Parasitic health risk associated with ecosan toilet manure, wastewater, and flood -runoff water in and around Dhaka city

A Dissertation submitted to The University of Dhaka in fulfillment of the requirements for the degree of
DOCTOR OF PHILOSOPHY in **Zoology**

TAMANNA AKTER
Reg NO: 95/2020-2021 (Re)

DEPARTMENT OF ZOOLOGY
UNIVERSITY OF DHAKA
DHAKA 1000, BANGLADESH

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DEDICATION

I would like to dedicate to My Father, My Mother, Family and Professor Dr. Hamida Khanum- whose guidance, encouragement and wisdom have been instrumental in shaping this work.

DECLARATION

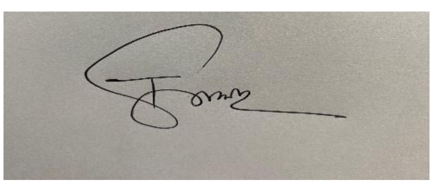
I, Tamanna Akter, hereby declare that the thesis entitled:

"Parasitic health risk associated with ecosan toilet manure, wastewater, and flood runoff water in and around Dhaka city"

submitted to the Department of Zoology, University of Dhaka, in partial fulfillment of the requirements for the degree of Doctor of Philosophy (PhD), is the result of my own original research work carried out under the supervision of Professor Dr. Hamida Khanum and Professor Dr. Sharmin Musa, Department of Zoology, University of Dhaka.

I also declare that this thesis has not been submitted previously, either in part or in full, for any degree or diploma at this or any other university or institution.

All sources of information and data have been properly acknowledged in the thesis.



Tamanna1Akter
Date: 13/04/2026

CERTIFICATE

This is to certify that the thesis entitled:

"Parasitic health risk associated with ecosan toilet manure, wastewater, and flood-runoff water in and around Dhaka city"

submitted by Tamanna Akter, of the Department of Zoology, University of Dhaka, Dhaka 1000, has been carried out under our joint supervision.

To the best of our knowledge, the research work presented in this thesis is an original work of the candidate and has not been submitted, either in part or in full, for any degree or diploma at this or any other university or institution.

We recommend that, this thesis be submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy (Ph D) in Zoology.

Hamida Khanum 29.03.2026

Prof. Hamida Khanum Ph D
Parasitologist
Department of Zoology
University of Dhaka
Dhaka 1000

29.3.2026

DR. SHARMIN MUSA
Professor
Department of Zoology
University of Dhaka

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ABBREVIATION TABLE

Abbreviation	Full Form	Brief Definition
BSL	Biosafety Level	Laboratory safety standards for handling biohazardous materials
CI	Confidence Interval	A range of values within which a true population parameter is likely to lie
Ds	Dry Season	Refers to periods with minimal rainfall in the Dhaka climate
DSIP	Dhaka Sanitation Improvement Project	A project aiming to enhance sewerage and sanitation infrastructure in Dhaka
EPG	Eggs per Gram	A measure used to quantify helminth egg concentration in solid samples (e.g., feces, compost)
EPL	Eggs per Liter	A measure used to quantify helminth egg concentration in liquid samples (e.g., water)
GIS	Geographic Information System	A framework for gathering, managing, and analyzing spatial or geographical data
IRB	Institutional Review Board	A committee that reviews and approves research involving human subjects
NGO	Non-Governmental Organization	A non-profit group operating independently of government
QMRA	Quantitative Microbial Risk Assessment	A systematic approach to estimate infection risk from microbial pathogens
Sd	Standard Deviation	A statistic that measures data dispersion around the mean
SDG	Sustainable Development Goal	Global goals set by the UN to address social, economic, and environmental challenges
UDDT	Urine-Diverting Dry Toilet	A type of Ecosan system that separates urine from feces for nutrient recovery
WASA	Water Supply and Sewerage Authority	The governmental body responsible for water and sewer services in Dhaka
WHO	World Health Organization	A specialized agency of the United Nations focusing on global public health

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This research was conducted over multiple phases, allowing for a comprehensive assessment of parasitic contamination under varying environmental conditions. Every effort was made to ensure the consistency, quality, and integrity of the data and analysis presented in this thesis.

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This work is dedicated to the cherished memory of my beloved father, whose inspiration and encouragement continue to guide me. His vision remains a constant source of strength in my life.

Finally, I hereby declare that this thesis is my original work, and I sincerely hope that it will contribute to the development of sustainable and effective sanitation solutions that promote environmental safety and public health.

Thank you.

Tamanna Akter

Dhaka, April 13th 2026

Parasitic health risk associated with ecosan toilet manure, wastewater, and flood -runoff water in and around Dhaka city

ABSTRACT

Rapid urbanization in Dhaka, Bangladesh, has led to high population density, inadequate sanitation, and increased exposure to parasitic pathogens, posing significant environmental and public health risks. This study investigates the prevalence, spatial distribution, and environmental transmission pathways of parasitic organisms in ecosan toilet manure, wastewater, and flood runoff water, with particular emphasis on ecosan sanitation systems.

The research was conducted in two phases (2017–2019 and 2022–2023) to capture temporal and spatial variations in contamination. A mixed-methods approach was applied, combining quantitative laboratory analysis with qualitative field investigations. Standard parasitological techniques, including microscopy, flotation, and concentration methods, were used to quantify helminth eggs (eggs per gram, EPG) and protozoan cysts (eggs per liter, EPL). Qualitative data were collected through focus group discussions (FGDs) and key informant interviews to assess sanitation practices and hygiene behaviors.

Results revealed a high level of environmental contamination, with overall parasitic prevalence exceeding 60% across all sample types. The results indicated that eco-san manure from peri-urban wards (Keraniganj and Savar) exhibited the highest helminth egg counts (135 ± 10 and 115 ± 12 EPG, respectively). Wastewater samples from urban slum areas (Kamrangirchar) showed moderate contamination levels (95 ± 9 EPL). In contrast, flood-prone wards (Badda and Demra) recorded significantly higher parasitic loads in runoff water (150 ± 15 and 165 ± 18 EPL, respectively; ANOVA, $F = 72.47$, $p = 0.0136$). GIS-based spatial analysis further identified flood-prone areas as major contamination hotspots.

Multiple parasite groups were detected, including protozoa, cestodes, and nematodes, with common organisms such as *Hymenolepis nana*, *Ascaris lumbricoides*, *Trichuris trichiura*, *Entamoeba* spp., and *Giardia* spp. Due to methodological limitations, some organisms were reported at the genus level or categorized as “parasite-like structures.” Seasonal variation indicated increased contamination during the rainy season due to flooding and enhanced pathogen dispersion.

Qualitative findings highlighted limited awareness of safe compost handling, inadequate sanitation practices, and increased exposure risks during flooding events. Overall, parasitic contamination was strongly influenced by sample type, environmental conditions, and human behavior.

This study underscores the need for integrated sanitation management, improved ecosan practices, effective wastewater treatment, flood-risk mitigation, and community-based health education to reduce environmental contamination and associated health risks. The adoption of advanced molecular diagnostic techniques is recommended to enhance the accuracy of parasite identification in future research.

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Rapid urbanization has become one of the most defining global transformations of the 21st century, particularly in developing countries where population growth is occurring at an unprecedented rate. Urban centers are expanding both spatially and demographically, often outpacing the development of essential infrastructure. Among the most critically affected sectors is sanitation, which remains a persistent challenge in densely populated cities. The inability to safely manage human waste has far-reaching consequences for environmental integrity, public health, and socio-economic stability.

Dhaka, the capital city of Bangladesh, represents a striking example of these challenges. Over recent decades, the city has experienced rapid population growth driven largely by rural-to-urban migration (Rana, 2011). This demographic surge has led to the proliferation of informal settlements and slum communities where access to improved sanitation remains limited. In such environments, existing sanitation systems are often overwhelmed, poorly maintained, or entirely absent. Consequently, untreated or inadequately treated human waste frequently contaminates the surrounding environment, contributing to widespread health risks and ecological degradation.

Traditional sanitation systems in urban areas typically rely on water-intensive flush toilets connected to centralized sewer networks. However, in cities like Dhaka, these systems face multiple constraints, including insufficient sewer coverage, aging infrastructure, and limited wastewater treatment capacity (Alam et al., 2020). As a result, a significant proportion of wastewater is discharged untreated into rivers, canals, and open drains. This continuous release of contaminants not only degrades water quality but also creates an environment conducive to the survival and transmission of pathogenic organisms, including parasites.

In response to these challenges, alternative sanitation approaches have gained increasing attention. Among these, Ecological Sanitation (Ecosan) has emerged as a promising and innovative solution. Ecosan systems aim to safely treat and reuse human excreta by transforming waste into valuable resources, such as organic fertilizer. By promoting nutrient recovery and minimizing environmental pollution, Ecosan offers a sustainable alternative to conventional sanitation models (Winblad, 2004; Münch et al., 2006).

Despite its potential advantages, the implementation of Ecosan systems raises important public health concerns. One of the most critical issues is the potential persistence of parasitic organisms in treated waste. If composting processes are not properly managed, parasites such as helminths and protozoa may survive and remain infectious (Hu et al., 2016). In densely populated urban environments like Dhaka, where exposure pathways are numerous, the presence of viable parasites in Ecosan-derived manure poses significant risks to human health.

The situation is further complicated by the city's vulnerability to seasonal flooding. Dhaka's low-lying geography and inadequate drainage infrastructure make it highly susceptible to flooding during monsoon periods. Floodwaters often mix with untreated sewage and solid waste, dispersing contaminants across residential areas (Shimi et al., 2010). This process significantly increases the likelihood of human exposure to parasitic pathogens through contaminated water, soil, and food.

Although previous studies have examined sanitation challenges, wastewater contamination, and parasitic infections independently, there remains a notable gap in understanding how these factors interact within an integrated urban system. In particular, limited research has explored the combined influence of Ecosan manure, wastewater, and flood runoff on parasitic health risks in Dhaka. Addressing this gap is essential for developing comprehensive sanitation strategies that effectively safeguard public health.

Therefore, this study seeks to investigate the parasitic health risks associated with Ecosan toilet manure, wastewater, and flood runoff water in and around Dhaka City. By examining the presence, survival, and transmission pathways of parasitic organisms across these interconnected environmental systems, the research aims to provide evidence-based insights that can inform safer sanitation practices and improved urban health outcomes

1.2 Ecological Sanitation (Ecosan)

The growing demand for sustainable and resource-efficient sanitation solutions has led to the development of alternative approaches that challenge conventional waste management paradigms. Ecological Sanitation (Ecosan) represents one such approach, emphasizing the safe reuse of human excreta as a resource rather than treating it solely as waste. This paradigm shift is rooted in the principles of sustainability, circular resource use, and environmental protection.

Ecosan systems are designed to separate urine and feces at the source, facilitating targeted treatment processes that enhance pathogen reduction and nutrient recovery (Werner et al., 2009). Urine, which is typically sterile, can be applied directly as a fertilizer, while fecal matter undergoes composting or dehydration processes to achieve hygienization. These processes aim to reduce the presence of pathogens, including bacteria, viruses, and parasites, to levels considered safe for agricultural use.

One of the defining advantages of Ecosan is its minimal reliance on water. Unlike conventional flush toilets, which require substantial volumes of water for waste transport, Ecosan systems operate with little to no water input (Münch et al., 2006). This feature makes them particularly suitable for regions facing water scarcity or lacking extensive sewer infrastructure. Additionally, by preventing the dilution of waste, Ecosan facilitates more efficient treatment and nutrient recovery processes.

The concept of resource recovery is central to Ecosan. Human excreta contain essential nutrients such as nitrogen, phosphorus, and potassium, which are vital for plant growth (Hu et al., 2016). By recycling these nutrients back into agricultural systems, Ecosan reduces dependence on chemical fertilizers and contributes to sustainable food production. This closed-loop approach not only enhances soil fertility but also minimizes the environmental impact associated with waste disposal.

However, the success of Ecosan systems depends heavily on proper design, operation, and user compliance. Composting processes must achieve and maintain conditions—such as elevated temperatures, appropriate moisture levels, and optimal pH—that are necessary for effective pathogen inactivation (Winblad, 2004). Failure to maintain these conditions can result in incomplete treatment, allowing resilient organisms such as helminth eggs to survive.

Moreover, social and cultural factors play a significant role in the adoption and effectiveness of Ecosan. In many communities, handling human excreta is associated with stigma and cultural taboos, which can hinder proper usage and maintenance (Drangert, 2004a). Without adequate training and awareness, users may inadvertently engage in practices that compromise the safety of the system, such as premature use of compost or improper storage of treated materials.

In urban contexts like Dhaka, the implementation of Ecosan presents both opportunities and challenges. While the system offers a decentralized and potentially cost-effective solution to sanitation problems, its integration into complex urban environments requires careful planning, continuous monitoring, and strong institutional support. Ensuring that Ecosan systems effectively mitigate health risks—particularly those associated with parasitic infections—is therefore critical for their long-term sustainability.

1.3 Sanitation Challenges in Dhaka City

Dhaka City exemplifies the multifaceted challenges associated with urban sanitation in rapidly developing regions. As one of the most densely populated cities in the world, Dhaka faces immense pressure on its infrastructure, particularly in the areas of water supply, waste management, and sanitation services. The rapid expansion of informal settlements has further exacerbated these challenges, creating environments where access to safe sanitation is severely limited.

A significant portion of the city's population relies on shared or poorly constructed sanitation facilities, many of which lack proper containment and treatment mechanisms (Muhammad et al., 2016). In some cases, open defecation persists, particularly in underserved areas. These practices contribute to widespread environmental contamination and increase the risk of fecal-oral disease transmission.

The city's wastewater management system is similarly inadequate. Existing treatment facilities are insufficient to handle the volume of wastewater generated, resulting in the discharge of untreated or partially treated sewage into natural water bodies (Alam et al., 2020). Open drains, which are common throughout the city, often carry a mixture of domestic waste, industrial effluents, and stormwater. These conditions create a persistent reservoir of pathogens, including parasitic organisms.

Flooding represents an additional and significant challenge. Dhaka's geographical location in a low-lying deltaic region makes it highly vulnerable to seasonal flooding. During the monsoon season, heavy rainfall overwhelms the city's drainage systems, leading to the accumulation of floodwater in residential areas. These floodwaters frequently mix with sewage and solid waste, facilitating the widespread dissemination of contaminants (Shimi et al., 2010).

The health implications of these conditions are profound. Flood events increase human exposure to contaminated water and surfaces, particularly among vulnerable populations such as children and low-income communities. The persistence of pathogens in floodwater and sediments further prolongs exposure risks even after floodwaters recede.

