Yes, indoors / Yes, outdoors / No / Other	
68	Are there visible animal faeces in the rest of the house (in the non-designated animal spaces)?	
69	**Q-** What is done with the produce from the animals? Only consumed in the house, only sold outside the house, both consumed and sold outside. *Kya aap gay ka dudh pite hai ya use bechte hai?*	
YOUNG CHILDREN		Answer
70	Is the child wearing…? Shoes (for mobile children) / lower body cloth / upper body cloth	
71	Is the child visibly dirty? No / face / hands / clothes / feet / hair / other	
72	Does the child have flies on their body? No / a few / many / a lot	
73	Does the child appear to have skin infections (i.e pimples, rash)? *Describe what:*	
74	Does the child have signs of dehydration? Cracked lips / dry skin / sunken eyes / no tears / skin turgor / other	
75	Does the child seem overall healthy/lethargic/irritable/sick/other? If yes, justify:	
76	**Q-** Has the child been acutely ill during the past 30 days? *Kya bacce pichli tis dinon ke doran bimar hua hai?*	
77	**Q-** Have they had any of this symptoms in the past 30 days? (mention all) Cough / Fever / Sore throat / Otitis / Conjunctivitis / Vomiting / Abdominal pain / Fatigue / Weight loss / Dermatitis - Skin rashes / Diarrhoea (3 loose stools per day) / Worms observed in faeces *Kaunse lakshan the? Khasi, Bukhar, Gale me kharash, kaan sankraman, aankh sankraman, Ulte, Pet me dard, takan, vazan me kami, tvacha sankraman, dast, mal me kire.*	

78	**Q-** Did you seek for medical help? No / ASHA / AWW / ANM / other *Kya aap ASHA/AWW/ANM/Hospital ke pas gae the?*	
79	**Q-** What is the mother's occupation? *Mata ji ke kam kya hai?*	
80	**Q-** What is the father's occupation? *Pita ji ke kam kya hai?*	
	Notes	

Appendix D. Caregivers' domestic practices observation data collection tool

HOUSEHOLD VISITS - MONITORING OF CAREGIVERS' DOMESTIC PRACTICES

HOUSEHOLD ID: VILLAGE ID:

DATE AND TIME OF START AND END:

ADDITIONAL INFORMATION: Tool used to be able to capture household-level behavioural infection risks posed by the immediate caregivers to the young child. Record behavioural features related to the following behaviours: Caregiver handwashing, Infant washing and faeces disposal, Cooking and feeding episodes, Child play, Animals and Family roles in childcare. The aim is to capture potential infection risks (behaviours, attitudes & practices that represent an infection risk)

Caregiver handwashing opportunities

#	Opportunities (mark with an X each opportunity)	Hands washed?	How? (Soap, mud, drying agent, place, water source…)	Person
	Before cooking or handling food			
	Before feeding child			
	After contact with animals or agricultural waste			
	After contact with stools (animal, child, or latrine)			
	Other trigger:			

Infant washing episodes and faeces disposal

#	What was washed?	How? (water source, soap, drying agent, disposal of faeces)	Triggers for washing	Person

Cooking and feeding episodes

#	Food type and source of food	Food preparation space and utensils	Feeding/eating setting	Hygiene condition of eating setting and food	Person

Child play			
	Spaces for child play	Objects for child play	Child play surveillance attitudes

Animals			
	Use of animal products (including faeces)	Care for the animals (who, how…?)	Attitudes towards hygiene safety related to animals

Family roles in childcare				
	Roles in child-caring from each family member	Decision-making in child-care	Dynamics between family members	Family dynamics with a potential impact on child infections

Final observer comments:
Did you feel that your presence triggered behaviour-change reactivity? (yes/no/explain)

Appendix E. Infants' exposures structured observation data collection tool

HOUSEHOLD VISITS - MONITORING OF INFANTS' EXPOSURES						
HOUSEHOLD ID:			DATE AND TIME OF START:			
VILLAGE ID:			MOBILITY OF THE CHILD: lying, sitting, crawl, walk			
ADDITIONAL INFORMATION: Tool to perform a hazard analysis of the faecal exposure pathways for young children. The aim is to identify child behaviours that pose a potential risk of infection with faecal bacteria. In "exposure quantification, visually assess dirtiness of object.						
INFANTS MOUTHING TALLIES						
Child age (months) & mobility	**Child location** (Exposure source)	**Child behaviour** (type of hazardous event)	**Caregiver** (Control/mitigation)	**Elements in mouth** (Exposure pathway)	**Exposure quantification (f, ", g)**	**Severity of hazard**

Appendix F. Key Informant Interviews topic guide tool

FRONT-LINE HEALTH WORKERS INTERVIEW GUIDE
अग्रणी स्वास्थ्य कार्यकर्ता साक्षात्कार मार्गदर्शिका

FRONT-LINE HEALTH WORKER ID
VILLAGE ID:
INTERVIEWER:
DATE AND TIME OF START AND END
INFORMATION: This interview is to assess the front-line health workers knowledge of enteric infections and perceptions of enteric infection risks, as well as their opinion on the village WASH infrastructures and committees.

TOPIC 1. ASHA's ROLES AND RESPONSIBILITIES
आशा की भूमिकाएं और जिम्मेदारियां

1. Tell me a little bit about your role as an ASHA. How long have you been working as an ASHA? On a typical week, what tasks do you carry out?
   मुझे आशा के रूप में अपनी भूमिका के बारे में कुछ बताएं। आप कितने समय से आशा के रूप में काम कर रही हैं? एक सामान्य सप्ताह में, आप कौन से कार्य करते हैं?

2. Could you tell me about the last VHND sessions? What did you do?
   क्या आप मुझे अंतिम वीएचएनडी सत्रों के बारे में बत सकती हैं? आपने क्या किया?

3. What is your role in the VHSNC sessions? Could you tell me about the last session?
   वीएचएनसएनसी सत्रों में आपकी क्या भूमिका है? क्या आप मुझे पिछले सत्र के बारे में बता सकती हैं?

TOPIC 2. CHILD GUT INFECTIONS- PERCEPTIONS ON BURDEN AND TREATMENT PRACTICES
बच्चों में आंत संक्रमणः प्रसार और उपचार की जानकारी

4. I wanted to ask you about the child diarrhoea cases in this village. Do many or few child diarrhoea cases happen in a month?
   मैं आपसे इस गांव में बच्चों के दस्त के मामलों के बारे में पूछना चाहता था। क्या आपको लगता है कि इस गांव में बच्चों में डायरिया के कई या कम मामले होते हैं?

5. How do the diarrhoea cases vary in the wet and dry season?
   गीले और सूखे मौसम में दस्त के मामलों में क्या अंतर सामने आता है?

6. If a father or mother comes to you with their baby of 1 year and tells you that he has been suffering from diarrhoea lately. What do you tell or do?
   अगर कोई पिता या माता अपने 1 साल के बच्चे को लेकर आपके पास आते हैं और आपको बताते हैं कि उन्हें हाल ही में दस्त हो रहे हैं। आप क्या कहते हैं या क्या करते हैं?
   Further prompts if needed:
   - Can you recount the last cases of child diarrhoea in which your help was sought? How did you manage those cases?
     क्या आपको पिछले मामले याद हैं, जब आपकी मदद ली गई थी? आपने उन मामलों में क्या कि या?
   - What do you advise parents to give the child? Or do you give them medicines from your drug kit?
     आप माता-पिता को बच्चे को क्या देने की सलाह देते हैं? या आप उन्हें अपनी दवा किट से दवा देते हैं?
   - When do you advise they go to the health centre?
     आप उन्हें अस्पताल जाने की सलाह कब देते हैं?
   - What advice do you give so diarrhoea does not come again?
     आप क्या सलाह देते हैं ताकि दस्त दोबारा न आए?

TOPIC 3. CHILD GUT INFECTIONS – PERCEPTIONS ON INFECTION RISKS AND CONSEQUENCES बच्चों के आंत संक्रमण- जोखिम धारणाएं

RISKS

7. In this village, what are the things that could cause children to get diarrhoea?
   इस गांव में, ऐसी कौन सी चीजें हैं जिनसे बच्चों को दस्त हो सकते हैं?
   Further prompts if needed:
   - Where do you think they can get it from? From water, food, flies, dirty hands, from soil, animals?) आप इसे कहाँ से प्राप्त करते हैं? पानी में, स्नान, भोजन में, हाथों से, मिट्टी से, जानवरों से?)

8. Do you think people are aware of all these risks as well?
   क्या आपको लगता है कि लोग इन सभी जोखिमों से भी अवगत हैं?
   Further prompts if needed:
   - Do you tell them about them? How? When? Do they listen to your advice? क्या आप उन्हें उनके बारे में बताते हैं? कैसे कब?

CONSEQUENCES

9. If a child in this village gets diarrhoea, how likely is it to cause very serious illness or death?
   यदि इस गाँव के किसी बच्चे को दस्त होते हैं, तो इसके बहुत गंभीर बीमारी या मृत्यु का कारण बनने की आशंका कितनी है?
   Further prompts if needed:
   - If a young child has many diarrhoea episodes during his first 2 years of life, do you think the child could have long-term consequences of this?
     यदि किसी छोटे बच्चे को जीवन के पहले 2 वर्षों में कई बार दस्त होते हैं, तो आपको लगता है कि बच्चे पर उसका क्या दीर्घकालिक परिणाम हो सकता है?

10. What are the 5 illnesses that you are most worried about for young children in this village.
    इस गाँव में छोटे बच्चों की किन 5 बीमारियों को लेकर आपको सबसे ज्यादा चिंता है।

TOPIC 4. PERCEPTIONS ABOUT VILLAGE WASH INFRASTRUCTURE AND DEVELOPMENT PRIORITIES ग्राम अवसंरचना और विकास प्राथमिकताओं के बारे में राय

11. Now, I want to ask you about the water and hygiene infrastructures in this village.
    अब, मैं आपसे गांव में पानी और स्वच्छता के बुनियादी ढांचे के बारे में पूछना चाहता हूं।
    Further prompts if needed:
    - Does water run out from the hand-pumps in the dry season? Do you think that water is good for drinking? How do people treat drinking water to make it safe?
      क्या गर्मियों या सूखे मौसम में हेंड पम्प्स सूख जाते हैं? क्या आपको लगता है कि पानी पीने के लिए अच्छा है? क्या लोग पीने के पानी को सुरक्षित बनाने के लिए उसका उपचार करते हैं?
    - Tell me about the latrines: Are they in good condition, do people use latrines? Would people want to use them if they were improved?
      मुझे शौचालयों के बारे में बताइए: क्या वे अच्छी स्थिति में हैं, क्या लोग शौचालय का उपयोग करते हैं? यदि उनकी हालत सुधरी तो क्या लोग इस्तेमाल करेंगे?
    - Tell me about the Nalas & Canals: What are they used for? Do you think that water is safe?
      मुझे नाले और नहर के बारे में बताइए: पानी का इस्तेमाल कहां होता है? आपको क्या लगता है, पानी इस्तेमाल करने योग्य है?