In this context, Ecosan systems offer a potential alternative to conventional sanitation approaches. By decentralizing waste management and promoting safe reuse, Ecosan can reduce the burden on existing infrastructure and limit environmental contamination. However, the effectiveness of these systems in flood-prone urban environments remains uncertain, particularly with regard to parasitic risks.

Addressing the sanitation challenges in Dhaka therefore requires a comprehensive understanding of how different factors—including Ecosan systems, wastewater management, and flood dynamics—interact to influence public health outcomes. This study aims to contribute to this understanding by examining the role of parasitic contamination within this complex urban system.

1.4 Significance of Parasitic Infections in Low-Income Urban Settings

Parasitic infections remain one of the most persistent yet often under recognized public health challenges in low- and middle-income countries. Despite global progress in controlling infectious diseases, intestinal parasites—particularly helminths and protozoa—continue to impose a substantial disease burden, especially in densely populated urban environments where sanitation infrastructure is inadequate. In cities such as Dhaka, the convergence of environmental contamination, high population density, and limited access to safe water creates ideal conditions for the transmission of parasitic organisms.

Table: Major Sources and Pathways of Parasitic Risk in Dhaka

Source	**Main Contaminants**	**Exposure Pathway**	**Risk Level**
Ecosan Manure	Helminth eggs, protozoa	Handling, agriculture use	Medium–High
Wastewater	Mixed pathogens (parasites)	Water contact, domestic use	High
Flood Runoff	Dispersed parasites	Direct contact, ingestion	Very High

Parasites are primarily transmitted through the fecal-oral route, which is closely linked to sanitation and hygiene practices. Protozoan parasites such as *Giardia* sp. and *Cryptosporidium sp.*, as well as helminths including *Ascaris lumbricoides*, *Trichuris trichiura*, and hookworms, are commonly associated with contaminated water, soil, and food (World Health Organization [WHO], 1987). These organisms are capable of surviving in harsh environmental conditions, particularly where sanitation systems fail to effectively contain and treat human waste.

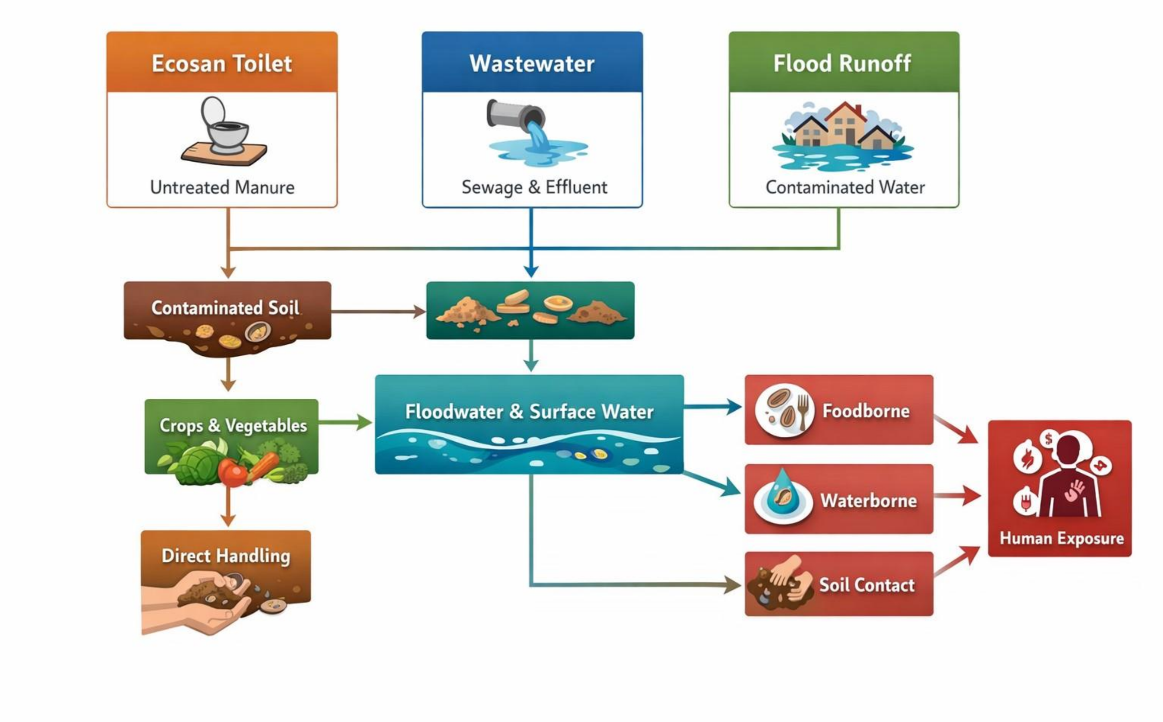
In low-income urban settings, the risk of parasitic infection is further exacerbated by overcrowding and limited access to healthcare services. Informal settlements often lack proper drainage systems, leading to the accumulation of stagnant water and waste. These conditions facilitate the persistence and spread of parasitic pathogens, increasing exposure risks among residents. Children are particularly vulnerable, as they frequently come into contact with contaminated environments during play and may lack adequate hygiene practices.

The health impacts of parasitic infections extend beyond immediate symptoms such as diarrhea and gastrointestinal discomfort. Chronic infections can lead to malnutrition, anemia, impaired cognitive development, and reduced physical growth, particularly among children (Torgerson & Macpherson, 2011). These effects can have long-term consequences, limiting educational attainment and economic productivity. In many cases, individuals may harbor multiple parasitic infections simultaneously, a condition known as poly-parasitism, which can exacerbate disease severity and complicate treatment (Pullan & Brooker, 2008; Vaumourin et al., 2015).

In Dhaka, environmental factors such as flooding significantly amplify the transmission of parasitic diseases. Floodwaters can mobilize pathogens from contaminated soil, sewage, and waste disposal sites, spreading them across residential areas (Shimi et al., 2010). As floodwaters recede, they often leave behind contaminated sediments that continue to pose health risks. The widespread exposure to such environments increases the likelihood of infection through direct contact, ingestion of contaminated water, or consumption of contaminated food.

Additionally, the presence of domestic animals and livestock in close proximity to human settlements introduces the risk of zoonotic transmission. Parasites that infect animals can be transmitted to humans, further complicating disease dynamics in urban settings (Macpherson, 2005). This highlights the need for a comprehensive approach that considers both human and environmental health.

Despite the recognized burden of parasitic diseases, they often receive less attention compared to bacterial or viral infections. This gap in focus can lead to insufficient monitoring, limited diagnostic capacity, and inadequate policy responses. Addressing parasitic infections in urban environments therefore requires a more integrated approach that combines improvements in sanitation, environmental management, and public health interventions.



Parasitic Transmission Pathways in Dhaka City

1.5 Ecosan and Parasitic Health Risks

While Ecological Sanitation (Ecosan) systems offer promising solutions for sustainable waste management, they also introduce specific challenges related to pathogen control, particularly concerning parasitic organisms. The effectiveness of Ecosan systems in reducing health risks depends largely on the ability of treatment processes—such as composting and dehydration—to inactivate pathogens present in human excreta.

In theory, properly managed composting processes can significantly reduce the viability of most pathogens. High temperatures generated during composting, combined with appropriate moisture levels and pH conditions, create an environment that is hostile to microbial survival (Winblad, 2004). However, the degree to which these conditions are achieved in real-world settings can vary considerably, particularly in low-resource urban environments.

Parasitic organisms, especially helminth eggs, are known for their resilience. For example, *Ascaris lumbricoides* eggs can survive for extended periods under adverse environmental conditions and are often used as indicators of sanitation safety (EFSA Panel on Biological Hazards et al., 2018). If composting temperatures do not reach sufficiently high levels or are not maintained for adequate durations, these eggs may remain viable, posing a risk when compost is handled or applied to agricultural land.

Similarly, protozoan cysts, such as those of *Giardia* and *Cryptosporidium*, can persist in moist environments and resist certain treatment processes. Inadequate drying or improper storage of composted material can therefore lead to incomplete pathogen inactivation. These risks are particularly concerning in densely populated urban settings where exposure pathways are numerous and difficult to control.

Another critical factor influencing parasitic risk in Ecosan systems is user behavior. The safe operation of Ecosan toilets requires adherence to specific practices, including proper separation of urine and feces, regular addition of bulking agents (such as ash or sawdust), and sufficient storage time before reuse. Deviations from these practices can compromise the effectiveness of the system and increase the likelihood of pathogen survival (Münch et al., 2006).

Improper handling of composted material further increases exposure risks. Individuals who come into direct contact with partially treated waste may be exposed to viable parasites, particularly if protective measures are not used. Additionally, the premature application of compost in agriculture can lead to contamination of crops, especially those consumed raw.

The effectiveness of Ecosan systems is also influenced by environmental conditions. In tropical climates such as that of Dhaka, high humidity and frequent rainfall can interfere with composting processes by increasing moisture levels and reducing temperatures. Flooding events can further disrupt containment systems, potentially dispersing partially treated waste into the surrounding environment.

These challenges highlight the importance of rigorous monitoring and management of Ecosan systems. Ensuring that composting processes consistently achieve the conditions necessary for pathogen inactivation is critical for minimizing health risks. This requires not only technical improvements but also strong community engagement and education to promote safe practices.

1.6 Wastewater, Flood Runoff, and the Amplification of Parasitic Hazards

Beyond the direct risks associated with Ecosan manure, wastewater and flood runoff play a crucial role in the transmission and amplification of parasitic hazards in urban environments. In Dhaka, where wastewater management systems are often inadequate, untreated or partially treated sewage is commonly discharged into open drains, rivers, and canals (Rana, 2011). These water bodies serve as reservoirs for a wide range of pathogens, including parasitic organisms.

Wastewater contamination is a continuous process in the urban landscape. Household waste, industrial effluents, and storm water runoff combine to create complex mixtures of pollutants. In the absence of effective treatment systems, these contaminants accumulate in the environment, increasing the risk of human exposure. Parasites present in human waste can enter wastewater streams through multiple pathways, including direct discharge, leakage from sanitation systems, and improper waste disposal.

Flooding significantly exacerbates this situation by redistributing contaminants across large areas. During heavy rainfall, drainage systems in Dhaka are often overwhelmed, causing floodwaters to overflow into residential neighborhoods. These floodwaters frequently carry a mixture of sewage, solid waste, and industrial pollutants, creating highly contaminated environments (Shimi et al., 2010).

As floodwaters spread, they facilitate the movement of parasitic organisms from localized sources to broader areas. This increases the number of exposure pathways, including direct contact with contaminated water, ingestion of contaminated food, and inhalation of aerosolized particles. After floodwaters recede, residual contamination in soil and sediments continues to pose risks.

Urban agriculture practices further contribute to the complexity of parasitic transmission. In some areas of Dhaka, crops are cultivated using water from contaminated sources, including wastewater and flood runoff (Alam et al., 2020). This practice can lead to the contamination of vegetables with parasitic eggs or cysts, particularly when crops are consumed raw. The use of untreated or partially treated Ecosan manure as fertilizer can also contribute to this risk if proper safety measures are not followed.

The interaction between wastewater, flood runoff, and sanitation systems creates a dynamic and interconnected network of contamination pathways. Even if Ecosan systems are functioning effectively at the household level, broader environmental factors can undermine their benefits by reintroducing pathogens into the community.

Addressing these challenges requires a holistic approach that integrates sanitation improvements with wastewater management and flood control measures. This includes upgrading drainage infrastructure, improving waste treatment capacity, and implementing strategies to reduce environmental contamination. Without such integrated efforts, the risk of parasitic transmission will remain high, particularly in flood-prone urban environments like Dhaka.

Ecosan Toilet
↓
Manure (if untreated)
↓
Contaminated Soil ——→ Crops ——→ Human (Foodborne)

Wastewater ——→ Floodwater —→ Human (Water Contact)

Flood Runoff ——→ Environment —→ Soil/Water —→ Human

Direct Handling ——→ Human Exposure

The diagram showed Conceptual model of parasitic transmission pathways involving Ecosan manure, wastewater, and flood runoff in Dhaka City.

1.7 Rationale of the Study

Sanitation remains one of the most pressing challenges in rapidly urbanizing cities, particularly in developing countries where infrastructure development often fails to keep pace with population growth. In Dhaka, the complexity of sanitation issues is intensified by a combination of high population density, inadequate wastewater management systems, and frequent flooding events. These interconnected challenges create an environment where human exposure to pathogenic organisms, especially parasites, is highly probable.

While Ecological Sanitation (Ecosan) has been promoted as a sustainable alternative to conventional sanitation systems, its application in densely populated and flood-prone urban settings introduces new dimensions of risk. The fundamental principle of Ecosan—

resource recovery through the reuse of treated human excreta—offers environmental and economic benefits. However, the safety of this approach depends critically on the effectiveness of pathogen inactivation during treatment processes.

In practice, achieving complete pathogen removal is often difficult, particularly in low-resource settings where operational conditions may not be optimal. Factors such as inconsistent composting temperatures, inadequate storage periods, and improper handling can result in the survival of parasitic organisms. These risks are further compounded in Dhaka due to environmental conditions such as high humidity and seasonal flooding, which can disrupt treatment processes and facilitate the spread of contaminants.

At the same time, wastewater and flood runoff represent significant but often under-integrated components of urban sanitation systems. The discharge of untreated wastewater into open drains and natural water bodies contributes to persistent environmental contamination. During flood events, these contaminants are redistributed across residential areas, increasing exposure risks through multiple pathways, including water contact, food contamination, and soil interaction.

Despite the recognition of these individual factors, there is a lack of comprehensive research that examines their combined impact on parasitic transmission. Most existing studies focus on either sanitation systems, wastewater contamination, or flood-related health risks in isolation. This fragmented approach limits the ability to fully understand the dynamics of parasitic exposure in complex urban environments.

Therefore, the rationale of this study lies in the need to adopt an integrated perspective that considers Ecosan manure, wastewater, and flood runoff as interconnected components of a broader environmental system. By examining how these elements interact to influence the presence, survival, and transmission of parasitic organisms, this research aims to provide a more holistic understanding of sanitation-related health risks in Dhaka.

Such an approach is essential for developing effective and context-specific interventions. Without a clear understanding of the pathways through which parasites are transmitted, efforts to improve sanitation may fail to address critical sources of contamination. This study therefore seeks to bridge existing knowledge gaps and contribute to the development of safer and more sustainable sanitation strategies.

1.8 Research Gap

Although significant research has been conducted on sanitation, wastewater management, and parasitic infections, several critical gaps remain, particularly in the context of rapidly urbanizing and flood-prone cities like Dhaka.

Firstly, much of the existing literature on Ecological Sanitation focuses on its environmental and agricultural benefits, with comparatively less emphasis on its potential health risks. While some studies have examined pathogen survival in composted human waste, there is limited empirical evidence on the presence and viability of parasitic organisms in Ecosan manure under real-world urban conditions. This gap is particularly important given the resilience of certain parasites, such as helminth eggs, which can survive standard treatment processes if conditions are not adequately maintained.

Secondly, studies on wastewater contamination in Dhaka have largely focused on chemical pollutants and bacterial pathogens, often overlooking parasitic organisms. Parasites differ significantly from bacteria and viruses in terms of their survival mechanisms and environmental persistence. As such, the lack of targeted research on parasitic contamination in wastewater represents a significant limitation in understanding overall public health risks.

Thirdly, while the impacts of flooding on waterborne diseases have been widely documented, there is a lack of detailed investigation into how floodwaters influence the distribution and transmission of parasitic organisms. Flood events not only spread contaminants but also create new exposure pathways by altering environmental conditions. The interaction between flood dynamics and parasitic transmission remains insufficiently explored.

Another major gap lies in the lack of integrated studies that examine the combined effects of Ecosan systems, wastewater, and flood runoff. These elements are often studied independently, despite being closely interconnected in urban environments. This fragmented approach limits the ability to identify cumulative risks and interactions that may significantly influence health outcomes.

Furthermore, there is limited context-specific research focused on Dhaka that combines environmental sampling with parasitological analysis. Many studies rely on generalized models or data from different geographical regions, which may not accurately reflect local conditions. Given the unique environmental and socio-economic characteristics of Dhaka, localized research is essential for developing effective interventions.

Finally, there is a lack of comprehensive frameworks that link environmental contamination to human exposure pathways and health outcomes. Understanding these linkages is critical for designing interventions that not only reduce contamination but also minimize human exposure.

This study addresses these gaps by adopting an integrated approach that examines parasitic contamination across multiple environmental sources and pathways within the specific context of Dhaka City.

1.9 Conceptual Framework of the Study

Understanding the transmission of parasitic infections in urban environments requires a systems-based approach that captures the interactions between multiple environmental and human factors. This study is guided by a conceptual framework that integrates Ecosan sanitation systems, wastewater management, and flood dynamics into a unified model of parasitic transmission.

At the core of this framework are three primary sources of contamination:

- Ecosan toilet manure
- Wastewater from domestic and urban sources
- Flood runoff water

These sources act as reservoirs for parasitic organisms, which can persist in the environment under favorable conditions. The movement of these contaminants through environmental pathways is influenced by factors such as rainfall, drainage infrastructure, and human activities.

From these sources, parasites are transmitted through several key pathways:

- **Waterborne transmission** through contaminated floodwater and wastewater
- **Soil-mediated transmission** through contaminated land and sediments
- **Foodborne transmission** through crops exposed to contaminated water or manure
- **Direct contact transmission** through handling of contaminated materials

These pathways ultimately lead to **human exposure**, which may result in infection depending on factors such as dose, immunity, and hygiene practices.

Environmental conditions, particularly flooding, play a critical role in amplifying these transmission pathways. Flood events facilitate the redistribution of contaminants, increasing the spatial reach of pathogens and creating new exposure opportunities. Similarly, inadequate wastewater management contributes to the continuous introduction of parasites into the environment.

Human behavior and socio-economic factors further influence the effectiveness of sanitation systems and the likelihood of exposure. Practices such as improper handling of compost, use of untreated wastewater in agriculture, and lack of hygiene awareness can significantly increase risk.

The conceptual framework therefore emphasizes the interconnected nature of sanitation, environmental processes, and human behavior in shaping parasitic health risks. It highlights the need for integrated interventions that address multiple components of the system rather than focusing on isolated factors.

1.10 Significance of the Study

This study holds significant importance from both scientific and practical perspectives. By focusing on the intersection of Ecosan systems, wastewater contamination, and flood dynamics, it provides a comprehensive understanding of parasitic transmission in a complex urban environment.

From a scientific standpoint, the study contributes to the existing body of knowledge by addressing critical gaps related to parasitic contamination in sanitation systems. It provides empirical insights into the presence and distribution of parasites across different environmental media, thereby enhancing understanding of their survival and transmission mechanisms.

From a public health perspective, the findings of this study have direct implications for disease prevention and control. By identifying key exposure pathways, the research can inform targeted interventions aimed at reducing human contact with contaminated environments. This is particularly important in vulnerable communities where the burden of parasitic infections is highest.

The study also has policy relevance, as it provides evidence that can support the development of improved sanitation strategies. By highlighting the limitations and risks associated with current practices, it can guide policymakers in designing more effective and sustainable solutions.

Furthermore, the research supports the broader goals of environmental sustainability by promoting safe waste management practices and reducing environmental contamination. It aligns with global initiatives aimed at improving sanitation and public health outcomes in urban areas.

1.11 Objectives of the Study

1.11.1 General Objective

The general objective of this study is to comprehensively assess the occurrence, distribution, and transmission dynamics of parasitic organisms associated with Ecosan toilet manure, wastewater, and flood runoff water in and around Dhaka City, with the ultimate aim of evaluating potential public health risks and informing sustainable sanitation strategies.

This objective reflects the need to move beyond isolated assessments of sanitation systems and instead adopt a systems-based approach that considers the complex interactions between environmental contamination sources and human exposure pathways. By integrating multiple environmental components, the study aims to provide a holistic understanding of parasitic risk within an urban ecosystem.

1.11.2 Specific Objectives

To achieve the general objective, the study is structured around the following specific objectives:

1. **To identify and characterize parasitic organisms present in Ecosan toilet manure**
   This objective focuses on determining the types and prevalence of parasites that persist in composted human excreta. It includes assessing whether treatment processes are sufficient to inactivate resistant forms such as helminth eggs and protozoan cysts.
2. **To investigate parasitic contamination in wastewater systems within Dhaka**
   This involve examining wastewater from drains, canals, or other urban sources to evalute the presence and concentration of parasitic organisms. The objective aims to understand the role of wastewater as a continuous reservoir of infection.
3. **To assess the presence and spread of parasites in flood runoff water**
   Given the seasonal flooding in Dhaka, this objective examines how floodwaters act as vectors for dispersing parasitic organisms across different environments, increasing exposure risks.
4. **To analyze environmental factors influencing parasite survival and transmission**
   This includes temperature, moisture, pH, and seasonal variations, all of which affect the persistence and infectivity of parasites in different environmental media.

5. **To provide recommendations for improving sanitation safety and public health outcomes**

Based on findings, the study aims to suggest practical and policy-level interventions to reduce parasitic transmission.

1.12 Research Questions

This study is guided by a series of research questions designed to address both environmental and public health dimensions of parasitic transmission:

Primary Research Question

- How do Ecosan toilet manure, wastewater, and flood runoff contribute to the transmission of parasitic infections in Dhaka City?

Secondary Research Questions

1. What types of parasitic organisms are present in Ecosan manure, wastewater, and floodwater?
2. To what extent do current Ecosan treatment processes reduce parasitic contamination?
3. How does wastewater contribute to environmental persistence of parasites?
4. What role does flooding play in redistributing parasitic organisms?
5. Which transmission pathways pose the greatest risk to human health?
6. How do environmental and seasonal factors influence parasite survival?
7. What interventions can effectively reduce parasitic exposure in urban settings?

1.13 Scope of the Study

The scope of this study encompasses both environmental and public health dimensions of parasitic contamination within the urban context of Dhaka City.

Geographically, the study focuses on selected areas within and around Dhaka where Ecosan systems are in use and where wastewater and flood-related issues are prominent. These areas represent a range of environmental and socio-economic conditions, allowing for a comprehensive assessment of sanitation-related risks.

Thematically, the study is limited to parasitic organisms, including helminths and protozoa, due to their resilience and public health significance. While other pathogens such as bacteria and viruses are also important, the focus on parasites addresses a critical gap in existing research.

The study examines three primary environmental components:

- Ecosan toilet manure
- Wastewater systems
- Flood runoff water

It also considers the interactions between these components, particularly in terms of how contamination is transferred and amplified across different environmental media.

However, the study does not include large-scale epidemiological surveys or clinical diagnosis of infections. Instead, it focuses on environmental contamination and potential exposure pathways.

1.14 Limitations of the Study

Despite its comprehensive approach, this study is subject to several limitations that must be acknowledged.

Firstly, environmental sampling may not capture the full variability of parasitic contamination due to spatial and temporal differences. Parasite presence can fluctuate based on environmental conditions, making it challenging to generalize findings across all settings.

Secondly, the detection of parasites in environmental samples does not necessarily indicate active infection risk, as viability and infectivity may vary. Some detected organisms may be non-viable, although their presence still indicates contamination.

Thirdly, the study is limited by resource constraints, which may affect the number of samples collected and the range of analytical techniques used. Advanced molecular methods, while more sensitive, may not always be feasible.

Additionally, the study focuses on environmental pathways rather than direct human health outcomes. As such, it does not establish causal relationships between exposure and infection but instead identifies potential risks.

Finally, socio-cultural factors influencing sanitation practices may not be fully captured, although they play an important role in shaping exposure pathways.

1.15 Ecosan Toilet Manure: Characteristics, Benefits, and Risks

Ecological Sanitation (Ecosan) toilet systems represent an innovative approach to waste management that seeks to transform human excreta into a usable resource. Unlike conventional sanitation systems that treat waste as something to be disposed of, Ecosan systems are based on the principle of nutrient recovery and recycling. Through controlled processes such as composting or dehydration, human feces are converted into a stabilized product commonly referred to as Ecosan manure.

Composition and Characteristics of Ecosan Manure

Ecosan manure is rich in essential plant nutrients, particularly nitrogen (N), phosphorus (P), and potassium (K), which are critical for soil fertility and agricultural productivity. In addition to these macronutrients, the manure may also contain organic matter that improves soil structure, water retention, and microbial activity. These properties make Ecosan manure an attractive alternative to chemical fertilizers, especially in resource-limited settings.

However, the composition of Ecosan manure is highly variable and depends on several factors, including:

- Type of toilet system (urine-diverting or non-diverting)
- Duration and conditions of composting
- Environmental factors such as temperature and humidity
- User practices, including the addition of bulking agents like ash or sawdust

If properly treated, Ecosan manure can be hygienically safe and environmentally beneficial. However, inadequate treatment can result in the presence of pathogens, including parasitic organisms.

Pathogen Survival and Parasitic Risks

One of the most critical concerns associated with Ecosan manure is the survival of parasitic organisms, particularly helminth eggs and protozoan cysts. These organisms are known for their resilience and ability to persist in harsh environmental conditions.

For example:

- *Ascaris lumbricoides* eggs can survive for months or even years in soil.
- *Trichuris trichiura* eggs are highly resistant to environmental stress.
- Protozoan cysts such as *Giardia* and *Cryptosporidium* can survive in moist conditions and resist conventional treatment.

The effectiveness of Ecosan systems in eliminating these pathogens depends largely on composting conditions. High temperatures (above 50–60°C), adequate drying, and sufficient storage time are essential for inactivating parasites. However, in many real-world settings—especially in tropical climates like Dhaka—these conditions are not consistently achieved.

Human Exposure Pathways from Ecosan Manure

Parasitic transmission from Ecosan manure can occur through several pathways:

- **Agricultural use:** Crops fertilized with contaminated manure may carry parasite eggs or cysts.
- **Direct handling:** Individuals handling manure without protective equipment may be exposed.
- **Environmental contamination:** Runoff from manure-applied fields can spread pathogens to water sources.

These pathways highlight the importance of proper treatment, handling, and application practices to minimize health risks.

1.16 Wastewater: Source, Composition, and Role in Parasitic Transmission

Wastewater in urban environments like Dhaka is a complex mixture of domestic sewage, industrial effluents, and stormwater runoff. It serves as a major reservoir for a wide range of contaminants, including organic matter, chemicals, and pathogenic microorganisms.

Sources and Characteristics of Wastewater

In Dhaka, wastewater originates primarily from:

- Household activities (toilets, kitchens, bathing)
- Industrial discharge
- Commercial establishments
- Surface runoff during rainfall

Due to limited treatment infrastructure, a significant portion of wastewater is discharged untreated into open drains, canals, and rivers. These water bodies become heavily contaminated and act as continuous sources of environmental pollution.

Wastewater typically contains:

- High organic load
- Suspended solids
- Nutrients (N, P)
- Pathogens (bacteria, viruses, parasites)

Parasitic Contamination in Wastewater

Wastewater is particularly important in the transmission of parasites because it directly receives human excreta. As a result, it often contains:

- Helminth eggs (*Ascaris*, hookworm)
- Protozoan cysts (*Giardia*, *Entamoeba*)
- Oocysts (*Cryptosporidium*)

These organisms can survive for extended periods in aquatic environments, especially when conditions are favorable.

Transmission Pathways Linked to Wastewater

Wastewater contributes to parasitic transmission through multiple pathways:

- **Direct contact:** People exposed to contaminated drains or water bodies
- **Domestic use:** In some areas, wastewater may be used for washing or cleaning
- **Agriculture:** Use of wastewater for irrigation
- **Groundwater contamination:** Leakage from drains may contaminate drinking water sources

Environmental Persistence

Parasites in wastewater can settle in sediments, attach to organic matter, or remain suspended. This allows them to persist even after water flows change, creating long-term contamination risks.

1.17 Flood Runoff Water: Dynamics and Public Health Implications

Flood runoff water is one of the most critical environmental factors influencing parasitic transmission in Dhaka. Due to its geographical location and inadequate drainage systems, the city experiences frequent flooding during the monsoon season.

Formation and Characteristics of Flood Runoff

Flood runoff occurs when heavy rainfall exceeds the capacity of drainage systems, causing water to accumulate and flow across urban surfaces. In Dhaka, floodwater typically mixes with:

- Sewage from drains
- Solid waste
- Industrial pollutants
- Soil contaminants

This creates a highly contaminated mixture that spreads across residential areas.

Role of Flooding in Parasite Distribution

Floodwater acts as a powerful transport mechanism for parasitic organisms. It can:

- Spread parasites from localized sources (e.g., toilets, drains) to wider areas
- Contaminate homes, roads, and agricultural land
- Deposit parasite-laden sediments after water recedes

This significantly increases the spatial reach of contamination and exposes populations that may not normally be at risk.