12. If more money was available from the Gram Panchayat, how do you think it would be better spent?
    यदि ग्राम पंचायत को ज्यादा राशि उपलब्ध कराई गई, आपको क्या लगता है कि उसे खर्च करने का सही तरीका क्या होगा?

Appendix G. Focus Group Discussions topic guide tool

FOCUS GROUP DISCUSSIONS TOPIC GUIDE
VILLAGE ID: INTERVIEWERS/MODERATORS: DATE AND TIME OF START AND END: NUMBER OF PARTICIPANTS: INFORMATION: This interview is to assess the front-line health workers knowledge of enteric infections and perceptions of enteric infection risks, as well as their opinion on the village WASH infrastructures and committees.
INTRODUCTION/ICE-BREAKER
TOPIC 1. PERCEPTIONS ON CHILD GUT INFECTIONS' BURDEN, DIAGNOSIS AND TREATMENT
Possible prompt questions if needed: • How do you feel about the cases of child diarrhoea in this village? Are they a cause for worry for you? • It can be hard to recognize loose stools in young children's - How do you recognize when a child has diarrhoea, do you ever doubt or is it ever difficult to see for you? • When the child is sick with diarrhoea, what do you do? • Do you use home remedies first or how do you decide when to go to hospital
TOPIC 2. PERCEPTIONS ON CHILD GUT INFECTIONS' CAUSES AND CONSEQUENCES
Possible prompt questions if needed: • In your home, where and how do you think your children might get infections in this village? • (Follow up) Why do you think water/food/nalas/soil/animals/environment in this village may make children sick? • What do you think happens to babies who have many diarrhoeas later on?
TOPIC 3. PERCEPTIONS ON VILLAGE RESOURCES
Possible prompt questions if needed: • In this village, do you face any problems with the hand-pumps, canals, school or Anganwadi buildings, with toilets, with roads or others? • Where do you think the Sar Panch should invest more money in this village? What would be the first priority need?

Appendix H. Health event observation data collection tool

SEMI-STRUCTURED OBSERVATIONS OF VILLAGE-LEVEL HEALTH EVENTS
EVENT NAME: VILLAGE ID: TEAM: DATE AND TIME OF START AND END: ADDITIONAL INFORMATION: This tool is to be used to assess the functioning of the village-level WASH and child-health relevant events. Relevant quotes from conversations to be annotated. Health events of interest: Events PUKAR meetings, VHND- Village Health and Nutrition Day at the Anganwadi Centres, VHSNC- Village Health Sanitation and Nutrition Committees.
FACILITIES
Physical space where the event is taking place?
HEALTH WORKERS & HEALTH LEADERS
Team of people in the event? Role of each? Contribution of each?
COMMUNITY MEMBERS
Involvement of community members? Input from the community? Community outreach of the event?
TOPIC OF DISCUSSION/SERVICES PROVIDED
What is being discussed or broadcasted, with what purpose and for what reason?
DISCUSSION DYNAMICS
How is it being discussed? How is it being recorded (e.g. notes taken, attendance registered)? How is the conversation being moderated?
Notes perceived reactivity effect?

Appendix I. Protocol for environmental sampling and analysis of faecal bacteria

PROTOCOL FOR ENVIRONMENTAL SAMPLING

Protocol developed to collect drinking water, surface water, stored water, hand samples and soil samples. Methods designed to collect samples for microbial analysis to detect possible faecal contamination.

SAMPLES TO BE COLLECTED

From each village:

- 3 samples from nalas (at different nalas or at 3 different sites 100m away from each other
- 3 samples from canals (at different canals or at 3 different sites 100m away from each other
- 3 samples from wells. From 3 different wells if available.
- 3 samples from ponds. From 3 different ponds if available, or from different sites 100m away from each other
- 3 samples from the public hand-pumps (from schools and AWC)
- 3 samples from earthen floors at schools and AWC

From each household:

- 1 sample from their main water source
- 1 sample from their stored drinking water
- 1 sample from caregiver's hands
- 1 sample from infants' hands
- 1 sample from household earthen floor composite

PROTOCOL FOR WATER & HAND RINSE SAMPLE COLLECTION

Equipment needed:

1. Gloves
2. Ice chest with frozen ice packs
3. Sterile 200mL Whirl-Pak bags
4. 70% ethanol
5. Clean clothes/Cotton
6. Bucket
7. Jug filled with saline water (PBS)
8. Sampling swabs/foam or cotton buds/Medical cotton wool balls
9. Android Device
10. Labels
11. Permanent Marker

Sampling protocol:

1. Take a photo of the sampling location and check coordinates with the phone
2. Label whirl-pak bag: Date_Time_Village_HHID/Coordinates_Source_#
3. Put on gloves and spray your hands with alcohol.
4. Collect sample
    a. **Tap water samples:** Remove any external fittings from the tap (rubber tubes or cloths). Let the water run for 5s. 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 200mL

mark. Close the Whirl-Pak bag by carefully and quickly rotate the bag, without spilling the sampled water, and then twisting the wire tabs together.

b. **Stored water:** Ask the HH members if we can pour water (using what they would normally use: ladle or glass) from their primary drinking water storage container into the bag. Open the bag properly (like above), fill the bag up to above the 200mL mark, and close the bag properly (like above).

c. **Canals & open drains samples:** Sample from the most accessible place where people would be able to bathe and wash clothes and therefore have more common access. Take care not to scoop any sediment. Open the bag properly (like above). Dip the bag into the water, the mouth of the bag facing upwards. Plunge it down about 30cm below the water surface, tilt the mouth against the current flow and let it fill completely by pushing it forward horizontally against the current flow if needed. Tilt it upwards and pull gently. Close the bag properly (like above).

d. **Wells:** Use the bucket commonly used by the locals to collect water from the well (already attached to the rope system of the wells). Lower the bucket into the well to a depth of about 1 metre. Take care not to scoop sediment if it is shallow. When no more air bubbles rise to the surface, raise the bucket out. Let the collected water settle for 5 minutes. Then, open the whirl-pak bag properly (like above), pour water to slightly above the 200mL mark and close the bag properly (like above). Dump the remaining water.

f. **Hand swabs**: Make sure you have a sterile glove on your dominant hand. Spray 70% alcohol in it. Grab a swab and wet it with PBS. Store it in a 50mL conical tube as a negative control. Grab another cotton and rub the dominant hand of the participant up and down like indicated by the lines in the picture (repeat movement twice per finger). Move the swab across the vertical lines overlapping them. Carefully open a sterile 50mL conical tube (previously filled with 40mL of PBS) and store the swab inside, carefully not touching the mouth of the tube, making sure that the swab does not dry and is completely soaked. Screw the tube lid tightly.

5. Confirm that the bag is labelled and place bag into ice chest with frozen ice packs. Transport samples to the lab within 6 hours.

PROTOCOL FOR SOIL SAMPLE COLLECTION

Equipment needed:

1. Gloves
2. 70% ethanol
3. Sterile spatula/spoon
4. Brushes
5. Sterile 200 mL Whirl-Pak bags
6. Ice chest with frozen ice packs
7. Mobile Device
8. Permanent marker
9. Labels

Sampling Protocol:

1. Take a photo of the sampling location and check coordinates with the phone
2. Label whirl-pak bag: Date_Time_Village_HHID/Coordinates_Source_#
3. Put on gloves and spray your hands with alcohol.
4. Identify the area of interest (the cooking place, the area where the young child has been most recently seen play/sleep/eat, the space observed to be the "living area" where people spend most time). Take care not to contaminate the area by walking over it.
5. Sterilize the spatula/brush with ethanol and a clean paper towel. Draw on the ground a square of approximately 10x10cm. Scrape the top layer of soil (the top mm of soil), and scoop approximately the volume of a teaspoon of soil. Open the bag properly (like above) and empty the contents into the 200mL whirl-pak bag. If the sample sticks to the scoop, use the interior of the bag to remove the sample. Repeat the process in 3 different locations within the area to obtain a 3-composite sample. Close the whirlpak bag properly (like above)
6. Sterilize the spatula (and brush) again by spraying with ethanol and wiping with a clean paper towel.
7. Confirm that the bag is labelled and place bag into ice chest with frozen ice packs. Transport samples to the lab within 6 hours.

PROTOCOL FOR MEMBRANE FILTRATION ANALYSIS OF E. COLI

Preparation:

1. Wipe down bench with 4% bleach followed by 70% ethanol.
2. Assemble the filter equipment, making sure all filter membrane holders have been sterilised. Attach vacuum tubing to side arm and attach vacuum source.
3. Insert filter base into mouth of manifold.
4. Prepare alcohol burner with lighter.
5. Prepare a small beaker with 100% ethanol for sterilizing the tips of the forceps. The ethanol should be 2-3 cm deep, just enough to cover the tips of the forceps when they are resting in the beaker. NOTE: The alcohol burner and ethanol should be on the same side as your dominant hand for easy forceps sterilization.
6. Prepare the plates then label the bottom of the plates with the date, dilution, sample ID, and initials. Be sure to include a plate for the negative control.

Equipment needed:

- Incubator
- Filtration apparatus vaccum unit
- Sterile water
- PBST (phosphate buffered saline, pH 7.2 with 0.04% Tween-80)
- Membrane filters
- Petri dishes
- Permanent marker
- Bucket
- 4% Bleach
- 70% Ethanol
- Pippettes (plastic, one use)- 1mL and 10mL
- Alcohol burner
- Lighter
- Tweezers (sterile)
- mColiblue
- 15mL &/or 50mL conical tubes for vortexing
- Gloves
- Vortex
- Weighing scale

- Beakers for dilutions: 100mL, 50mL, 10mL?