Human Exposure Pathways During Flooding

Flood-related exposure occurs through:

- **Direct contact:** Walking or living in floodwater
- **Ingestion:** Accidental consumption of contaminated water
- **Food contamination:** Floodwater contacting stored or growing food
- **Post-flood exposure:** Contact with contaminated soil and surfaces

Children and low-income populations are particularly vulnerable due to higher exposure levels and limited protective measures.

1.18 Integrated Perspective: Interaction of Ecosan, Wastewater, and Flood Runoff

The three components—Ecosan manure, wastewater, and flood runoff—do not operate independently. Instead, they form an interconnected system that amplifies parasitic transmission risks.

- Ecosan manure may introduce parasites into soil
- Wastewater continuously contaminates the environment

- Floodwater redistributes contaminants across large areas

Together, they create a cycle of contamination and exposure that is difficult to control without integrated interventions.

Ethical and Safety Considerations

Handling fecal matter, wastewater, and floodwater contaminated with potential pathogens necessitates strict adherence to biosecurity protocols, institutional review board (IRB) guidelines, and local regulations. These steps can slow sample processing and place constraints on how frequently fieldwork can occur—particularly during severe floods, which pose additional safety hazards for researchers.

Timeline Constraints

Research Duration:

The timeline for this project is designed to capture both monsoonal and dry-season data. However, unforeseen circumstances—such as political unrest, extreme weather events, or public health crises (e.g., pandemic restrictions)—can alter the project schedule significantly. Each of the following phases faces potential delays:

1. Initial Field Reconnaissance (Weeks1–4):
   Locating suitable Ecosan toilet sites and flood-prone neighborhoods can be lengthier han anticipated if community gatekeepers require extensive consultation or if roads are impassable after heavy rainfall.
2. Sampling Campaigns (Months 2–6):
   Targeted for pre-monsoon, peak monsoon, and post-monsoon periods. In cases of delayed monsoon rains or sudden flash floods, sampling windows may need to shift.
   Seasonal unpredictability may limit the direct comparability of data collected at different times.
3. Laboratory Analyses (Months 2–8):
   Dependent on local lab capacity. Overburdened labs or equipment breakdowns can cause backlogs.
   Collaboration with external research institutions may introduce shipping or administrative delays.
4. Data Analysis and Write-Up (Months 7–12):
   Statistical processing may extend if data cleaning (e.g., verifying outliers, handling

missing values) is more complex due to the environmental variables or if new sub-questions emerge during fieldwork.

Flexibility is therefore pivotal in the project plan, with contingency measures (like expanding collaborations with additional labs) to reduce disruptions to data quality.

Inherent Limitations and Potential Biases

Sample Representativeness

Dhaka is a vast megacity with diverse socio-economic and topographical conditions. Though the study attempts to sample multiple neighborhoods and wastewater channels, it cannot claim full representativeness of all city areas. Marginalized communities living in unauthorized slums or along remote riverbanks may be harder to access consistently due to security or logistical hurdles.

Reliance on Self-Reported Data

Qualitative components—particularly user surveys and interviews—depend on self-reported practices (how often a household empties its compost chamber or the frequency of flooding in a neighborhood). Memory recall issues or social desirability bias may skew the accuracy of such data. Triangulating self-reports with direct observations is one mitigation strategy, but time and resource limits might constrain repeated visits.

Dynamic Socio-Political Context

Policy changes or development projects in Dhaka can occur rapidly. For instance, a new sewage treatment plant might commence operations mid-study, or a local NGO might distribute improved Ecosan toilets in certain wards. These unforeseen factors could alter the baseline conditions, complicating the attribution of parasitic contamination patterns solely to existing practices.

Flood Variability

Flood severity and timing vary yearly in Bangladesh, influenced by upstream river flows, monsoonal intensity, and urban infrastructure changes (Sakib et al., 2023). If the monsoon is unusually weak or strong, the data may not reflect typical conditions. Consequently, the results must be interpreted with caution, acknowledging that they represent a snapshot of possibly atypical flooding scenarios.

Cross-Contamination and Overlapping Sanitation Systems

Urban residents often use multiple sanitation strategies in parallel (e.g., shared pit latrines, partial sewer connections, or open defecation areas), making it difficult to isolate the effects of Ecosan systems on parasitic contamination. The study attempts to recruit households using exclusively Ecosan solutions, but cross-contamination from neighboring latrines remains a possibility.

Justification Despite Limitations

While these limitations pose challenges, they do not invalidate the study‘s overall significance. Instead, explicitly articulating constraints helps frame research findings within realistic bounds, allowing policymakers, practitioners, and academic audiences to interpret the results appropriately. The interplay of geographic focus, methodological rigor, and careful timeline management still enables robust, meaningful conclusions—albeit with the caveat that further research may be necessary to generalize findings or track long-term trends

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview of Dhaka's Sanitation Context

2.1.1 Introduction

Dhaka, the capital city of Bangladesh, is one of the world‘s most densely populated megacities, hosting an ever-growing population that exceeds 20 million (Alam et al., 2020; Rana, 2011). Urbanization in Dhaka has largely been rapid and unplanned, placing enormous pressure on infrastructure, especially in the water, sanitation, and hygiene (WASH) sectors (Hossain et al., 2018). The city‘s sanitation crisis is multifaceted, characterized by inadequate or incomplete sewer coverage, a reliance on on-site systems such as pit latrines or septic tanks, and the prevalence of informal or slum settlements with rudimentary facilities. These conditions create an environment conducive to the spread of waterborne diseases, including parasitic infections (Muhammad et al., 2016).

In this section, we examine Dhaka‘s sanitation landscape, looking at the conventional toilet systems in use, the extent of Ecosan (ecological sanitation) deployment, and relevant government policies and initiatives aimed at improving sanitation outcomes. This overview situates the broader context for analyzing parasitic contamination in Ecosan manure, wastewater, and flood runoff.

2.1.2 Current Toilet Systems and Practices

2.1.2.1 Conventional Systems: Pit Latrines, Septic Tanks, and Sewerage

Historically, Dhaka‘s sanitation infrastructure has been a patchwork of on-site and off-site systems. On-site systems include pit latrines (both unimproved and partially improved) and septic tanks (Rahman et al., 2014). Pit latrines, especially those in slum areas, are often poorly constructed with inadequate containment, leading to effluent leakage into surrounding soil and water bodies (Alam et al., 2020). Where septic tanks exist, they are frequently undersized oremptied infrequently, causing them to overflow during heavy rains or floods, releasing fecal matter into open drains.

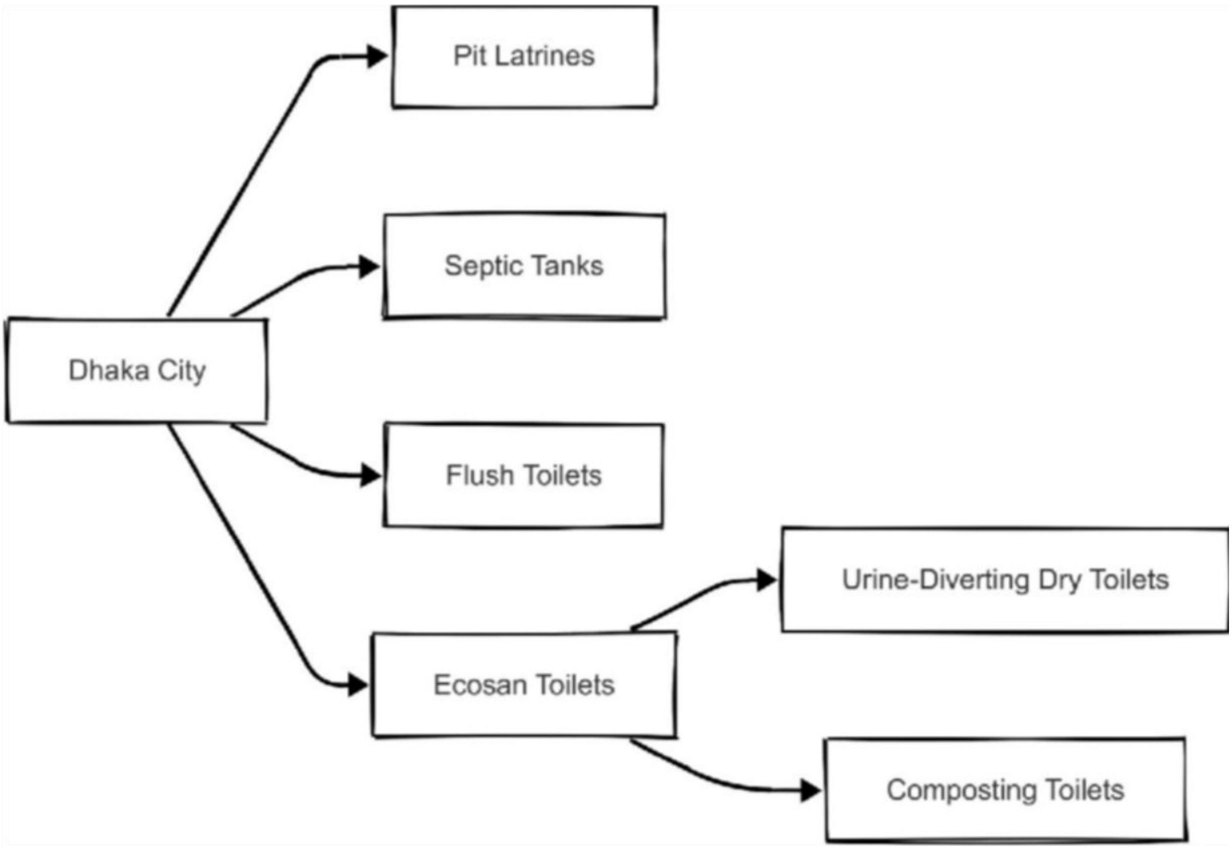


Figure 2.1: Dhaka City Sanitation Infrastructure Overview

Dhaka also has a centralized sewerage network, operated by the Dhaka Water Supply and Sewerage Authority (DWASA). However, this network covers only a fraction of the city; in many peripheral or informal settlements, households remain unconnected (Hossain et al., 2018). Even within the connected areas, treatment facilities are insufficiently scaled or poorly maintained, allowing significant volumes of untreated sewage to enter local rivers such as the Buriganga and Turag (Yin, Islam, &Ju, 2021). This fragmented system underscores the persistent gap between sanitation needs and service provision in a city growing at an unprecedented rate (Rana, 2011).

Table 2.1: Sanitation Infrastructure in Dhaka City

Aspect	**Description**	**References**
Sewer Coverage	Limited coverage; majority of households rely on pit latrines or septic tanks	Alam et al. (2020); Rahman et al. (2014)
On-Site Sanitation	Pit latrines (both improved/unimproved), septic tanks with partial maintenance	Muhammad et al. (2016); Chowdhury & Amin (2006)
Shared Toilets in Slums	Common in high-density areas, often poorly maintained, leading to hygiene issues	Seguftah (2009); Brouwer et al. (2023)
Flood-Prone Areas	Floodwaters regularly inundate low-lying wards, mixing with sewage and waste	Saha et al. (2024); Sakib et al. (2023)
Government Initiatives	Dhaka Sanitation Improvement Project (DSIP), some NGO-led community toilets	Alam et al. (2020); Nahrin (2020)
Main Challenges	Institutional fragmentation, lack of funding, rapid urban growth, and flooding	Rana (2011); Hossain et al. (2018)

Notes*:*

- *Data on exact sewer coverage rates vary; some estimates suggest only 20–30% of households are connected to formal sewer lines (Alam et al., 2020).*
- *Shared toilet usage can exceed 10+ households per latrine in certain slums (Chowdhury & Amin, 2006).*

2.1.2.2 Prevalence of Shared Toilets

Due to extreme population density, many residents in Dhaka share toilet facilities. In slum settings, a single latrine may be used by multiple families, leading to high user-to-toilet ratios (Chowdhury & Amin, 2006; Seguftah, 2009). Overcrowding exacerbates toilet maintenance challenges and accelerates fill-up rates, which in turn compound hygiene issues. During floods or heavy rainfall, shared toilets can become inaccessible, prompting open defecation or use of makeshift solutions that further compromise sanitation (Shimi et al., 2010).

2.1.2.3 Emergence of Ecological Sanitation (Ecosan) in Dhaka

In recent years, NGOs and development agencies have introduced Ecosan toilets in selected communities, aiming to improve sanitation while recovering nutrients from human excreta (Alam et al., 2020; Ali, 2012). Ecosan systems divert or compost fecal matter, reducing the reliance on water for flushing, an important consideration in Dhaka where waterlogging is a persistent threat (Nahrin, 2020). However, adoption rates remain modest due to limited awareness, cultural barriers to handling composted human waste, and the technical complexity of maintaining Ecosan facilities properly (Rahaman et al., 2023).

2.1.3 Government Policies and Initiatives

2.1.3.1 National Sanitation Policies

Bangladesh‘s national sanitation policies have historically focused on eradicating open defecation, primarily through pit latrine promotion. While considerable progress has been made—Bangladesh is often lauded for its drastic reduction in open defecation—challenges remain around safely managed sanitation, especially in urban areas (Muhammad et al., 2016). Policies such as the ―National Strategy for Water Supply and Sanitation‖ emphasize universal access, but local implementation in Dhaka faces financial, technical, and institutional bottlenecks (Alam et al., 2020).

2.1.3.2 Dhaka Sanitation Improvement Project (DSIP)

DWASA and the World Bank have collaborated on initiatives like the Dhaka Sanitation Improvement Project (DSIP) to rehabilitate and expand sewer networks, upgrade sewage treatment plants, and extend coverage to underserved neighborhoods (Alam et al., 2020). A key objective is to integrate low-income communities into improved sewerage systems, but the complexities of land tenure, rapid urban growth, and limited capacities often hinder progress (Brouwer et al., 2023). Additionally, DSIP has yet to fully incorporate decentralized or alternative sanitation solutions like Ecosan, which remain on the periphery of mainstream policy discourse.

2.1.3.3 NGO and Community-Led Efforts

Numerous NGOs (WaterAid, BRAC, Practical Action) have been active in promoting hygiene education, constructing latrines, and, in some instances, piloting Ecosan toilets (Seguftah, 2009). Some of these efforts incorporate participatory approaches, empowering local residents to co- design facilities and manage communal sanitation blocks (Chowdhury & Amin, 2006). While these programs show promise, sustainability remains a concern. The absence of a cohesive institutional framework often results in short-lived interventions that disintegrate once external funding or project oversight ends (Rahman et al., 2014).

2.1.3.4 Challenges in Policy Implementation

Despite these initiatives, several barriers impede the establishment of a robust sanitation infrastructure in Dhaka. These include:

1. **Financial Constraints:** High costs associated with sewer expansion and wastewater treatment upgrades.
2. **Institutional Fragmentation:** Overlapping mandates among city corporations, DWASA, and national government agencies, leading to coordination gaps.

3. **Land-Use Issues:** Rapid, informal urbanization complicates planning, as many slum dwellers lack land rights that would allow construction of improved toilets (Chowdhury & Amin, 2006).
4. **Socio-Cultural Barriers:** Stigma around handling human waste limits acceptance of Ecosan (Drangert, 2004a; Mulonga, 2007).
5. **Climate and Environmental Factors:** Seasonal flooding disrupts both conventional and alternative sanitation systems, underscoring the need for resilient designs (Shimi et al., 2010).

In sum, Dhaka‘s sanitation context is marked by significant infrastructural deficits, socio- economic complexities, and environmental vulnerabilities. While Ecosan technologies have gained some attention, their integration into mainstream sanitation strategies remains partial. The ensuing sections examine how Ecosan fits into the global sanitation narrative, the nature of parasitic infections relevant to this context, and how local conditions such as flooding influence parasitic spread.

2.2 Ecosan Toilets: Design, Function, and Global Perspective

2.2.1 Principles of Ecological Sanitation

Ecological sanitation (Ecosan) is predicated on the idea that human excreta are valuable resources rather than waste products (Winblad, 2004). By safely treating and transforming urine and feces into nutrient-rich fertilizers, Ecosan aims to foster a ―closed loop‖ system. Key tenets include:

1. **Resource Recovery:** Retaining nutrients like nitrogen, phosphorus, and potassium within local agricultural systems.
2. **Reduced Water Usage:**Ecosan systems minimize or eliminate the need for water flushing, which is critical in water-scarce or flood-prone environments.
3. **Pathogen Inactivation:** Through composting, dehydration, or high-temperature treatments, pathogens in fecal matter can be significantly reduced or eliminated (Maharjan, 2020; Stenström, 2004).

4. **Environmental Protection:**Ecosan lessens the ecological footprint of sanitation by curbing water pollution and cutting down on chemical fertilizer use (Hu et al., 2016).

These principles contrast with conventional sanitation models that typically rely on waterborne conveyance and centralized treatment. While flush toilets are convenient, they consume large volumes of water and require extensive infrastructure—challenges that are especially pronounced in Dhaka's dense urban fabric and limited municipal resources (Drangert, 2004b).

2.2.2 Ecosan System Designs

2.2.2.1 Urine-Diverting Dry Toilets (UDDTs)

Perhaps the most common Ecosan design involves urine-diverting dry toilets (UDDTs). These feature two separate receptacles, one for urine and another for feces (Werner et al., 2009). Urine is often collected in sealed containers or diverted to soak pits, while feces are covered with ash or sawdust, aiding in drying and odor reduction (Senecal-Smith, 2013). After sufficient retention time, the fecal material becomes a soil-like compost that can be applied to crops. The dryness environment also helps in pathogen die-off.

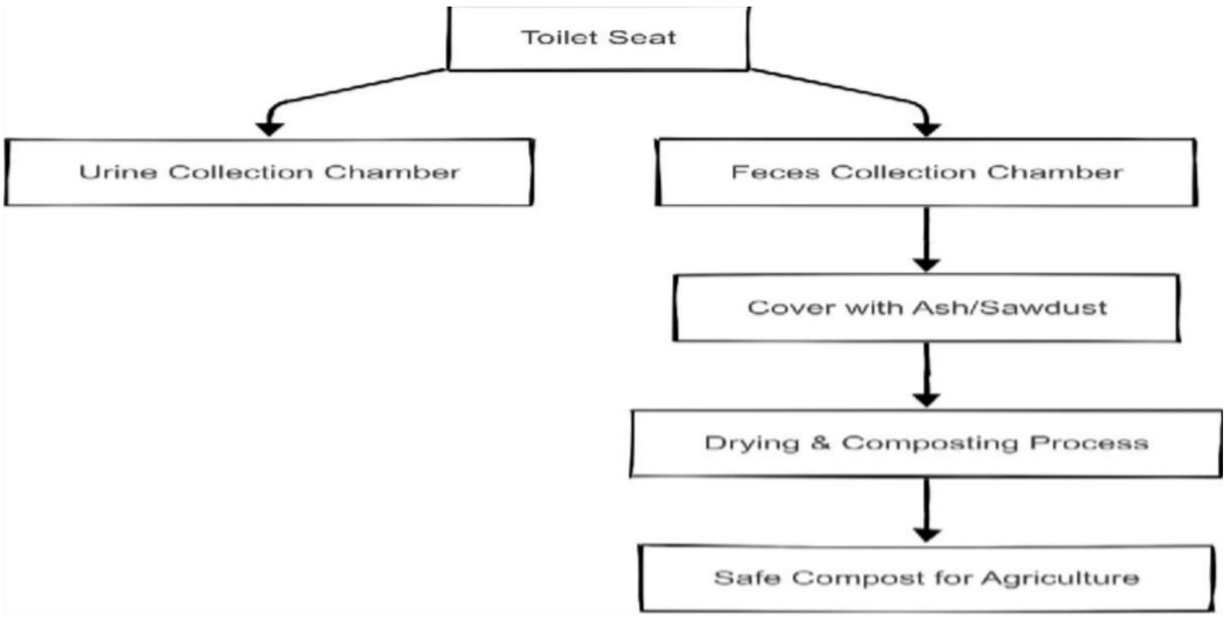


Figure 2.2: Typical Urine-Diverting Dry Toilet (UDDT) Design

2.2.2.2 Composting Toilets

Another Ecosan approach involves composting toilets where feces, along with carbon-rich additives (e.g., straw, sawdust), decompose over time in a ventilated chamber (Pynnönen, 2012). Ideally, thermophilic composting (50–60°C) inactivates pathogens, including many helminth eggs (Werner et al., 2009). Regular turning or mixing of the compost ensures aeration and promotes microbial activity, hastening decomposition (Senecal-Smith, 2013).

2.2.2.3 Hybrid and Innovative Models

Innovations continue to emerge, particularly in regions with distinct climate challenges. For instance, solar-assisted composting toilets leverage solar heat to boost pathogen kill rates, a design that may hold promise for flood-prone, hot climates like Dhaka (Mayaka et al., 2018). Other models integrate portable containers for easier removal of compost or incorporate advanced filtration for urine sterilization. Yet each design must be context-specific, reflecting local cultural norms, climate conditions, and resource availability (Gelder, 2011).

Table 2.2: Overview of Ecosan Technologies

Ecosan Design	Key Features	Advantages	Challenges	References
Urine-Diverting Dry Toilets (UDDTs)	Separates urine & feces; feces are dried with ash or sawdust	Low water use; nutrient-rich urine can be utilized separately	Requires consistent covering material and user training	Werner et al. (2009); Hu et al. (2016)
Composting Toilets	Thermophilic composting; frequent turning/mixing	Produces valuable compost; can reach high	Needs proper ventilation, temperature monitoring;	Winblad (2004); Senecal-Smith (2013)

		pathogen kill rates	potential odors	
Hybrid/Solar-Assisted Models	Incorporates solar heating or improved insulation	Faster inactivation of parasites with higher temperatures	Higher initial cost; technology acceptance in local contexts	Mayaka et al. (2018)
Container-Based Sanitation	Sealed containers collected for off-site composting	Portable, suitable for dense slums; controlled compost process	Logistics of regular collection, disposal, and social acceptance	Gelder (2011); Mulonga (2007)

Notes:

- *User acceptance remains a common barrier, linked to cultural norms about handling feces (Drangert, 2004b).*
- *Dry conditions are essential for effective pathogen inactivation in UDDTs (Werner et al., 2009).*

2.2.3 Comparison with Conventional Sanitation Systems

2.2.3.1 Advantages

1. Water Conservation: Ecosan significantly reduces water consumption compared to flush toilets, critical in areas facing water stress or frequent flooding (Langergraber & Muellegger, 2005).
2. Nutrient Recycling: By returning nutrients to the soil, Ecosan supports agriculture, reducing reliance on synthetic fertilizers (Hu et al., 2016).
3. Decentralized Application: Ecosan can be implemented in remote or informal settings where conventional sewers are impractical (Esrey, 2001).
4. Lower Infrastructure Costs: Small-scale Ecosan installations can be cheaper to build and maintain than centralized sewage networks (Mulonga, 2007).

2.2.3.2 Disadvantages and Challenges

1. User Acceptance: Cultural taboos around handling human feces can impede Ecosan adoption (Drangert, 2004a).
2. Maintenance Requirements: Regular addition of bulking agents, temperature monitoring, and emptying of compost chambers may be labor-intensive (Winblad, 2004).
3. Risk of Incomplete Treatment: If composting parameters (time, temperature, pH) are not strictly maintained, pathogens—including parasites—may remain viable (Werner et al., 2009).
4. Limited Policy Support: Many governments and municipalities are more accustomed to conventional sanitation planning and may not readily invest in alternative systems (Münch et al., 2006).

2.2.4 Global Success Stories and Reported Challenges

2.2.4.1 Case Studies of Ecosan Adoption

- China: Large-scale implementation of urine-diverting toilets in some rural communities, showcasing how nutrient recycling can boost agricultural productivity (Esrey, 2001).
- Kenya: School-based Ecosan projects demonstrate improved toilet access, but highlight maintenance and cultural acceptance as persistent hurdles (Pynnönen, 2012; Diana, 2012).
- Malawi: Kumwenda et al. (2017) found that Ecosan toilets can reduce pathogen exposure under controlled conditions. However, user commitment to adding ash and managing compost is crucial.

2.2.4.2 Lessons for Dhaka

Dhaka can draw from these global experiences to shape context-specific Ecosan solutions, particularly around:

1. Flood Resilience: Elevated or sealed composting chambers that prevent water ingress.
2. User Education: Ongoing training to help households understand compost maturation times and safe handling practices (Barrett, 2021).
3. Integration with Local Policies: Coordination with city authorities to

integrate Ecosan within broader sanitation and environmental frameworks, ensuring alignment with projects like DSIP (Alam et al., 2020).

Nevertheless, the city‘s unique context—marked by dense settlements, ephemeral flooding, and socio-economic inequities—calls for rigorous assessments of how Ecosan performs in real-world conditions. Central to that performance is the question of parasitic inactivation and subsequent health outcomes, which the next sections address.

2.3 Parasitic Infections: Types, Life Cycles, and Transmission

2.3.1 Major Parasites of Concern

Parasitic infections remain a major global health issue, disproportionately affecting low- and middle-income regions with inadequate sanitation and hygiene (Pullan & Brooker, 2008). In Dhaka, the risk is magnified by overcrowded living conditions, suboptimal waste disposal, and frequent flooding events that facilitate pathogen dispersal (Shimi et al., 2010).

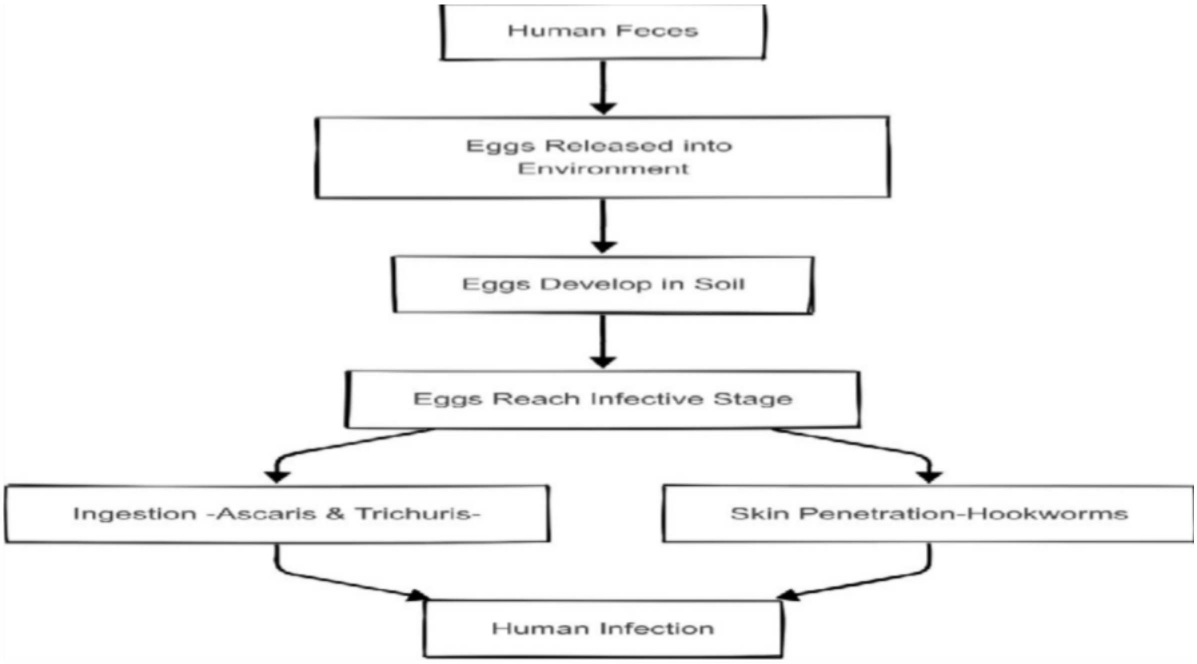


Figure 2.3: Life Cycles of Major Helminths (*Ascaris*, *Trichuris*, Hookworms)

This section explores the primary parasitic organisms that pose significant health risks in human populations, emphasizing those most relevant to fecal contamination in Ecosan systems, wastewater, and flood runoff.