Pre-processing of samples:

- Drinking water samples: Test 100mL (1:1) or **10mL (1:10).** Remember to prepare negative control with sterile water to see how aseptically we are working.
- Drains, canals, wells, ponds, Nalas: Depending on how dirty it is: Test 100mL (1:1), 10mL (1:10) or 1mL (adding 9mL PBS-1:100 dilution), or maybe even (dilute previous dilution-1mL + 9mL- 1:1000 dilution).
- Hand rinses: Test 100mL (1:1) or **10mL (1:10)** or 1mL (+9mL- 1:100 dilution)
- Swabs: Swab contamination depends a lot. Test 10mL (1:10) or 1mL (+9mL- 1:100 dilution), or maybe even (dilute previous dilution-1mL + 9mL- 1:1000 dilution).
    - Put gloves on and spray alcohol.
    - Vortex the conical tube with the cotton swab and PBS inside for 30s. Let it settle for 5 minutes. Vortex for 30s again. Or according to Navab, shake by hand for 2 minutes and let it settle for 15. Using the sterile tweezers, press the swab against the side of the tube to squeeze out as much remaining possible solution and discard the swab.
    - You should have around 35mL left of elute in the tube ready to test.
- Soil: Test 10mL (1:10), or **1mL (+9mL- 1:100 dilution)** or dilute previous dilution-1mL + 9mL- 1:1000 dilution).
    - Put gloves on and spray alcohol. Spray the outside of the bag with ethanol and rub it well.
    - Label a sterile 50mL conical tube. Prepare a weighing scale. Put the conical plastic tube on the scale and tare its weight.
    - Shake the bag with the sample for 5 seconds to mix it well. Open the bag. Using a sterile spatula, take a little bit of the sample and put it in the conical tube (which is on the scale) until 1gr is in the conical tube.
    - Add 20mL of PBS on the conical tube. Screw the cap on and manually vortex for 6mins (2mins-shake, 2mins-decant, 2mins-centrifuge). Let the sample settle for 30 minutes.
    - With a sterile pipette, carefully pipette from the supernatant from the top (and dilute or filter). Take care not to suck up particulate matter or debris.

Processing of samples:

1. Flame forceps for ~5 seconds to sterilize. Take care to hold the forceps horizontally to avoid burning your hand. Put the pad in the petri dishes.
2. Prepare the petri dishes for all the samples and dilutions that we are going to make. Take a pad with the sterilised tweezers and place it in the petri dish. With a sterile pipette, wet the pad with mColiblue using 1.5-2mL of liquid until the pad is completely saturated. Remove any bubbles. Label the metallic lids WITH A PENCIL, specifying the dilution. (label: Date_Time_Village_HHID or Coordinates_Source_#_Dilution).
3. Remove a sterile filter from the packaging with sterile forceps. Remove the filter holder and place the filter on the filter base, grid side up. Affix filter holder to the base. Ensure the vacuum unit is well assembled.
4. Pour 100 mL sterile PBS on the filter. Vacuum it through, carefully not too strong to not break the filter.
5. Carefully, remove membrane filter from filter base with sterile forceps, avoiding contact with the centre of the membrane.
6. Place the filter, gridded side up, onto the plate labeled “Negative Control”. By rolling the filter onto the plate, you can avoid the formation of bubbles between the membrane and the agar surface, which can invalidate your results.

7. Replace the lid of the Petri plate.
8. Repeat steps 2 to 5
9. Add a minimum of 10 mL and up to 100 ml of liquid containing the highest dilution of the sample to the filter. Note: always start with highest dilution (lowest concentration) of sample to avoid introducing significant contamination from higher concentrations. If the test volume is 1ml, add 9mL PBS and spike the PBS with the 1mL sample aliquot (the total volume filtered is 10mL). This ensures that the solution is dispersed evenly around the filter surface.
10. Open the manifold valve and vacuum the liquid through the filter.
11. Use a 10 ml serological pipet to rinse the sides of the filter cup with 10 ml clean water.
12. Close valve on manifold and remove filter cup.
13. Flame forceps for ~5 seconds to sterilize.
14. Remove filter from base using sterile forceps, taking care not to disturb inner area of filter.
15. Place the filter onto a plate labelled with the Sample ID (label: Date_Time_Village_HHID or Coordinates_Source_#_Dilution). Take care to avoid the formation of bubbles between the filter and the agar.
16. Replace the plate lid.
17. Using the same filter holder, repeat steps 10 to 18 for the other dilutions of the sample being tested, going from most dilute to least dilute.
18. For each new sample you will need to re-sterilize gloves with alcohol and use a new filter holder.
19. Do not invert petri dishes. Stack them into the strap and wait for 30 minutes to avoid the bacteria dying from all the handling around. Turn on incubator to allow it to raise to the required temperature before starting.
20. Incubate the plates at 35°C for 24 hours (according to media manufacturer's guidelines). If using mColiBlue, incubate plates in box to avoid desiccation. Be sure not to close the lid tightly, it should just sit on top of the box so that oxygen can still circulate.
21. Record the date and time that the sample was placed in the incubator
22. Retrieve samples from the incubator and count colonies within the next 15 minutes to avoid bacterial colonies going cold and changing colour:
    - First check the negative controls! We can do 2 different controls: Negative control 1: Sterile pad, with sterile media and sterile membrane filter. Negative control 2: Sterile pad, clean water runned through the membrane filter, and sterile media.
    - Count if there are between 3-300 colonies. Count if colonies are between 1-3 millimetres (remember each square of the grid is 3mm width). If there are > 300 colonies, record the results as 999 for "too numerous to count (TNTC)".
    - If individual E. coli colonies cannot be clearly distinguished from background growth or dirt on the filter, record the result as 998 "too dirty to count" (TDTC)).
    - If any E. coli colonies are found on the Negative Control plate, indicate the results next to "Negative Control". Record 0 for no colonies.

Sterilising the material:

1. Buy a pressure cooker with some support cradles and a support surface. Place the support cradles at the bottom of the pot. Pour water up to the top of the cradles, and place the support surface. Make sure that the water does not touch the support surface. Place the material on top of the support surface, making sure it does not touch the walls of the pot or each other. Plastic then will not melt.
2. Place the lid of the pressure cooker and close tightly. Wait until the first burst of steam appears. Then maintain full power for 15 minutes. Then, turn the heat source off and

wait until the pot is cool enough so that we can touch it with bare hands. Check that the sterilisation process has been successfully completed with the autoclave tape.

3. Sterilise the vacuum fold either with the pressure cooker or with the methanol method.

Appendix J. Ethical approval letters

The following pages contain the letters from the ethics boards confirming ethical approval. Letters are provided in the following order:

- Ethical approval letter from the UCL Research Ethics Committee- UK (Project ID: 14703/001)
- Ethical approval letter from the IIHMR Institutional Review Board- India (Project ID: 03042019)

UCL RESEARCH ETHICS COMMITTEE
OFFICE FOR THE VICE PROVOST RESEARCH

10th May 2019

Professor Monica Lakhanpaul
Great Ormond Street Institute of Child Health
UCL

Dear Professor Lakhanpaul

Notification of Ethics Approval with Provisos
Project ID/Title: 14703/001: Exploring the household environment in rural India to characterise the Faecal-oral transmission routes leading to enteric infections in young people

Further to your satisfactory responses to the Committee's comments, I am pleased to confirm in my capacity as Joint Chair of the UCL Research Ethics Committee (REC) that your study has been ethically approved by the UCL REC until **1st September 2021.** Approval is granted on condition that recruitment does not commence until local ethics approval (outlined in Section B3 of your ethics application) has been secured with written evidence provided for our records.

Ethical approval is also subject to the following conditions:

Notification of Amendments to the Research
You must seek Chair's approval for proposed amendments (to include extensions to the duration of the project) to the research for which this approval has been given. Each research project is reviewed separately and if there are significant changes to the research protocol you should seek confirmation of continued ethical approval by completing an 'Amendment Approval Request Form'
http://ethics.grad.ucl.ac.uk/responsibilities.php

Adverse Event Reporting – Serious and Non-Serious
It is your responsibility to report to the Committee any unanticipated problems or adverse events involving risks to participants or others. The Ethics Committee should be notified of all serious adverse events via the Ethics Committee Administrator (ethics@ucl.ac.uk) immediately the incident occurs. Where the adverse incident is unexpected and serious, the Joint Chairs will decide whether the study should be terminated pending the opinion of an independent expert. For non-serious adverse events the Joint Chairs of the Ethics Committee should again be notified via the Ethics Committee Administrator within ten days of the incident occurring and provide a full written report that should include any amendments to the participant information sheet and study protocol. The Joint Chairs will confirm that the incident is non-serious and report to the Committee at the next meeting. The final view of the Committee will be communicated to you.

Final Report
At the end of the data collection element of your research we ask that you submit a very brief report (1-2 paragraphs will suffice) which includes in particular issues relating to the ethical implications of the research

Office of the Vice Provost Research, 2 Taviton Street
University College London
Tel: +44 (0)20 7679 8717
Email: ethics@ucl.ac.uk
http://ethics.grad.ucl.ac.uk/

i.e. issues obtaining consent, participants withdrawing from the research, confidentiality, protection of participants from physical and mental harm etc.

In addition, please:

- ensure that you follow all relevant guidance as laid out in UCL's Code of Conduct for Research: https://www.ucl.ac.uk/srs/file/579
- note that you are required to adhere to all research data/records management and storage procedures agreed as part of your application. This will be expected even after completion of the study.

With best wishes for the research.

Yours sincerely

[redacted]

Professor Lynn Ang
Joint Chair, UCL Research Ethics Committee

Cc: Julia Guilera

IIHMR UNIVERSITY
An Exclusive Health Research and Post Graduate University
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Sanganer Airport, Jaipur-302029
Phone: 91-141-3924700
Fax: 91-141-3924738

Institutional Review Board for Protection of Human Subjects

September 1, 2017– August 31, 2019
Approval Form

Dated: 24/05/2019

	Serial No.	May 2019	1
1	Project Title	**Exploring the household environment in rural India to characterize the faecal-oral transmission routes leading to enteric infections in young children**	
2	Name of Study Coordinator	**Julia Vila Guilera**	
3	Date of Submission to the Committee	0 3 0 4 2 0 1 9	
4	Date of Submission to the Agency	N A	
5	Review Category of the Proposal		
	Expedited Review		
	Full review	✓	
6	Date of Review	0 4 0 5 2 0 1 9	
7	Reviewer's Name	Dr Ravi Verma, Dr Ashoo Grover, Dr Vinod SV, Dr Suresh Joshi, Ms Kamaljeet Yadav, Mr Umesh Saraswat, Dr Neetu Purohit, Dr Nutan Jain, Mr Rahul Sharma, Mr Azeem-ur-rehman	
8	Reviewer's Feedback (Please tick the following, if you are satisfied)		
8.1	Respect for person	✓	
8.2	Fair subject selection	✓	
8.3	Informed consent	✓	
8.4	Maintaining privacy	✓	
8.5	Maintaining confidentiality	✓	
9	Final Comment		
	Approved without suggestions		
	Approved with suggestions	✓	
	Sent back for revision and re-submission		
	Not approved		
10	Suggestions were incorporated up to the satisfaction of the IRB and the Members approved.	[redacted]	

Appendix K. Informed Consent Forms

The following pages contain the informed consent forms that were used for the collection of data from the study participants. All study participants provided written informed consent prior to being included in the study.

Informed consent sheets are provided in the following order:

- Participant Informed Consent Form for household visits in English
- Participant Informed Consent Form for household visits in Hindi
- Participant Informed Consent Form for key informant interviews with frontline health workers in English
- Participant Informed Consent Form for key informant interviews with frontline health workers in Hindi
- Participant Informed Consent Form for focus group discussions with mothers in English
- Participant Informed Consent Form for focus group discussions with mothers in Hindi
- Participant Informed Consent Form for collecting pictures of people in English and Hindi
- Participant Informed consent Form for online interviews with experts in English

<u>Participant Informed Consent Form For: Family Household Visits</u>

UCL Research Ethics Committee Approval ID Number: 14703/001

IIHMR Institutional Review Board: 03042019

Study title: Exploring the household environment in rural India to characterise the faecal-oral transmission routes leading to enteric infections in young children
Principal Investigator: Monica Lakhanpaul
Funding: UCL Great Ormond Street Institute of Child Health

You are being invited to take part in a research study conducted by UCL and Save the Children. Please read this information carefully to decide if you want to take part. We are investigating if the environment in this area is contaminated with germs and if children are getting infections like diarrhoea from it.

Since you have a young child and you live in this area, we would like to visit your house and ask you some questions. If you agree, we would be here for approximately 2 hours: we would observe, take some notes, and ask you some questions about your place, your habits and your child's health. We would also take a small sample of soil, of water and from the palms of your hands (rubbing your hands with cotton). We would also like to take some pictures of your house (not people's faces).

The risks to your family as a result of this study are minimal: you might be worried about what your neighbours will say. We will explain to them that this research will help identify sources of infections and inform guidelines to improve children's health in this area.

While the results of this research will be published, the identity of the individual information will be kept strictly confidential. If you want us to leave at any point or information not to be recorded, you can withdraw from the study at any time without needing to say why. UCL will oversee the protection of personal data, and can be contacted at data-protection@ucl.ac.uk. Following the data protection legislation, you have the right to access, rectify, erase, withdraw, and restrict the use of your data at any time.

Please ask us if there is anything else that is not clear. If you have further doubts you may contact the research team at: Hemant Chaturvedi ([redacted] tel: [redacted]), or the ethics committee at [redacted]

<u>CONSENT:</u>

I confirm I have read and understood the above, and all my questions have been answered. The purpose of the research, the study procedures, the purpose of the information collected, the potential risks and benefits, and the confidentiality concerns have been explained to me. I confirm I want to take part in the household visits and I consent to participate in the study.

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Name of participant	Date	Signature
________________________	______________	________________
Researcher	Date	Signature

<u>परिवारों से मिलने के लिए दौरों में प्रतिभागी को दी जाने वाली सूचना पर सहमति पत्र</u>
<u>यूसीएल रिसर्च एथिक्स कमेटी अप्रूवल आईडी नंबरः</u> 14703/001
IIHMR **संस्थागत समीक्षा बोर्ड**: 03042019

अध्ययन शीर्षकः ग्रामीण भारत में घरेलू वातावरण की पड़ताल करना, जो छोटे बच्चों में आंतों के संक्रमण के मल-मुंह संचरण मार्गों को चिह्नित करना
प्रमुख जांचकर्ताः मोनिका लखनपाल
फंडिंगः यूसीएल ग्रेट ऑरमंड स्ट्रीट इंस्टिट्यूट ऑफ चाइल्ड हेल्थ

यूसीएल और सेव द चिल्ड्रन द्वारा किए जा रहे एक शोध अध्ययन में भाग लेने के लिए आपको आमंत्रित किया जा रहा है। यदि आप इसमें भाग लेना चाहते हैं तो कृपया इस जानकारी को ध्यान से पढ़ें। हम इस बात की पड़ताल कर रहे हैं कि क्या इस क्षेत्र का वातावरण कीटाणुओं से दूषित है और क्या बच्चों को इससे दस्त (डायरिया) जैसे संक्रमण हो रहे हैं।

चूंकि, आपका एक छोटा बच्चा है और आप इस क्षेत्र में रहते हैं, इसलिए हम आपके घर जाना चाहेंगे और आपसे कुछ सवाल पूछेंगे। यदि आप सहमत हैं, तो हम यहां लगभग 2 घंटे रहेंगे: हम निरीक्षण करेंगे, कुछ नोट्स लेंगे, और आपसे आपके घर, आपकी आदतों और आपके बच्चे के स्वास्थ्य के बारे में कुछ सवाल पूछेंगे। हम मिट्टी का, पानी का और आपके हाथों की हथेलियों से (रुई से अपने हाथों को रगड़कर) एक छोटा सा नमूना लेंगे। हम आपके घर की कुछ तस्वीरें (लोगों के चेहरे नहीं) लेना चाहेंगे।

इस अध्ययन के परिणामस्वरूप आपके परिवार के लिए जोखिम बहुत कम हैं: आपको यह चिंता हो सकती है कि आपके पड़ोसी क्या कहेंगे। हम उन्हें समझाएंगे कि यह शोध संक्रमण के स्रोतों की पहचान करने और इस क्षेत्र में बच्चों के स्वास्थ्य को बेहतर बनाने के लिए गाइडलाइन बनाने में मदद करेगा।

इस शोध के परिणाम प्रकाशित किए जाएंगे, लेकिन व्यक्तिगत जानकारी को कड़ाई से गोपनीय रखा जाएगा। यदि आप चाहते हैं कि हम किसी भी बिंदु या जानकारी को दर्ज न करें, तो आप बिना कारण बताए किसी भी समय इस अध्ययन से बाहर हो सकते हैं। यूसीएल पर्सनल डेटा की सुरक्षा की देखरेख करेगा, और इसके लिए data-protection@ucl.ac.uk पर संपर्क किया जा सकता है। डेटा सुरक्षा कानून के बाद, आपके पास किसी भी समय अपने डेटा के उपयोग तक पहुँच, सुधार, मिटाने, वापस लेने और प्रतिबंधित करने का अधिकार है।

यदि कुछ स्पष्ट नहीं हैं तो कृपया हमसे पूछें। यदि आपको और संदेह है, तो आप रिसर्च टीम से संपर्क कर सकते हैं: हेमंत चतुर्वेदी ([redacted] tel: [redacted]), या एथिक्स कमेटी से [redacted] पर संपर्क कर सकते हैं।

<u>सहमतिः</u>

मैं पुष्टि करता/करती हूं कि मैंने ऊपर दी गई जानकारी को पढ़ा और समझा है, और मेरे सभी सवालों का संतोषजनक जवाब दिया गया है। इस अनुसंधान का उद्देश्य, अध्ययन प्रक्रियाएं, एकत्र की गई जानकारी का उद्देश्य, संभावित जोखिम और लाभ, और गोपनीयता की चिंताओं से मुझे अवगत कराया गया है। मैं पुष्टि करता/करती हूं कि मैं अपने घर का दौरा करने और अध्ययन में भाग लेने के लिए सहमति देता/देती हूं।

____________________	______________	________________
प्रतिभागी का नाम	दिनांक	हस्ताक्षर
____________________	______________	________________
शोधार्थी	दिनांक	हस्ताक्षर

<u>Participant Informed Consent Form: Key Informant Interviews</u>

UCL Research Ethics Committee Approval ID Number: 14703/001

IIHMR Institutional Review Board: 03042019

Study title: Exploring the household environment in rural India to characterise the faecal-oral transmission routes leading to enteric infections in young children
Principal Investigator: Monica Lakhanpaul
Funding: UCL Great Ormond Street Institute of Child Health

You are being invited to take part in a research study conducted by UCL and Save the Children. Please read this information carefully to decide if you want to take part. We are investigating if the environment in this area is contaminated with germs and if children are getting infections like diarrhoea from it.

Since you are a front-line health worker in this area, we would like to ask you some questions. If you agree, the interview would take approximately 1 hour. We would ask you questions about the children's infections in this area: what are they caused by, how are they diagnosed and treated. We would like to audio record the interview.

The risks to you as a result of this study are minimal: you might be worried about what your community members will say. We will explain to them that this research will help identify sources of infections and inform guidelines to improve children's health in this area.

While the results of this research will be published, your personal identifiable information will be kept strictly confidential. No one outside the research team will be allowed access to the original recordings. Only anonymous transcripts will be used for analysis. If you want us stop the interview or information not to be recorded, you can withdraw from the study at any time without needing to say why. UCL will oversee the protection of personal data, and can be contacted at data-protection@ucl.ac.uk. Following the data protection legislation, you have the right to access, rectify, erase, withdraw, and restrict the use of your data at any time.

Please ask us if there is anything else that is not clear. If you have further doubts you may contact the research team at: Hemant Chaturvedi ([redacted] tel: [redacted]), or the ethics committee at [redacted]

<u>CONSENT:</u>

I confirm I have read and understood the above, and all my questions have been answered. The purpose of the research, the study procedures, the purpose of the information collected, the potential risks and benefits, and the confidentiality concerns have been explained to me. I confirm I want to take part in the household visits and I consent to participate in the study.

________________________	________________	__________________
Name of participant	Date	Signature
________________________	________________	__________________
Researcher	Date	Signature

सूचना देने वालों के साक्षात्कार के लिए प्दी जाने वाली सूचना पर सहमति पत्र
यूसीएल रिसर्च एथिक्स कमेटी अप्रूवल आईडी नंबरः 14703/001
IIHMR **संस्थागत समीक्षा बोर्ड**: 03042019

अध्ययन शीर्षकः ग्रामीण भारत में घरेलू वातावरण की पड़ताल करना, जो छोटे बच्चों में आंतों के संक्रमण के मल-मुंह संचरण मार्गों को चिह्नित करना
प्रमुख जांचकर्ताः मोनिका लखनपाल
फंडिंगः यूसीएल ग्रेट ऑरमंड स्ट्रीट इंस्टिट्यूट ऑफ चाइल्ड हेल्थ

यूसीएल और सेव द चिल्ड्रन द्वारा किए जा रहे एक शोध अध्ययन में भाग लेने के लिए आपको आमंत्रित किया जा रहा है। यदि आप इसमें भाग लेना चाहते हैं तो कृपया इस जानकारी को ध्यान से पढ़ें। हम इस बात की पड़ताल कर रहे हैं कि क्या इस क्षेत्र का वातावरण कीटाणुओं से दूषित है और क्या बच्चों को इससे दस्त (डायरिया) जैसे संक्रमण हो रहे हैं।

चूंकि, आप इस क्षेत्र में एक फ्रंट-लाइन स्वास्थ्य कार्यकर्ता हैं, इसलिए हम आपसे कुछ प्रश्न पूछना चाहते हैं। यदि आप सहमत हैं, तो साक्षात्कार में लगभग 1 घंटा लगेगा। हम आपसे इस क्षेत्र में बच्चों के संक्रमण के बारे में सवाल पूछेंगे: संक्रमण किस कारण से हो रहे हैं, इनका निदान और उपचार कैसे किया जाता है। हम साक्षात्कार को रिकॉर्ड करना चाहते हैं।