Table 2.3: Major Parasites of Concern in Urban Dhaka

Parasite	**Type**	**Key Transmission Route**	**Environmental Persistence**	**Health Impact**	**References**
Ascaris lumbricoides	Helminth	Fecal-oral (ingestion of eggs)	Eggs survive months/years in soil	Malnutrition, l obstruction	EFSA Panel on BIOHAZ et al. (2018); WHO (1987)

Trichuris trichiura	Helminth	Fecal-oral (contaminated food/soil)	Resistant eggs, though slightly less robust than Ascaris	Dysentery, anemia, growth retardation	Pullan&Broo ker (2008); Torgerson& Macpherson (2011)
Hookworms	Helminth	Skin penetration from contaminated soil	Larvae survive in moist soil	Iron deficiency anemia, protein loss	Drangert (2004); Macpherson (2005)
Giardia lamblia	Protozoan	Fecal-oral, often via water	Cysts persist in cool, moist conditions	Diarrhea, malabsorption	Gofti-Laroche et al. (2003); Pisarski (2019)
Cryptosporidium spp.	Protozoan	Fecal-oral via water	Highly resistant oocysts, chlorine tolerant	Severe diarrhea, especially in immune-compromised	EFSA Panel on BIOHAZ et al. (2018)
Entamoeba histolytica	Protozoan	Fecal-oral (cyst ingestion)	Cysts survive in water/moist soil	Amoebic dysentery, liver	Pullan & Brooker (2008); WHO (1987)

Notes:

- *Multiparasitism is common in low-income, high-density settings, complicating diagnosis and treatment (Vaumourin et al., 2015).*
- *Helminth eggs can remain viable in compost if temperatures do not reach 50–60°C for sufficient durations (Werner et al., 2009).*

2.3.1.1 Helminths (Worms)

1. *Ascaris lumbricoides* (Roundworm):
   Often cited as the most common human helminth infection worldwide. *Ascaris* eggs can survive harsh environmental conditions (e.g., high humidity, moderate temperatures) and can remain viable in soil or feces for extended periods (EFSA Panel on BIOHAZ et al., 2018). Ingestion of *Ascaris* eggs through fecal-oral routes leads to intestinal infections, malnutrition, and, in severe cases, intestinal obstruction (Torgerson & Macpherson, 2011).
2. *Trichuris trichiura* (Whipworm):
   Another intestinal nematode prevalent in tropical regions. Its eggs, like *Ascaris*, exhibit notable environmental resilience, complicating efforts to achieve complete inactivation in compost (World Health Organization, 1987).
3. Hookworms (*Ancylostoma duodenale*, *Necator americanus*):
   Penetrate human skin (commonly feet) from contaminated soil. Although different from fecal-oral parasites, hookworms thrive in environments where open defecation or poor sanitation fosters feces-soil contact (Drangert, 2004).

2.3.1.2 Protozoa

1. *Giardia lamblia*:
   A flagellated protozoan causing giardiasis, often associated with diarrhea and malabsorption. *Giardia* cysts resist conventional chlorine disinfection and can persist in cool, moist conditions (Gofti-Laroche et al., 2003).
2. *Cryptosporidium* spp.:
   Well-known for extreme chlorine tolerance, *Cryptosporidium* oocysts persist in water systems, especially where sewage is released untreated (EFSA Panel on BIOHAZ et al., 2018). Outbreaks often follow contamination of drinking or recreational water sources.

3. *Entamoeba histolytica*:
   The causative agent of amoebiasis. Although it may be less robust in the environment compared to some helminths, poor sanitation can lead to widespread cyst dispersal.

2.3.1.3 Other Parasites of Emerging Concern

- *Strongyloides stercoralis*: Capable of autoinfection, leading to chronic or disseminated disease.
- *Taenia* spp. (Tapeworms): Occur where livestock feces or cross-contamination is prevalent, though less commonly linked to Ecosan manure.
- Zoonotic Parasites: Including protozoa like *Toxoplasma gondii* or helminths like *Echinococcus*, relevant if animal manure or contaminated surfaces intersect with human feces (Macpherson, 2005).

2.3.2 Life Cycles and Transmission Routes

Parasites often have complex life cycles, involving multiple stages and, at times, multiple hosts (Despommier & Karapelou, 2012). For instance:

1. Direct Life Cycle (Monoxenous): Parasites such as *Ascaris* or *Trichuris* require only one host to complete their cycle. Eggs are shed in feces, develop in the environment, and infect a new host upon ingestion.
2. Indirect Life Cycle (Heteroxenous): Some protozoa or helminths involve intermediate hosts. While this study primarily focuses on parasites transmitted via fecal-oral routes, indirect life cycles can become relevant if livestock or wild animals ingest contaminated Ecosan manure (Macpherson, 2005).

Transmission occurs most commonly via fecal-oral pathways, encompassing:

- Contaminated Water: Drinking, bathing, or cooking with water carrying infective stages of parasites (Pisarski, 2019).
- Contaminated Food: Vegetables or other produce fertilized with improperly treated manure (Pham-Duc et al., 2013).
- Direct Contact: Handling contaminated fecal matter, floodwater, or soil without proper hygiene (Penakalapati et al., 2017).

In high-density settings like Dhaka, close household proximity multiplies infection risks. Floods and inadequate wastewater management further facilitate the spread of parasitic eggs and cysts across broad swathes of the city (Shimi et al., 2010).

2.4 Parasitic Contamination in Human Feces and Manure

2.4.1 Persistence and Survival Rates

Fecal matter is a primary reservoir for many parasites (Mahmud et al., 2016). The survival rate of parasitic eggs or cysts in feces depends on temperature, humidity, pH, and exposure to ultraviolet radiation (Pham-Duc et al., 2013; Pell, 1997). Helminth eggs like those of *Ascaris* can remain infective for months or even years under optimal conditions, whereas many protozoa (like *Cryptosporidium*) can survive weeks in moist environments (Gofti-Laroche et al., 2003).

Key Factors Influencing Parasite Survival in Manure:

1. Temperature: Higher compost temperatures (thermophilic range: 50–60°C) accelerate parasite egg destruction, but incomplete or poorly managed composting might not reach lethal temperatures (Werner et al., 2009).
2. Moisture Content: Parasites often survive longer in moist, cool conditions. In drier ecosystems, desiccation can kill many eggs, but certain species like *Ascaris* remain viable in partially dried environments (EFSA Panel on BIOHAZ et al., 2018).
3. pH and Ammonia Concentration: Adding ash or urea can create alkaline conditions that inactivate eggs more rapidly.
4. Duration of Storage: Extended composting periods—up to 6–12 months—are frequently recommended to ensure thorough die-off, yet real-world practices vary widely (Drangert, 2004b).

2.4.2 Humanure and Ecosan: Safe Handling and Risks

2.4.2.1 Humanure Concept

—Humanure refers to composted human feces used as a soil amendment (Pell, 1997). The concept underpins many Ecosan approaches, but safety hinges on rigorous pathogen inactivation. In Dhaka, where monitoring frameworks are scarce, improper handling or early application of compost may perpetuate parasitic infections.

Table 2.4: Examples of Parasite Survival Rates in Feces and Manure

Parasite	Optimal Inactivation Conditions	Approx. Survival in Compost	Relevant Studies
Ascaris lumbricoides	Temperatures above 50°C for ≥1 week	Can survive >6 months in suboptimal compost	EFSA Panel on BIOHAZ et al. (2018); Ali (2012)
Trichuris trichiura	Sustained high temp (≥50°C) + low moisture	Similar to *Ascaris,* slightly faster kill	Pham-Duc et al. (2013); Kumwenda et al. (2017)
Giardia lamblia	Dry conditions + moderate-high temperatures	Weeks to months if compost remains moist	Gofti- Laroche et al. (2003); Pell (1997)
Cryptosporidium spp.	High temp & UV exposure	Oocysts can persist weeks if compost is cool	Werner et al. (2009); Stenström (2004)

Notes:

- *Ash addition (increasing pH) can expedite inactivation of helminth eggs (Stenström, 2004).*
- *Intermittent turning of compost ensures higher internal temperatures and more uniform pathogen kill rates (Hu et al., 2016).*

2.4.2.2 Past Studies on Ecosan-Related Contamination

Research in rural Bangladesh indicates that while Ecosan can reduce bacterial contaminants, helminth eggs can persist if compost temperatures remain suboptimal or if users frequently deposit fresh feces into the same chamber (Ali, 2012). In Malawi, Kumwenda et al. (2017) reported lower helminth loads in well-maintained Ecosan toilets compared to traditional pit latrines, but stressed that consistent user training on ash addition and compost turn-over was critical. Similarly, Gaspard et al. (1997) observed that urban sludges often harbor helminths unless carefully treated at elevated temperatures.

2.4.2.3 Handling Practices and User Behavior

Behavioral factors, including reluctance to handle feces or ignorance of the minimum composting time, often undermine the potential of Ecosan (Mulonga, 2007; Drangert, 2004a). An incomplete composting cycle risks infecting farmers or gardeners who apply partially treated manure. Moreover, flood-prone contexts like Dhaka raise additional concerns: elevated water can infiltrate compost chambers, reactivating dormant eggs or dispersing them into surrounding soils (Saha et al., 2024a).

2.5 Wastewater and Flood Runoff: Pathogen Survival and Spread

Dhaka‘s wastewater network is insufficient for the city‘s population size, with only a small percentage of sewage receiving full treatment (Alam et al., 2020). The majority of domestic and commercial effluents flow into open drains and canals, leading to heavy pollution of rivers and wetlands (Yin et al., 2021). Although bacterial indicators like *E. coli* are commonly monitored, parasitic organisms (helminth eggs, protozoan cysts) are seldom assessed (Deb et al., 2021). This gap allows parasites to remain undetected yet widespread in water bodies.

2.5.1 Key Transmission Pathways

Untreated or partially treated wastewater can contaminate:

1. Surface Waters: Rivers, canals, and ponds that local communities use for bathing, washing dishes, or sometimes even drinking.
2. Irrigation Channels: Urban farmers often rely on contaminated canals for crop irrigation, thereby transferring parasites to produce (Pham-Duc et al., 2013).
3. Groundwater: Infiltration through fissured soils, especially where pit latrines or

wastewater lines are close to shallow aquifers (Rahman et al., 2014).

Flood Dynamics and Parasite Dispersal

Seasonal Flooding in Dhaka

Dhaka experiences monsoonal rains typically from June to September, frequently inundating low-lying areas (Sakib et al., 2023). Drainage systems often fail under heavy rainfall, causing stormwater to mix with raw sewage. Floodwater can spread parasites over large areas, contaminating roads, homes, and community spaces (Shimi et al., 2010).

Pathogen Survival in Floodwaters

Floodwaters can maintain moderate temperatures suitable for parasitic survival, while sediment in stagnant waters can protect eggs or cysts from sunlight-induced inactivation (Ten Veldhuis et al., 2010; Bradford et al., 2013). Studies in other tropical regions illustrate that monsoon rains mobilize fecal contaminants, increasing exposure risk (Prayoga et al., 2021). In Dhaka, flood events often recede slowly, leaving behind pools or damp soils where parasitic stages can remain viable.

Case Studies of Waterborne Parasitic Outbreaks

Although large-scale parasitic outbreaks often receive less attention than bacterial illnesses (e.g., cholera), documented outbreaks of giardiasis and cryptosporidiosis have been traced to floods that compromised water treatment facilities (Rose et al., 2001). In Dhaka‘s context, sporadic investigations suggest heightened gastrointestinal illnesses following flood events, but detailed parasitological data remain sparse (Saha et al., 2024; Sakib et al., 2023).

Table 2.5: Key Studies on Wastewater/Flood Contamination and Parasite Spread

Study/Region	**Focus**	**Key Findings**	**References**
Pham-Duc et al. (2013), Vietnam	Wastewater use in agriculture &helminth infection	*Ascaris* and *Trichuris* infections correlated with irrigated fields using wastewater	Pham-Duc et al. (2013)
Ten Veldhuis et al. (2010), Netherlands	Urban floodwater contamination	Stagnant floodwaters can protect pathogens by reducing UV exposure	Ten Veldhuis et al. (2010)
Prayoga et al. (2021), Vietnam	Monsoon rains & fecal bacteria dispersion	Heavy rainfall mobilizes pathogens from sewers to peri- urban farms	Prayoga et al. (2021)
Saha et al. (2024), Dhaka	Flood management issues in Dhaka City	Seasonal flooding exacerbates water logging, mixing sewage with flood runoff	Saha et al. (2024)
Kumwenda et al. (2017), Malawi	Ecosan latrines & pathogen risks	Reduced helminth presence in well-managed Ecosan compared to conventional pits	Kumwenda et al. (2017)

Notes:

- While some studies emphasize bacterial indicators, parasitic eggs or cysts often remain underreported (Deb et al., 2021).
- Flood-susceptible neighborhoods in Dhaka face repeated contamination from open drains and latrines (Nahrin, 2020; Sakib et al., 2023).

2.5.2 Interactions with Ecosan Systems

Even if Ecosan toilets effectively inactivate parasites under controlled conditions, flood events can undermine those gains by:

1. Inundating Compost Chambers: Introducing moisture that revitalizes dormant eggs or flushes partially treated fecal matter into local drains.
2. Cross-Contamination of Storage Areas: If bagged or stored compost is kept at ground level, floodwaters may disperse it into surrounding neighborhoods.
3. Community Behavioral Responses: Households unable to access latrines in flooded conditions might revert to open defecation, raising overall parasite loads in the environment (Shimi et al., 2010).

These interactions stress the importance of integrating flood resilience measures and robust compost management protocols within the design and implementation of Ecosan initiatives in Dhaka.

2.6 Health Risk Assessment Approaches

2.6.1 WHO Guidelines on Water and Sanitation Safety

The World Health Organization provides **risk-based guidelines** for water and sanitation safety, recommending multiple barriers to pathogen transmission (WHO, 1987). While the guidelines often target bacterial indicators, they also endorse comprehensive approaches that account for protozoa and helminths. In the context of Ecosan, WHO guidelines emphasize:

- Safe handling of excreta: Minimizing direct contact.
- Adequate storage/composting times: Ensuring pathogen inactivation.
- Monitoring final product safety: Testing compost or sludge before agricultural application (Stenström, 2004).

2.6.2 Quantitative Microbial Risk Assessment (QMRA)

2.6.2.1 Basics of QMRA

Quantitative Microbial Risk Assessment (QMRA) is a framework used to estimate the likelihood of infection from exposure to pathogens (Soller et al., 2010). It involves:

1. Hazard Identification: Determining the pathogens (parasites, bacteria, viruses) of concern.
2. Exposure Assessment: Evaluating how individuals come into contact with contaminated media (manure, water, flood runoff).
3. Dose-Response Assessment: Linking exposure levels to infection probabilities.
4. Risk Characterization: Integrating the above steps to provide an overall infection risk estimate (Leandro et al., 2022).

For Dhaka, a QMRA approach could compare different sanitation scenarios (e.g., Ecosan vs. conventional pit latrines vs. partial sewer coverage) to quantify parasitic infection risks. This would guide prioritization of resources in areas with the highest risks or suboptimal sanitation designs (Ferguson et al., 2003).

2.6.2.2 Case Studies on Parasite Risk Assessments

- Pham-Duc et al. (2013), Vietnam: Found a correlation between *Ascaris/Trichuris* infections and the use of wastewater in agriculture.
- Kumwenda et al. (2017), Malawi: Applied risk assessment to Ecosan latrines, indicating lower infection probabilities when composting is diligently managed.
- Soller et al. (2010), Recreational Waters: Highlighted how different fecal pollution sources affect infection risks, underscoring that parasite-laden human wastes often pose higher risks than animal feces.