इस अध्ययन के परिणामस्वरूप आपके परिवार के लिए जोखिम बहुत कम हैं: आपको यह चिंता हो सकती है कि आपके पड़ोसी क्या कहेंगे। हम उन्हें समझाएंगे कि यह शोध संक्रमण के स्रोतों की पहचान करने और इस क्षेत्र में बच्चों के स्वास्थ्य को बेहतर बनाने के लिए गाइडलाइन बनाने में मदद करेगा।

इस शोध के परिणाम प्रकाशित किए जाएंगे, लेकिन व्यक्तिगत जानकारी को कड़ाई से गोपनीय रखा जाएगा। रिसर्च टीम के बाहर किसी को भी मूल रिकॉर्डिंग तक पहुंचने की अनुमति नहीं होगी। एनालिसिस के लिए केवल अनाम टेप का उपयोग किया जाएगा | यदि आप चाहते हैं कि हम किसी भी बिंदु या जानकारी को दर्ज न करें, तो आप बिना कारण बताए किसी भी समय इस अध्ययन से बाहर हो सकते हैं। यूसीएल पर्सनल डेटा की सुरक्षा की देखरेख करेगा, और इसके लिए data-protection@ucl.ac.uk पर संपर्क किया जा सकता है। डेटा सुरक्षा कानून के बाद, आपके पास किसी भी समय अपने डेटा के उपयोग तक पहुँच, सुधार, मिटाने, वापस लेने और प्रतिबंधित करने का अधिकार है।

यदि कुछ स्पष्ट नहीं हैं तो कृपया हमसे पूछें। यदि आपको और संदेह है, तो आप रिसर्च टीम से संपर्क कर सकते हैं: हेमंत चतुर्वेदी ([redacted] tel: [redacted]), या एथिक्स कमेटी से [redacted] पर संपर्क कर सकते हैं।

सहमतिः

मैं पुष्टि करता/करती हूं कि मैंने ऊपर दी गई जानकारी को पढ़ा और समझा है, और मेरे सभी सवालों का संतोषजनक जवाब दिया गया है। इस अनुसंधान का उद्देश्य, अध्ययन प्रक्रियाएं, एकत्र की गई जानकारी का उद्देश्य, संभावित जोखिम और लाभ, और गोपनीयता की चिंताओं से मुझे अवगत कराया गया है। मैं पुष्टि करता/करती हूं कि मैं अपने घर का दौरा करने और अध्ययन में भाग लेने के लिए सहमति देता/देती हूं।

____________________	______________	________________
प्रतिभागी का नाम	दिनांक	हस्ताक्षर
____________________	______________	________________
शोधार्थी	दिनांक	हस्ताक्षर

Participant Informed Consent Form: Focus Group Discussions
UCL Research Ethics Committee Approval ID Number: 14703/001
IIHMR Institutional Review Board: 03042019

Study title: Exploring the household environment in rural India to characterise the faecal-oral transmission routes leading to enteric infections in young children
Principal Investigator: Monica Lakhanpaul
Funding: UCL Great Ormond Street Institute of Child Health

You are being invited to take part in a research study conducted by UCL and Save the Children. Please read this information carefully to decide if you want to take part. We are investigating if the environment in this area is contaminated with germs and if children are getting infections like diarrhoea from it.

Since you are family member of a young child in this village, we would like to ask you some questions. If you agree, we are going to talk about the health of the young children in this area and discuss the hygiene resources and habits. The discussion would take approximately 1 hour. We would like to audio-record the discussion.

The risks to you as a result of this study are minimal: you might be worried about what your neighbours will say. We will explain to them that this research will help identify sources of infections and inform guidelines to improve children's health in this area.

While the results of this study will be published, we will keep your information strictly confidential. However, we ask you to respect other people in the group and not share their information. No one outside the research team will be allowed access to the original recordings. If you want us to stop the interview or information not to be recorded, you can withdraw from the study at any time without needing to say why. UCL will oversee the protection of personal data, and can be contacted at data-protection@ucl.ac.uk. Following the data protection legislation, you have the right to access, rectify, erase, withdraw, and restrict the use of your data at any time.

Please ask us if there is anything else that is not clear. If you have further doubts you may contact the research team at: Hemant Chaturvedi ([redacted] tel: [redacted]), or the ethics committee at [redacted]

<u>CONSENT:</u>

I confirm I have read and understood the above, and all my questions have been answered. The purpose of the research, the study procedures, the purpose of the information collected, the potential risks and benefits, and the confidentiality concerns have been explained to me. I confirm I want to take part in the household visits and I consent to participate in the study.

____________________	____________	______________
Name of participant	Date	Signature
____________________	____________	______________
Researcher	Date	Signature

फोकस ग्रुप डिस्कशन (केंद्रित समूह चर्चा) प्दी जाने वाली सूचना पर सहमति पत्र
यूसीएल रिसर्च एथिक्स कमेटी अप्रूवल आईडी नंबरः 14703/001
IIHMR **संस्थागत समीक्षा बोर्ड**: 03042019

अध्ययन शीर्षकः ग्रामीण भारत में घरेलू वातावरण की पड़ताल करना, जो छोटे बच्चों में आंतों के संक्रमण के मल-मुंह संचरण मार्गों को चिह्नित करना
प्रमुख जांचकर्ताः मोनिका लखनपाल
फंडिंगः यूसीएल ग्रेट ऑरमंड स्ट्रीट इंस्टिट्यूट ऑफ चाइल्ड हेल्थ

यूसीएल और सेव द चिल्ड्रन द्वारा किए जा रहे एक शोध अध्ययन में भाग लेने के लिए आपको आमंत्रित किया जा रहा है। यदि आप इसमें भाग लेना चाहते हैं तो कृपया इस जानकारी को ध्यान से पढ़ें। हम इस बात की पड़ताल कर रहे हैं कि क्या इस क्षेत्र का वातावरण कीटाणुओं से दूषित है और क्या बच्चों को इससे दस्त (डायरिया) जैसे संक्रमण हो रहे हैं।

चूंकि, आप इस गांव के एक छोटे बच्चे के परिवार के सदस्य हैं, इसलिए हम आपसे कुछ सवाल पूछना चाहते हैं। यदि आप सहमत हैं, तो हम इस क्षेत्र में छोटे बच्चों के स्वास्थ्य के बारे में बात करने और स्वच्छता संसाधनों और आदतों पर चर्चा जा रहे हैं। चर्चा में लगभग 1 घंटा लगेगा। हम चर्चा को ऑडियो-रिकॉर्ड करना चाहेंगे।

इस अध्ययन के परिणामस्वरूप आपके परिवार के लिए जोखिम बहुत कम हैं: आपको यह चिंता हो सकती है कि आपके पड़ोसी क्या कहेंगे। हम उन्हें समझाएंगे कि यह शोध संक्रमण के स्रोतों की पहचान करने और इस क्षेत्र में बच्चों के स्वास्थ्य को बेहतर बनाने के लिए गाइडलाइन बनाने में मदद करेगा।

इस अध्ययन के परिणाम प्रकाशित किए जाएंगे, हम आपकी जानकारी को कड़ाई से गोपनीय रखेंगे। हालांकि, हम आपसे उम्मीद रखते हैं कि आप समूह के अन्य लोगों का सम्मान करेंगे और उनकी जानकारी साझा नहीं करेंगे। रिसर्च टीम के बाहर किसी को भी मूल रिकॉर्डिंग तक पहुंचने की अनुमति नहीं होगी। एनालिसिस के लिए केवल अनाम टेप का उपयोग किया जाएगा | यदि आप चाहते हैं कि हम किसी भी बिंदु या जानकारी को दर्ज न करें, तो आप बिना कारण बताए किसी भी समय इस अध्ययन से बाहर हो सकते हैं। यूसीएल पर्सनल डेटा की सुरक्षा की देखरेख करेगा, और इसके लिए data-protection@ucl.ac.uk पर संपर्क किया जा सकता है। डेटा सुरक्षा कानून के बाद, आपके पास किसी भी समय अपने डेटा के उपयोग तक पहुँच, सुधार, मिटाने, वापस लेने और प्रतिबंधित करने का अधिकार है।

यदि कुछ स्पष्ट नहीं हैं तो कृपया हमसे पूछें। यदि आपको और संदेह है, तो आप रिसर्च टीम से संपर्क कर सकते हैं: हेमंत चतुर्वेदी [redacted] tel: [redacted]), या एथिक्स कमेटी से [redacted] पर संपर्क कर सकते हैं।

सहमतिः

मैं पुष्टि करता/करती हूं कि मैंने ऊपर दी गई जानकारी को पढ़ा और समझा है, और मेरे सभी सवालों का संतोषजनक जवाब दिया गया है। इस अनुसंधान का उद्देश्य, अध्ययन प्रक्रियाएं, एकत्र की गई जानकारी का उद्देश्य, संभावित जोखिम और लाभ, और गोपनीयता की चिंताओं से मुझे अवगत कराया गया है। मैं पुष्टि करता/करती हूं कि मैं अपने घर का दौरा करने और अध्ययन में भाग लेने के लिए सहमति देता/देती हूं।

___________________	___________	______________
प्रतिभागी का नाम	दिनांक	हस्ताक्षर
___________________	___________	______________
शोधार्थी	दिनांक	हस्ताक्षर

Photography Consent Form

UCL Research Ethics Committee Approval ID Number: 14703/001

IIHMR Institutional Review Board: 03042019

I, ________________________________, hereby give permission to the photographer to use the photography of me (or of my child) for the purposes of marketing, advertising, promotion, publication and/or in any other manor, as he/she requires and in any such format or media.

मैं यहां फोटोग्राफर और द क्राउन एस्टेट को मार्केटिंग, विज्ञापन, प्रचार, प्रकाशन और / या किसी अन्य जागीर के

प्रयोजनों के लिए मेरी (या मेरे बच्चे की) फोटोग्राफी का उपयोग करने की अनुमति देता हूं। प्रारूप या मीडिया।

The identity of the model will not be released nor published in any manner

मॉडल की पहचान किसी भी तरह से जारी या प्रकाशित नहीं की जाएगी

DATED: __________/_____________/_______________

SIGNED: ____

*If the model is under 18 year of age, a parent or legal guardian must also sign

यदि मॉडल 18 वर्ष से कम आयु का है, तो माता-पिता या कानूनी अभिभावक को भी हस्ताक्षर करना चाहिए

PARENT/GUARDIAN SIGNATURE AND DATE:

__________/_____________/____________

____

Participant Informed Consent Form: Key Informant Interviews

UCL Research Ethics Committee Approval ID Number: 14703/001
IIHMR Institutional Review Board: 03042019

Study title: Exploring faecal pathogen transmission routes leading to enteric infections in young children in rural India
Researchers: Julia Vila Guilera ([redacted]),
Prof Monica Lakhanpaul ([redacted])

You are being invited to take part in a research study conducted by UCL. Please read this information carefully to decide if you want to take part.

We are investigating the environmental factors that contribute to children's intestinal infections such as diarrhoea in rural tribal villages of Banswara (Rajasthan, India). Since you are a key informant in the field of child infections and hygiene and rural development, we would like to ask you your opinion on topics related to child enteric infection prevention. If you agree, the interview would take approximately 30 minutes through videocall with the project researcher only. We would like to audio record the interview.

There are no risks to you as a result of this study as this is an online interview and no personal information will be asked. There is no compensation for taking part in the interviews but you will be contributing to progress in child health and rural development research. While the results of this research may be used for illustration in research publications and other public engagement platforms, your personal identifiable information will be kept strictly confidential. No one outside the research team will be allowed access to the original recordings. Anonymous transcripts will be used for analysis. Following the data protection legislation, you have the right to access, rectify, erase, withdraw, and restrict the use of your data at any time.

If you have further doubts you may contact the research team at: Julia Vila [redacted]

Local Data Protection Privacy Notice: The controller for this project will be University College London (UCL). The UCL Data Protection Officer provides oversight of UCL activities involving the processing of personal data, and can be contacted at data-protection@ucl.ac.uk. This 'local' privacy notice sets out the information that applies to this particular study. Further information on how UCL uses participant information can be found in our 'general' privacy notice:

- For participants in health and care research studies, click here
- The information that is required to be provided to participants under data protection legislation (GDPR and DPA 2018) is provided across both the 'local' and 'general' privacy notices.
- The lawful basis that will be used to process your personal data are: 'Public task' for personal data.
- Your personal data will be processed so long as it is required for the research project. If we are able to anonymise or pseudonymise the personal data you provide we will undertake this, and will endeavour to minimise the processing of personal data wherever possible.
- If you are concerned about how your personal data is being processed, or if you would like to contact us about your rights, please contact UCL in the first instance at data-protection@ucl.ac.uk.

VOLUNTARY CONSENT:
I confirm I have read and understood the above and all my questions have been answered.
I confirm I want to take part in the interviews. I give voluntary consent to the interviews being recorded.

Name of participant	Date	Signature

Appendix L. Algebraic relationship between distribution parameters for log-normal distributions

The U.S. EPA Exposure Factors Handbook[237] reports the age-specific mean and 95th percentile statistics for the drinking water and bathing water ingestion intake volumes. The literature indicates that a log-normal distribution can be assumed to represent the variability in water intake volumes. Therefore, the log-mean and log-standard deviation (SD) parameters were required as input parameters to simulate a log-normal distribution of water intake volumes in our QMRA model. However, because the log-normal distribution is skewed, the algebraic relationships between the mean and the log-mean (the mean of the logarithms of the population data), and the SD and log-SD are not straightforward. Nevertheless, Strom and Stansbury, in their journal article "Determining Parameters of Lognormal Distributions from Minimal Information"[238] describe the algebraic relationships between mean, log-mean, SD and log-SD in the following equations:

Equation L1. Log-normal SD from minimal information

$$\sigma = \begin{cases} z_1 + \sqrt{z_1^2 + 2\ln(\bar{x}/x_1)} & \text{for } \bar{x} < x_1 \quad \text{or} \\ z_1 - \sqrt{z_1^2 + 2\ln(\bar{x}/x_1)} & \text{for } \bar{x} > x_1. \end{cases}$$

Where σ is the log-SD (i.e., the SD of natural logarithms of x, the population data), and it can be found if $z_1, x_1, \bar{x}$ are known, z_1 being the standard normal deviate (in our case, the 95th percentile), x_1 the value corresponding to the 95th percentile, and $\bar{x}$ being the population mean, as reported in the U.S. Exposure Factors Handbook. Once log-SD (σ) is known from Equation L1, Equation L2 can be used to find the log-mean (μ), or mean of the natural logarithms of x, the population data.

Equation L2. Log-normal mean from minimal information

$$\mu = \ln(x_1) - \sigma z_1.$$

Using these equations, we were able to calculate the log-normal distribution input parameters from the mean and 95th percentiles reported by the U.S. EPA Exposures Handbook. The calculations of the log-mean and log-SD age-specific values for drinking water intake are captured in the Tables L1 and L2 below.

Table L1. Source information to calculate the log-mean and log-SD for drinking water intake volumes

Age groups	**Mean water intake (ml/day)**	**95th percentile (ml/day)**	**Contextual information**
0-1 month	184	851	No water intake at this age group
1-3 months	145	905	No water intake at this age group
3-5 months	187	981	Infants ingest water during months 4 and 5
6-11 months	269	988	-
12-23 months	146	565	-
Source of information	US EPA Exposure Factors Handbook. Chapter 3. Ingestion of water and other selected liquids. 2019 Update. (Table 3.1)		Observed in this study

Table L2. Log-mean and log-SD drinking water intake distribution input parameters for the re-categorised aged groups in this study

Re-categorised age groups for this study	Mean water intake (ml/day)	95th percentile (ml/day)	Log-SD	Log-mean
0-5 months	62	327	1.23	3.37
6-11 months	269	988	0.85	5.24
12-23 months	146	565	0.89	4.58
Source of information	Derived from U.S. EPA Exposure Factors Handbook, Chapter 3. Weighted mean calculated for the 0–5-month age group, considering water ingestion only at ages 4 and 5 months		Derived from Equation L1, Strom and Stansbury.	Derived from Equation L2, Strom and Stansbury.

The calculations of the log-mean and log-SD age-specific values for bathing water intake are captured in the Tables L3 and L4 below.

Table L3. Source information to calculate the log-mean and log-sd for bathing water intake volumes

Age groups	Mean involuntary water ingestion while bathing (ml/event)	95th percentile (ml/event)	Contextual information
<11 years	38	96	Bathing events observed only from age 12 months onwards
Source of information	US EPA Exposure Factors Handbook. Chapter 3. Ingestion of water and other selected liquids. 2019 Update. (Table 3.1)		Observed in this study

Table L4. Log-mean and log-SD for the bathing water intake distribution input parameters for the re-categorised aged groups in this study

Re-categorised age groups for this study	Mean involuntary water ingestion while bathing (ml/event)	95th percentile (ml/event)	Log-SD	Log-mean
0-5 months	-	-	-	-
6-11 months	-	-	-	-
12-23 months	38	96	0.55	3.49
Source of information	US EPA Exposure Factors Handbook. Chapter 3. Ingestion of water and other selected liquids. 2019 Update. (Table 3.1)		Derived from Equation L1, Strom and Stansbury.	Derived from Equation L2, Strom and Stansbury.

Similar to the calculations of the log-mean and log-SD for drinking and bathing water intakes, the soil ingestion distribution parameters were also derived from the literature. Estimates for direct soil ingestion were extracted from a study in rural Bangladesh by Kwong *et al.,*[94]. In this study, Kwong *et al* provided estimates for the mean and SD of soil ingestion across age-specific categories for infants under-2 years of age. It is also assumed that the volume of direct soil ingested by infants follows a log-normal distribution[236]. Therefore, using Strom and Stansbury's equations[238], we were able to obtain the log-mean and log-SD.

First, Kwong *et al.*, [94] reported the age-specific mean of total mg of soil ingested by infants (column 2 of Table L5), and the fraction of these total mg that were ingested via direct ingestion (column 4 of table L5), therefore we were able to calculate the mean of direct soil ingested by infants (column 5 of table L5, mean total soil ingested x fraction of total soil ingested via direct ingestion).

Table L5. Source information to calculate the log-mean and log-sd for soil ingestion volumes

Age groups	**Mean total soil ingested (mg/day)**	**Geo SD (mg/day)**	**Fraction of total soil ingested via direct ingestion**	**Mean direct soil ingested (mg/day)**
0-5 months	162	2	0.12	19
6-11 months	224	2	0.4	90
12-23 months	234	2	0.38	89
Source of information	Reported in Kwong *et al*[94]			Derived from mean total soil ingested and the % of soil ingested directly

Using Equation L3 from Strom and Stansbury[238], we were able to calculate the log-SD from the geometric SD provided by Kwong et al[94]. Then, following Equation L2, we were able to calculate the log-mean. The final input parameters are expressed in Table L6.

Equation L3. Log-SD from minimal information

$$\sigma = \ln(GSD)$$

Where GSD is the geometric standard deviation from the population data.

Table L6. Log-mean and log-SD for the direct soil ingestion volume distribution input parameters

Age groups	**Mean direct soil ingested (mg/day)**	**Geo SD (mg/day)**	**Log-SD**	**Log-mean**
0-5 months	19	2	0.69	2.73
6-11 months	90	2	0.69	4.26
12-23 months	89	2	0.69	4.25
Source of information	Derived from mean total soil ingested and the % of soil ingested directly		Derived from Equation L3, Strom and Stansbury.	Derived from Equation L2, Strom and Stansbury.

Appendix M. Age-specific normal distribution of infants' sleeping hours per day

Infant sleeping pattern distributions were necessary as an input for our QMRA model, particularly since many exposures occurred during the hours the infants were awake, but not when they were asleep. A study by Galland *et al.*[241] reported estimates for the mean hours of sleep for specific age categories of infants, providing the mean and 95th percentile number of hours (Table M1), and suggesting that a normal distribution can be assumed.