These studies collectively illustrate QMRA‘s utility in making data-driven decisions about sanitation investments and interventions.

2.6.3 Case Studies on Parasite Risk Assessments

Beyond the examples cited above, several large-scale epidemiological and risk assessment studies in Asia and Africa demonstrate how helminths and protozoa hamper public health when sanitation is inadequate (Torgerson & Macpherson, 2011). However, few have specifically examined how Ecosan, wastewater mismanagement, and flooding converge in urban megacities like Dhaka. Thus, local adaptation of these frameworks remains essential.

Table 2.6: Health Risk Assessment Frameworks for Parasitic Infections

Framework	Key Steps	Typical Application	Limitations	References
WHO Water Safety Plans	Assess–Monitor–Manage hazards in water sources	Drinking water supply, small-scale community systems	Primarily focuses on bacterial indicators; parasitic coverage less explicit	WHO (1987); Stenström (2004)
Quantitative Microbial Risk Assessment (QMRA)	Hazard ID, Exposure, Dose-Response, Risk Characterization	Recreational waters, sanitation technology evaluation, floodwater analysis	Requires robust dose- response data for parasites; can be resource-intensive	Soller et al. (2010); Leandro et al. (2022)
Sanitation Safety Planning	Systematically identifies and mitigates risks in sanitation services	Ecosan project management, sewage treatment facilities, sludge handling	Often user compliance not fully integrated into risk analysis	Stenström (2004); Werner et al. (2009)
One Health Approach	Integrates human, animal, environmental health	Addressing zoonotic parasites, wastewater-agriculture linkages	Implementation complexity due to multi-sector coordination	Macpherson (2005); Torgerson& Macpherson (2011)

Notes:

- QMRA is increasingly used to estimate infection probabilities under scenarios like partial compost inactivation or flood exposure (Kumwenda et al., 2017).
- WHO guidelines stress multiple barriers—proper toilet design, safe compost application, and user education (WHO, 1987).

2.7 Environmental and Socioeconomic Impacts

2.7.1 Socioeconomic Burden of Parasitic Diseases

Parasitic infections often trap communities in cycles of poverty:

- Health Costs: Households bear medical expenses and lost work days due to illness.
- Children's Education: Chronic helminth infections lead to malnutrition, cognitive impairment, and absenteeism from school (Pullan & Brooker, 2008).
- Gender Inequities: Women may bear disproportionate burdens in caregiving, limiting their economic participation (Macpherson, 2005).

In Dhaka, inadequate sanitation aggravates these effects, particularly in low-income neighborhoods where residents have minimal financial buffers (Muhammad et al., 2016).

2.7.2 Environmental Degradation and Public Health Nexus

2.7.2.1 Water Quality Decline

Unmanaged sewage flows and flood-borne contaminants degrade water quality, impairing aquatic ecosystems and reducing fisheries productivity in Dhaka's rivers (Yin et al., 2021). Parasitic contamination further threatens biodiversity if certain parasite life stages involve aquatic hosts, although the full ecological ramifications remain under-studied (Macpherson, 2005).

2.7.2.2 Soil Fertility and Urban Agriculture

When Ecosan manure is properly treated, it can enhance soil fertility and reduce dependence on chemical fertilizers (Hu et al., 2016). However, parasitic contamination can lead to produce tainted with helminth eggs, jeopardizing food safety and consumer confidence (Pham-Duc et al., 2013). Balancing these trade-offs is vital for sustainable urban agriculture in peri-urban Dhaka.

Table 2.7: Identified Research Gaps Relevant to Dhaka's Parasitic Sanitation Issues

Research Gap	**Description**	**Implications**	**References**
Urban-Focused Ecosan Efficacy	Limited data on Ecosan performance in high-density, flood-prone megacities	Unclear if compost consistently inactivates parasites under real-world usage in Dhaka	Mulonga (2007); (2012)
Flood Impact on Ecosan and Parasite Dynamics	Few longitudinal or comparative studies linking flooding events to parasitic spread	Floods may undermine compost safety, reintroducing helminth eggs into local soils and water	Saha et al. (2024b); Sakib et al. (2023)
User Behavior and Compost Management	Gaps in understanding how cultural attitudes and daily practices affect parasite inactivation	Insufficient user training can lead to incomplete composting or misapplication of manure	Drangert (2004a); Kumwenda et al. (2017)
Comparative Risk Assessment (Ecosan vs. Conventional Sewer/Pit)	Lack of studies contrasting parasitic risks in different urban sanitation systems	Policymakers lack data-driven evidence to invest in or scale up alternative sanitation technologies	Werner et al. (2009); Münch et al. (2006)

Multi-Season Monitoring of Helminths and Protozoa	Cross-sectional studies abound; longitudinal analyses are rare	Seasonal variations remain poorly understood, limiting accurate risk management for Dhaka's monsoon cycle	Ali (2012); Mahmud et al. (2016)
Integration with Municipal Planning	Ecosan often remains an NGO-driven initiative, not fully integrated into city-wide projects	Potential fragmentation of solutions, minimal synergy with large-scale infrastructure (e.g., DSIP)	Alam et Rahman et al. (2014)

Notes:

- Addressing these gaps can enhance the design of future Ecosan projects, inform flood resilience strategies, and guide policy interventions targeting parasitic disease control in Dhaka (Alam et al., 2020).

2.7.3 Integrating Sanitation, Health, and Environmental Goals

Given the global emphasis on the Sustainable Development Goals (SDGs)—especially SDG 3 (Health), SDG 6 (Clean Water and Sanitation), and SDG 11 (Sustainable Cities)—Dhaka's parasitic challenges offer a microcosm of broader development dilemmas (Akter, 2024). Ecosan, if properly managed, can advance multiple SDGs by:

- Reducing Infectious Diseases: Cutting down on fecal-oral transmission routes.
- Promoting Resource Recovery: Encouraging circular economy principles through compost-based agriculture.
- Enhancing Climate Resilience: Building decentralized sanitation solutions that are less dependent on flood-vulnerable centralized networks (Saha et al., 2024a).

Yet these benefits will not materialize unless the critical issue of parasitic inactivation is comprehensively addressed (Münch et al., 2006).

2.8 Research Gaps

2.8.1 Inconsistencies or Missing Data

Despite the growing body of literature on Ecosan and parasitic infections, notable gaps persist:

1. Urban-Focused Ecosan Studies: Many investigations concentrate on rural or peri-urban scenarios, leaving a relative dearth of data on Ecosan‘s effectiveness in high-density urban environments such as Dhaka (Mulonga, 2007).
2. Flood Impact on Ecosan Performance: Few studies systematically assess how seasonal floods compromise or interact with Ecosan toilets, especially regarding parasitic contamination (Saha et al., 2024a).
3. Longitudinal Monitoring: While cross-sectional data on parasite presence exist, detailed year-round or multi-year analyses are scarce. Seasonal dynamics of parasite inactivation in compost or wastewater remain under-documented (Ali, 2012).
4. User Compliance and Behavioral Factors: Literature acknowledges cultural barriers but often lacks rigorous evaluations of how user practices—e.g., adding ash, turning compost—directly influence parasite survival rates (Drangert, 2004a).
5. Comparative Health Risk Assessments: The relative risks of Ecosan manure vs. conventional sewage in Dhaka‘s flood conditions remain largely unexplored. It remains unclear which scenario poses the greatest parasitic threat under different environmental stressors (Shimi et al., 2010).

2.8.2 Linking These Gaps to the Current Study

Addressing these research gaps is crucial to formulating integrated solutions that can make a measurable impact on public health in Dhaka. By systematically analyzing parasitic contamination in Ecosan manure, wastewater, and flood runoff—and correlating these findings with user behaviors and environmental parameters—this study offers to bridge key knowledge deficits:

1. Urban Ecosan Efficacy: Investigating whether composting times and techniques in a megacity environment are sufficient to neutralize high parasite loads.
2. Flood Resilience: Identifying how floods disperse parasites from multiple sources, including improperly managed Ecosan compost.

3. Behavioral Insights: Documenting real-world user practices (e.g., ignoring recommended composting durations) to see how these behaviors amplify or mitigate parasitic risks.
4. Holistic Risk Assessment: Employing or adapting QMRA frameworks to compare the parasite transmission risks of different sanitation practices, especially during monsoon seasons.

This integrated approach not only contributes to scientific knowledge but also provides actionable insights for public health interventions and policy reform.

2.9 Summary

Chapter 2 has offered a comprehensive review of the existing body of knowledge relevant to parasitic risks in Dhaka‘s sanitation context, with a specific focus on Ecosan systems, wastewater management, and flood-induced contamination pathways. The key takeaways are:

1. Dhaka‘s Sanitation Landscape: Characterized by a mixed patchwork of pit latrines, septic tanks, and limited sewer coverage. Ecosan remains a niche but emerging solution with potential for nutrient recycling and water conservation (Alam et al., 2020; Ali, 2012).
2. Ecosan Principles and Challenges: While Ecosan technologies offer environmental benefits, ensuring parasite inactivation requires consistent high temperatures, adequate moisture control, and user compliance (Winblad, 2004; Werner et al., 2009).
3. Parasite Biology and Transmission: Helminths (Ascaris, Trichuris) and protozoa (e.g., Giardia, Cryptosporidium) remain primary concerns, surviving for extended periods in feces, wastewater, and floodwaters (EFSA Panel on BIOHAZ et al., 2018; Gofti-Laroche et al., 2003).
4. Flood Exacerbation of Risks: Seasonal monsoons in Dhaka mobilize pathogens across vast areas, including inundating sanitation systems, thereby intensifying parasitic infection risks (Shimi et al., 2010; Saha et al., 2024b).
5. Health Risk Assessment Frameworks: Tools like QMRA can contextualize infection probabilities under various sanitation conditions, but localized data on parasitic loads in Ecosan manure and flooded neighborhoods remain limited (Kumwenda et al., 2017).

6. Socioeconomic and Environmental Implications: Parasitic diseases contribute to poverty cycles, hamper education, and degrade environmental resources. Conversely, well- managed Ecosan could address multiple SDGs if parasitic threats are mitigated (Pullan & Brooker, 2008; Hu et al., 2016).
7. Outstanding Research Gaps: There is a pronounced need for urban-centric, flood-aware studies on parasitic inactivation in Ecosan systems, alongside comparative risk assessments that evaluate whether Ecosan or conventional sewage practices carry higher parasitic burdens in Dhaka‘s monsoon context.

Building on these insights, the subsequent chapters will detail how this study tackles the identified gaps, describe the methodological framework for sample collection and parasite analysis, and ultimately quantify parasitic contamination across Ecosan, wastewater, and flood runoff environments in Dhaka. This evidence can inform targeted health interventions, refined Ecosan designs, and integrated sanitation policies that collectively reduce parasitic disease burden and promote sustainable urban development.

CHAPTER THREE

METHODOLOGY

Chapter 3 presents the systematic approach used to investigate parasitic health risks associated with Ecosan toilet manure, wastewater, and flood runoff in Dhaka City. In this chapter, we detail the research design that guided data collection, laboratory analysis, and interpretive processes, ensuring that each step aligns with the specific objectives outlined earlier in this thesis. Given the multifaceted nature of the research problem—encompassing environmental science, public health, and socio-cultural dimensions—a robust and adaptable methodology is crucial. Therefore, this chapter integrates both quantitative and qualitative methods, enabling a comprehensive exploration of parasitic prevalence, user behaviors, and infrastructural conditions.

We begin by justifying our choice of methodological framework, including the rationale behind using mixed methods to capture both empirical and experiential data. Next, we describe how the study was structured in phases, from selecting sampling sites in diverse Dhaka neighborhoods to processing the collected materials in the laboratory for parasitic identification. Special attention is paid to maintaining rigorous quality control protocols—ranging from the sterilization of sampling equipment to the calibration of laboratory instruments. The chapter also outlines how data were interpreted through statistical analyses, geographical mapping, and thematic evaluation of user interviews, ensuring that our findings rest on a strong empirical foundation. By the end, readers will have a clear understanding of the methodological choices that shape the subsequent chapters on results and discussion.

3.1 Research Design

Purpose:

To explain the overall methodological framework adopted by this study, justifying the choice between quantitative, qualitative, or mixed methods, and outlining the sequential phases—from sampling to lab analysis to data interpretation—that underpin the research.

1. **Justification of Mixed Methods**

Complexity of the Research Problem**:** Parasitic infections in Ecosan systems are influenced by both measurable environmental factors (compost temperatures, water contamination levels) and human behaviors (compliance with composting protocols, community acceptance). A purely quantitative approach would overlook qualitative nuances, while a strictly qualitative design might lack the empirical rigor to establish parasite prevalence rates. Consequently, a mixed- methods approach allows for a deeper, more holistic understanding.

Complementary Data Sources**:** Quantitative data (parasite egg counts, water testing results) provide objective measures of contamination, while qualitative insights (interviews with Ecosan users, field observations of flood events) reveal socio-cultural drivers and contextual factors that shape sanitation practices.

2. <u>Overall Methodological Phases</u>

Phase 1: Sampling Strategy

1. Site Selection: Identification of diverse neighborhoods in Dhaka City, including low-lying flood-prone zones, slum areas with shared or rudimentary latrines, and communities using Ecosan toilets.
2. Sampling Framework: Collection of Ecosan manure samples, wastewater from selected drains/canals, and flood runoff during monsoon peaks.
3. Ethical Clearances and Permissions: Ensuring informed consent from households for compost sampling, adherence to local regulations for water sampling, and ethical approvals from relevant institutional review boards.

Phase 2: Laboratory Analysis

4. Pathogen Detection Methods: Employing standardized microscopy (Kato- Katz) to identify helminth eggs and protozoan cysts.
5. Quality Control: Using negative and positive controls, calibrating laboratory equipment, and following biosafety protocols to handle potentially infectious materials.
6. Data Logging: Recording parasite counts, compost temperatures, and pH levels in a centralized database for subsequent analysis.

Phase 3: Data Interpretation

7. Quantitative Analyses: Statistical evaluations (descriptive statistics, regression models) to link environmental factors (temperature, flood depth, composting duration) with parasite prevalence.
8. Qualitative Synthesis: Thematic coding of interview transcripts and observational notes to understand community behaviors, cultural perceptions, and acceptance of Ecosan technology.

9. Integrated Risk Assessment: Triangulating findings from both data streams to assess how parasitic contamination and user practices intersect, thereby informing policy and public health recommendations.