Table M1. Source information for the mean and SD for the infant's sleeping hours distribution input parameters

Age groups	**Mean hours of sleep (h/day)**	**95th percentile (h/day)**	**SD (h/day)**
0-2 months	14.6	20	2.76
3 months	13.6	17.8	2.14
6 months	12.9	17	2.09
9 months	12.6	15.8	1.63
12 months	12.9	15.8	1.48
12-23 months	12.6	15.2	1.33
Source of information	Reported in Galland *et al.*[241]		

Table M2. Mean and SD normal distribution input parameters for infants' number of hours awake per day

Re-categorised age groups for this study	**Mean hours of sleep (h/day)**	**SD (h/day)**	**Mean hours awake (h/day)**
0-5 months	13.7	2.3	10.3
6-11 months	12.8	1.6	11.3
12-23 months	12.6	1.3	11.4
Source of information	Derived from Galland *et al.*[241]. Weighted means calculated for the re-categorised age groups		Derived from the mean hours of sleep per day

Appendix N. Summary table with all the QMRA model input parameters

Model variable	Input parameters	Reference
E. coli: pathogen ratio		
Ratio	*E. coli* O157:H7 = 0.08 *Campylobacter* = 0.66 Rotavirus = 0.00005	Machdar *et al.,* 2013[230]
Exposure assessment parameters: E. coli loads in exposure pathways		
Culturable *E. coli* in stored water (CFU/mL)	Ln N (0.37, 1.87)	this study, MLE
Culturable *E. coli* in surface water (CFU/mL)	Ln N (3.23, 1.57)	this study, MLE
Culturable *E. coli* in courtyard soil (CFU/mg)	Ln N (16.85, 1.84)	this study, MLE
Culturable *E. coli* per hand-swab of infant (CFU/hand-swab)	Ln N (5.64, 1.91)	this study, MLE
Culturable *E. coli* per hand-swab of caregiver (CFU/hand-swab)	Ln N (5.06, 1.85)	this study, MLE
Culturable *E. coli* in hand-pump water (CFU/mL)	Ln N (-2.41, 2.03)	this study, MLE
Culturable *E. coli* in stored hand-pump water (CFU/mL)	Ln N (0.33, 1.72)	this study, MLE
Culturable *E. coli* in borewell water (CFU/mL)	Ln N (-2.70, 2.34)	this study, MLE
Culturable *E. coli* in stored borewell water (CFU/mL)	Ln N (-0.94, 2.90)	this study, MLE
Culturable *E. coli* in well water (CFU/mL)	Ln N (1.20, 1.32)	this study, MLE
Culturable *E. coli* in stored well water (CFU/mL)	Ln N (2.17, 0.51)	this study, MLE
Culturable *E. coli* in surface water (CFU/mL)	Ln N (3.23, 1.57)	this study, MLE
Exposure assessment parameters: Intake volumes		
Drinking water intake (mL/day)	0-5 months: Ln N (3.37, 1.23) (mean=62, P_{95th}=327) 6-11 months: Ln N (5.24, 0.85) (mean=269, P_{95th}=988) 12-23 months: Ln N (4.58, 0.89) (mean=146, P_{95th} =565)	U.S. EPA, Exposure Factors Handbook Chapter 3, 2019 Update[237]
Bathing water intake (mL/day)	0-5 months: 0 5-12 months: 0 12-23 months: Ln N (3.49, 0.55) (mean=38, P_{95th} =96)	U.S. EPA, Exposure Factors Handbook Chapter 3, 2019 Update[237]
Direct soil intake (mg/day)	0-5 months: Ln N (2.73, 0.69) (geomean=19, geo SD=2) 6-11 months: Ln N (4.26, 0.69) (geomean=90, geo SD=2)	Kwong et al., 2019[94]

	12-23 months: Ln N (4.25, 0.69) (geomean=89, geo SD=2)	
Hand-to-mouth frequency (hand contacts/hour awake)	0-5 months: Wb (1.58, 58.22) (mean=52.4, SD=34.4) 6-11 months: Wb (1.58, 58.22) (mean=52.4, SD=34.4) 12-23 months: Wb (2.66, 56.62) (mean=51.0, SD=20.2)	Kwong et al., 2020[95]
Number of hours awake (hours awake/day)	0-5 months: N (10.3, 2.3) 6-11 months: N (11.3, 1.6) 12-23 months: N (11.4, 1.3)	Galland et al., 2012[241]
Fraction of hand residue transferred	$Fraction_{HT}$=0.067	Kwong et al., 2020[229]
Fraction of hand-to-mouth contacts that involved caregiver's hands	0-5 months: 0.04 6-11 months: 0.46 12-23 months: 0.23	Kwong et al., 2020[229]
Dose-response parameters		
Parameter α	*E. coli* O157:H7 = 0.2099 *Campylobacter = 0.1450* Rotavirus = 0.2531	Haas et al., 1999[242]

Ln N =Log-normal distribution (mean log, SD log). N = Normal distribution (mean, SD). Wb= Weibull distribution (shape, scale).

Appendix O. Summary of Research for online consultations

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UCL

Summary of research

Co-developing a set of tailored recommendations to enhance infant hygiene and enteric infection prevention in rural tribal Banswara

Julia Vila-Guilera

Supervisors: Dr Priti Parikh, Prof Rajib Dasgupta, Dr Lena Ciric & Prof Monica Lakhanpaul

Project background

In India, a **heavy burden of enteric infections** such as diarrhoeal infections persist, particularly in rural settings with poor water, sanitation and hygiene (WASH)[1]. Enteric infections in the first 2 years of life (a critical period for development) are linked to **severe short & long-term consequences** such as child malnutrition and stunting[2].

Source: UNICEF WASH Infographic

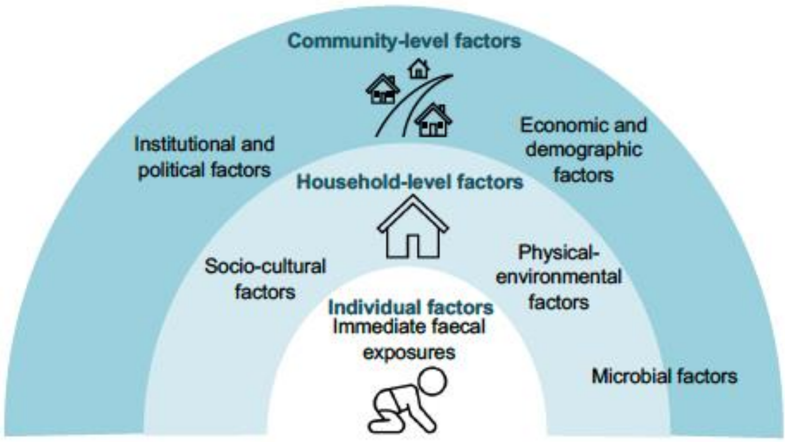
So far, WASH interventions have mostly focused on improving WASH in schools, WASH in health clinics, or improving water access and quality, handwashing, and toilet availability and uptake. None of these interventions are particularly relevant to infants aged 0-2 years. **Infants have specific infection risk factors** and transmission pathways that pose additional risks at a critical developmental stage, and that have only started to be better recognised. Recent trials targeting infants **-BabyWASH trials- still mostly failed to block enough infection risks and transmission pathways in the infants' environment to improve child health outcomes**[3]. So, what key enteric infection risk factors for infants are being missed?

This project aimed **to better understand the multiple risk factors to infant enteric infection** using a holistic integrated approach and identify the key enteric infection transmission pathways to **infants in rural tribal Banswara**, India.

Project approach

Case study research using interdisciplinary mixed methods

In-depth case study research was conducted across 9 rural tribal villages in Banswara, to develop a holistic understanding of the infants' environments and the multiple factors contributing to their enteric infections. Individual, household, and community-level factors were explored using a range of mixed methods.



Methods used included:

- Transect walks and observations across the 9 study villages
- 12 qualitative interviews with the frontline health workers and 4 group discussions with mothers of infants
- Observational data of 47 infants and caregivers at 42 different households
- Household surveys of the built environment
- Environmental sampling and faecal contamination analysis of water, soil and hand samples

Research findings

~ Question: Why and how infants in rural tribal Banswara end up getting exposed to faecal pathogens leading to enteric infections? ~

Infants' immediate exposures

Infants in their first two years of life continuously performed **exploratory and mouthing behaviours that exposed them to faecal pathogens** via several pathways that are **specific to infants** and need to be considered:

- Via **mouthing of soil**, **soiled hands**, soiled **objects,** toys or cloths while **crawling and playing** on the household earthen floors
- Via mouthing of caregiver's hands while feeding and ingesting contaminated food
- Via ingesting **contaminated water** while drinking or bathing
- Via having **flies** on face mucus

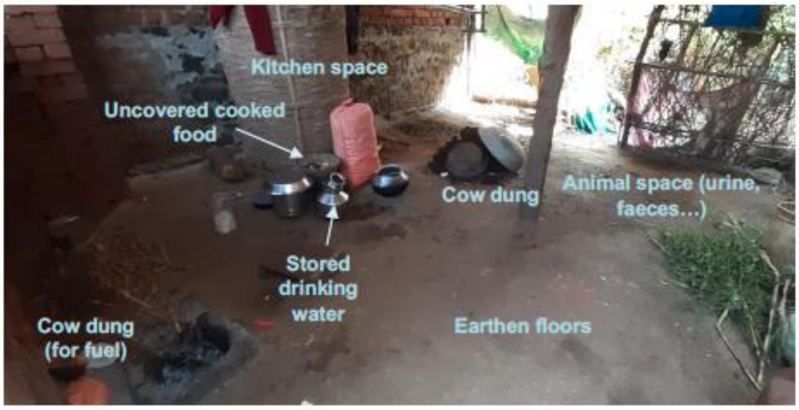
Infant exposures while eating

Infant exposures during child play

4

Household-level factors

Infant's microbial exposures were inevitably **shaped by their immediate household surroundings**. Several household-level factors contributed to infants' faecal exposures:



Typical household distribution

- *Kacha* households, the typical houses across tribal villages (86% of the study households), are made with **earthen floors** and walls and did not enable a hygienic domestic environment, since earthen surfaces **could not be cleaned**. Earthen surfaces also meant that there was no place for safe food preparation and storage separate from soil. Infants were therefore constantly exposed to soil and soiled-contaminated objects, clothes, or food.

- The common ownership of **domestic animals** (98% of study households) and the many local uses of animal faeces (such as cow dung as fuel) **meant that faeces were often present across the domestic settings,** including in cooking spaces and child play areas, introducing faecal exposure risks to infants.

Animals around the child play spaces

- The typical *Kacha* **households often lacked improved sanitation facilities** (88% of study households) and none of them had access to running water within the household premises. The typical domestic **water sources** were public handpumps, which were often **reported to deplete during the dry season.** Water was filtered through a cloth (often visibly dirty) to make it safe to drink, but the causes of water contamination and **safe water treatment strategies were often unclear.**

Stored water for drinking

Despite the difficult material circumstances and housing conditions, some unsafe hygiene practices posed additional infection risks:

- The use of **soap for handwashing was not habitual**, not even at key times such as before cooking. Soap was also not commonly used for washing kitchen utensils, most often rinsed with soil, potentially increasing the risk of food contamination.

Cooking event

Washing kitchen utensils

6

Caregivers mostly recognised that a lack of handwashing, poor eating and drinking habits, or ingesting soil were enteric infection risks for infants. However, they felt **unable to avoid infants' microbial exposures due to the dirt and farming environment where they lived.** Furthermore, caregivers reported not being able to interrupt infant's microbial exposures due to their **lack of availability to supervise child play,** which was often done by other carers such as older children and grandparents while they worked in the fields.

> *"At times children eat mud and clay. Our kids can even put their hands in the cow dung, and it has so many germs which is the cause of their illness. If we do not have farms and animals around us, then ours kids will be also clean. But even if we try to keep our kids neat and tidy, they again get themselves in dirt and mud. It happens, but what to do?" (Mothers)*
>
> *"We go to work every day so we are unaware of their act and only come to know about it when we come back from work. What to do?" (Mothers)*

Community-level factors

Wider-village level factors hindered opportunities for development and contributed to to the burden of enteric infections in infants.

- Villages often faced **water scarcity** during the summer months, impairing not only their domestic tasks, but also their livelihoods, which were based on sustenance agriculture that required water for irrigation.
- **Caste stratification** was observed in education, job and housing opportunities, with tribal families facing socio-economic barriers to these opportunities that did not appear to constrain the non-tribal families in the study villages. The historical reliance of tribal populations on government interventions for development programmes may have also contributed to shaping their attitudes of resignation and lack of self-efficacy to improve their living conditions.
- **Weak and unreliable local governments** hindered local investment for development through embezzlement of funds for public infrastructure: for example, leading to insufficient public water sources to cover basic needs, or poor sanitation and hygiene infrastructures in public schools and childcare centres. They hindered the delivery of development programmes and services through a lack of monitoring.

2. Microbial assessment of key infection transmission pathways

~ Question: What are the faecal contamination levels in the infants' surroundings and which transmission pathways pose the highest risk of infection to infants in rural Banswara? ~

Faecal contamination of water sources

Faecal contamination levels were high for all the water sources sampled relative to WHO drinking water guidelines, which specify there should be no detectable faecal bacteria in any 100mL water sample, but **particularly high for household stored water,** which doubled the levels of faecal contamination from water sources, and for **open well water** and **surface water from ponds and drains.**

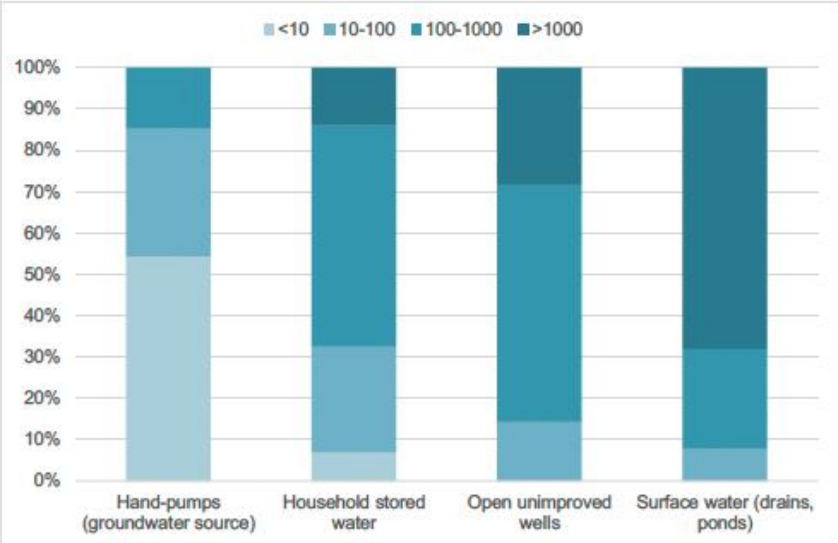


Figure 1- Percentage of samples in each category of Escherichia coli CFU (colony-forming units) per 100mL of sampled water.

Faecal contamination of hands and soil

Since infants were constantly exposed to soil from the households' earthen floors, and constantly mouthed their own and caregivers' hands, soil and hand samples were also analysed.

- Over 90% of the **infants and caregiver's hands samples were positive for faecal indicator bacteria.**
- All the **soil samples showed high levels** of faecal contamination.

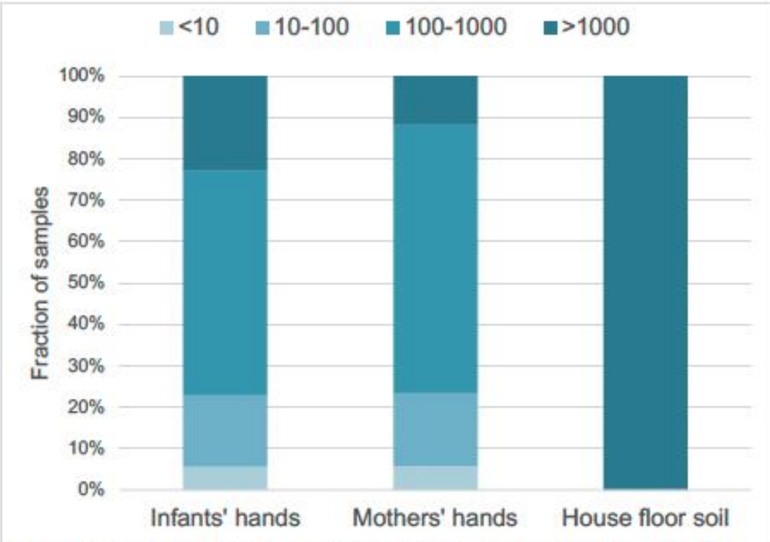


Figure 2- Percentage of samples in each category of Escherichia coli CFU (colony-forming units) per 1g of soil and per hand swab.

Escherichia coli bacterial colonies (blue dots) indicate faecal contamination. They were found in over 90% of the hand swab samples from infants and mothers that were collected >

Risk of enteric infection

Based on estimates of the quantities of water, soil and hand-to-mouth contacts that infants were exposed to every day, we were able to model the daily risk of enteric infection caused by ingestion of faecal pathogens through the different pathways (i.e. water, hands, soil), and compare them.

- After a single day of **drinking household stored water, infants had over a 30% chance of an enteric infection**. This risk would be reduced to less than 10% if water was drunk straight from the handpump sources, due to the contamination introduced at point-of-use during storage.
- Infants that are bathed at local ponds and streams, even when ingesting very small amounts of water, **faced an almost 50% chance of infection after a single bathing event,** due to the very high contamination levels of ponds and streams.
- The high frequency of **hand-to-mouth contacts** with own infant's hands, led to a high daily **risk of infection of almost 50%,** and the **direct ingestion of soil** also meant a high daily infection **risk of above 50%.**
- The very **high and widespread faecal contamination levels led to practically a 100% probability of enteric infection** from faecal pathogens after each week, from any of the exposure pathways that were assessed.

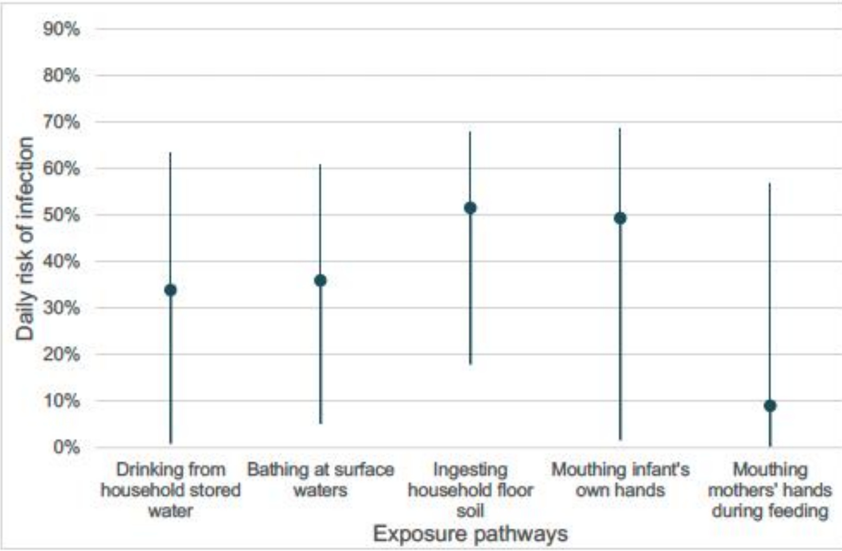


Figure 3- Daily risk of Campylobacter infection in infants after exposure to several different pathways

3. Barriers to the delivery and uptake of current rural child health & hygiene programmes

~ Question: What are the barriers for the delivery and uptake of current child health and hygiene rural development programmes? ~

As part of the National Health Mission (NHM) in India, **Accredited Social Health Activists (ASHA)** are the front-line health workers who focus on assisting mothers during pregnancy and lactation time, promoting health, sanitation and hygiene, and serving as a link for rural referrals into the healthcare system.

- Observations of the ASHAs roles and village events revealed that **frontline health workers were focusing on performing those tasks for which they were more strictly monitored** (such as child vaccination services) rather than hygiene and sanitation promotion activities, for which guidelines were more vaguely defined. ASHAs reported being overburdened with the number of different tasks under their roles. **A lack of accountability and effective monitoring of frontline health workers'** role on child hygiene promotion and infection prevention hindered the delivery of public health programmes.
- Caregivers sometimes reported a lack of trust in the health advise from community frontline health-workers due to a lack of higher education. **Caregivers had a medicalized idea of high-quality health treatment, which led families to private health practitioners,** hindering public health service delivery.

Overall key findings

1. Infants were exposed to faecal pathogens through various pathways. In addition to ingesting contaminated food and water, infants exploratory and mouthing behaviours which involved crawling and mouthing elements of their surroundings exposed them to faecal pathogens when mouthing soiled hands, soiled objects or soil itself.
2. Practically all tribal families in rural Banswara lived in earthen houses (*Kacha*), which were hard to clean. All of the household floor soil samples were highly contaminated with faecal bacteria.
3. Practically all tribal families had domestic animals, which contributed to faecally contaminating the domestic environments surrounding infants.
4. Domestic water sources often depleted during the dry season, and they mostly appeared to be contaminated with faecal bacteria. Household storage of drinking water doubled the levels of faecal contamination from water sources. Local streams and ponds used for bathing were particularly highly contaminated. Safe water treatment strategies were also unclear.
5. There was a lack of soap use habit for handwashing and washing kitchen utensils, which increased the risk of food and water contamination.
6. There was a lack of latrine facilities available, with financial constraints being reported as the biggest barrier to their construction.
7. Health and hygiene promotion services delivered at the village-level by frontline health workers were not emphasised: there was a lack of clear guidelines and a lack of monitoring and accountability of these services.
8. Caregivers often relied on private practitioners for healthcare and did not trust the health knowledge of frontline health workers, which hindered opportunities to deliver hygiene promotion and infection risk awareness programmes through public schemes.
9. Opportunities for village-level development were hindered by a weak local level governance, limited job opportunities and marked caste stratification of opportunities.
10. The risk of enteric infection for infants under-2 was considerable after a single day of drinking household stored water, after a single bathing event at the local streams, and after a single day of crawling on the household earthen floors and ingesting soil directly or via hand-to-mouth contacts, given the constant environmental exposures and the contamination levels. However, parents reported feeling unable to avoid infants' faecal exposures due to the farming environment and *Kacha* houses where they lived. The historical discrimination of tribal castes may have shaped the tribal attitudes of limited self-efficacy to improve their living conditions, hindering their opportunities for development.

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