The study ensures a systematic progression from field data collection to laboratory analysis and, ultimately, to synthesized insights. This design not only provides a robust empirical basis for concluding the parasitic risks in question but also underscores the socio-cultural dimensions that can either amplify or mitigate these risks in Dhaka's urban setting.

3.2 Study Area and Population

Dhaka City, the capital of Bangladesh, is one of the most densely populated megacities in the world, with an estimated population exceeding 20 million (Alam et al., 2020). The city's rapid urban growth has led to diverse infrastructural patterns, including a mixture of formal housing, slum settlements, and peri-urban zones that are undergoing continuous expansion. Within this mosaic, sanitation challenges persist at multiple levels, to capture these complexities for the present study on parasitic risks in Ecosan toilet manure, wastewater, and flood runoff, a strategic selection of sampling sites was undertaken. These included (1) communities known for adopting Ecosan toilets, (2) flood-prone wards routinely affected by monsoonal inundation, and (3) areas where open drains or canals carry domestic wastewater.

The city is administratively divided into multiple zones or wards, each exhibiting unique environmental and socio-economic conditions. Flooding is a recurring phenomenon, especially in low-lying and river-adjacent neighborhoods, contributing significantly to pathogen dispersion (Saha et al., 2024; Sakib et al., 2023). Communities that have embraced ecological sanitation (Ecosan) typically lie on the peri-urban fringe or are part of small-scale pilot programs led by NGOs and local stakeholders (Ali, 2012). Meanwhile, central Dhaka wards rely heavily on combined sewer and drainage systems, some of which discharge partially treated or untreated wastewater into nearby canals and rivers (Rahman et al., 2014).

In terms of mapping and sampling logistics, field teams utilized GPS coordinates to pinpoint water sampling stations along open drains and canals, with additional emphasis on zones hit hardest by monsoon floods. The aim was to capture the spatial variability of contamination. For Ecosan manure sampling, the research prioritized households actively using urine-diverting or composting toilets for at least six months, ensuring there was a sufficiently mature compost pile to analyze. During the peak monsoon season, flood runoff samples were collected in temporarily inundated streets or ground depressions, focusing on visually turbid areas likely to reflect raw sewage overflow or compost infiltration. Where permission was granted, household interviews further revealed patterns in sanitation maintenance, user compliance, and the perceived reliability of Ecosan toilets in flood scenarios.

Overall, this strategic site selection process—coupled with a consideration of demographic variables—provides a nuanced understanding of Dhaka‘s sanitation spectrum. From high-density slums struggling with rudimentary latrines to peri-urban clusters where Ecosan toilets are gaining traction, the study covers a broad cross-section of conditions that influence parasitic contamination. Such variability is essential for robust comparisons and, ultimately, for formulating evidence-based recommendations on how best to protect public health through resilient, ecologically sustainable sanitation solutions in a flood-prone megacity context.

3.3 Sample Collection and Handling

Collecting and properly handling samples of Ecosan toilet manure, wastewater, and flood runoff is central to assessing parasitic health risks in Dhaka City. This section describes the protocols governing sampling times, frequency, sample sizes, and the storage and transportation conditions necessary to maintain sample integrity until laboratory analysis. Given Dhaka‘s climatic variability—particularly the monsoon season—and heterogeneous urban fabric, sampling protocols were designed to account for seasonal changes, diverse toilet technologies, and variable flooding intensities.

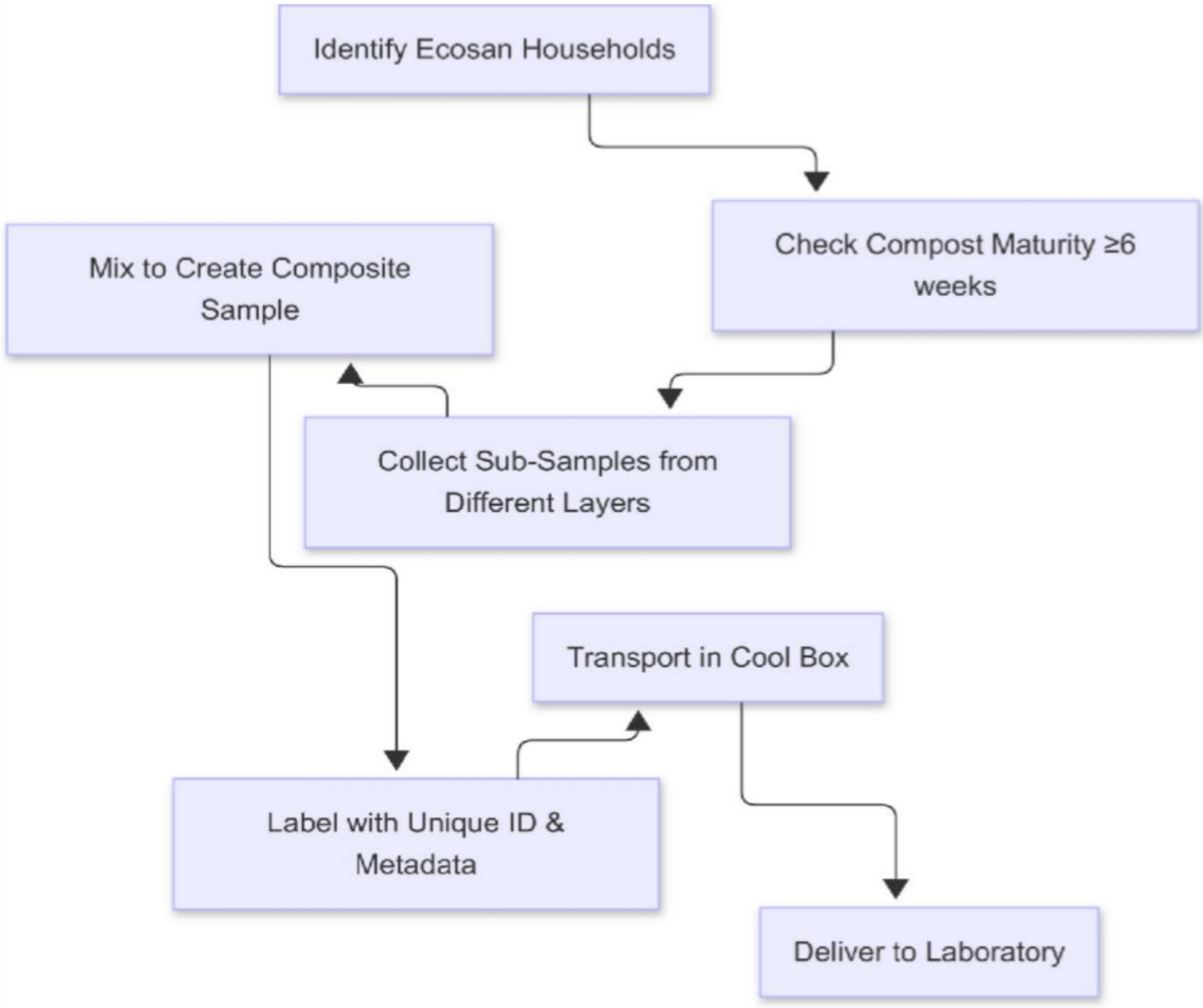


Figure 3.1: Sample Collection Procedure for Ecosan Compost

3.3.1 Overview of Sampling Strategy

By stratifying sites into Ecosan-focused communities, flood-prone wards, major wastewater outfalls, and control areas, we aimed to capture the full spectrum of sanitation practices and environmental conditions:

1. Ecosan Manure Samples: Collected from households that use ecological sanitation toilets (UDDTs or composting toilets).
2. Wastewater Samples: Drawn from open drains, canals, or sewer outfalls in both high- and low-density wards, capturing a range of contamination levels.
3. Flood Runoff Samples: Obtained during peak monsoon events, focusing on areas visibly inundated by water mixing with sewage or stormwater.

Table 3.1 below summarizes the key parameters—sample type, timing/frequency, and approximate sample size—for each category.

Table 3.1: Sampling Protocols for Ecosan Manure, Wastewater, and Flood Runoff

Sample Type	**Collection Timing**	**Frequency**	**Approx. Sample Size**	**Remarks**
Ecosan Manure	Typically morning or midday to align with user disposal patterns	Once per compost chamber cycle (every 2-3 months), with supplementary sampling in transitional phases	~200–300 g per Sample	Targeted households with UDDTs or composting toilets in Ward 56 and peri-urban sites; if two-chamber system, each chamber sampled Separately
Wastewater	Morning and afternoon to account for variable flows (peak household discharge)	2–3 times per season (pre-monsoon, monsoon, post-monsoon)	~500 mL in sterile containers	Collected at designated points near drains, canals, or outfalls (e.g., near Buriganga River)
Flood Runoff	During peak flood stage or immediately after	Opportunistic sampling: 1–2 times per major flood event,	~1 L from standing floodwater or	Priority to low-lying wards (Ward 33) and slum settlements

	heavy rainfall	up to 3 events per monsoon	waterlogged areas	prone to waterlogging; sampling from multiple points to capture spatial variability

Note: Sample sizes reflect typical lab recommendations for parasitic analysis (EFSA Panel on BIOHAZ et al., 2018). Additional replicate samples (2–3) were taken in cases of large compost pits or wide flood zones.

3.3.2 Ecosan Manure Collection

3.3.2.1 Selection of Household Chambers

For each Ecosan household the compost chamber had been in use for at least 6 weeks (to ensure partial decomposition). Households utilizing urine-diverting systems were selected if they consistently added ash or other bulking agents.

3.3.2.2 Sampling Procedure

- Protective Measures: Field staff wore gloves, masks, and protective clothing due to the potential presence of pathogens.
- Location of Sub-samples: Five or more sub-samples were taken from different depths and corners of the compost pile (top, middle, bottom).
- Composite Sample Creation: These sub-samples were thoroughly mixed in a sterile container to form a composite sample of approximately 200–300 g.
- Labeling & Documentation: Each sample was labeled with a unique ID, noting the household address, date, and compost chamber temperature (if measured).

3.3.3 Wastewater Collection

3.3.3.1 Site Selection and Timing

Sampling points were selected at outfalls, drains, and canals that represent different cross- sections of the city‘s wastewater network. Morning (07:00–09:00) and late afternoon (15:00– 17:00) collections were planned to capture variations in household effluent loads (Alam et al., 2020).

3.3.3.2 Sampling Steps

- Sterile Container Prep: 500 mL autoclaved bottles (for parasitic examination) and separate containers for any additional chemical or bacterial analyses.
- Mid-Stream Sampling: Whenever possible, the container was submerged mid-stream to avoid sediment-laden edges, ensuring a more representative sample.
- Field Measurements: Temperature, pH, and turbidity were recorded on-site using portable meters.
- Composite Sampling (Optional): In large canals, multiple sub-samples from the same site were combined to account for flow heterogeneity.

3.3.3.3 Rain Events and Seasonal Variation

Since Dhaka experiences significant rainfall variability, care was taken to sample both before and after rainstorms. This approach distinguished ―baseline‖ wastewater contamination from potentially elevated parasite loads during runoff events (Ten Veldhuis et al., 2010).

3.3.4 Flood Runoff Collection

3.3.4.1 Opportunistic Sampling During Monsoon

Flood runoff sampling was more opportunistic, tied to actual flood events. Field teams maintained a rapid response protocol, mobilizing within hours of moderate to heavy flooding in target wards.

3.3.4.2 Sampling Procedure

- Safety Checks: Only areas deemed safe for access were sampled, avoiding swift currents or deeper waters.
- Sample Volume: Typically 1 L per location, gathered in wide-mouth sterile bottles to accommodate suspended solids.
- Surface vs. Subsurface: Bottles were dipped just below the surface (~10–15 cm) to capture well-mixed water rather than floating debris or sediment alone.
- Multiple Points: In flooded streets or open spaces, 2–3 points were sampled if the water body was extensive, ensuring spatial coverage.

3.3.4.3 Monitoring Flood Peak and Recession

Where feasible, samples were taken at two time points—peak (when water levels are highest) and receding flood stage—to observe potential changes in parasitic concentrations as contaminated waters drain away (Sakib et al., 2023).

3.3.5 Storage and Transportation Conditions

Maintaining sample integrity from collection sites to the laboratory was essential to prevent parasite degradation or contamination. Table 3.2 summarizes the conditions and procedures for each sample type, ensuring reliable laboratory results.

Table 3.2: Storage and Transportation Conditions for Collected Samples

Sample Type	Initial Field Handling	Storage Temperature	Max Transport Time	Additional Notes
Ecosan Manure	Sealed in double-layer zip-lock bags within rigid containers; labeled with date & chamber ID	Ambient (25–30°C), but avoid direct sunlight	hours to lab	If transport exceeded 6 hours, samples kept in cool boxes (~4°C)
Wastewater	Filled in sterilized 500 mL bottles; minimal headspace	frigerate at 4°C if possible	≤ 4 hours ideally	If rapid transport not possible, stored in portable coolers with ice packs
Flood Runoff	Collected in wide-mouth sterile bottles, labeled with location & flood stage	4°C recommended	2–3 hours ideally	High turbidity samples thoroughly mixed before aliquoting in lab

Note: Laboratory guidelines suggest that fecal or water samples for parasitological examination should ideally be analyzed within 6–12 hours of collection to ensure parasite viability for microscopic detection (Stenström, 2004).

3.3.6 Quality Control Measures

To strengthen sample reliability, the study integrated the following quality control steps:

1. Duplicate Samples: Approximately 10% of each sample type was collected in duplicates for cross-verification, allowing internal consistency checks during analysis.
2. Blank Samples: Sterile water blanks accompanied each field mission to ensure no cross- contamination occurred during handling.
3. Chain of Custody Forms: Detailed records of collection times, transport conditions, and receiving lab personnel.
4. Decontamination of Equipment: After each sampling run, containers and tools (e.g., scoops for manure) were disinfected with a 0.5% sodium hypochlorite solution (WHO, 1987) and rinsed with distilled water.

These protocols aimed to minimize contamination and preserve parasite viability for accurate detection and enumeration (EFSA Panel on BIOHAZ et al., 2018).

3.3.7 Challenges and Adaptations

Field teams encountered various logistical challenges including:

- Unpredictable Flood Timing: Flood events sometimes occurred outside scheduled sampling windows, necessitating rapid field mobilization.
- Access to High-Risk Areas: Security concerns or infrastructural obstacles (blocked roads, deep water) limited sample collection in some slums.
- Community Acceptance: Households unfamiliar with Ecosan or research practices occasionally resisted sample collection, underscoring the importance of prior awareness campaigns.

Where obstacles arose, the research team adapted by rescheduling or focusing on safer, more accessible sites. These real-world constraints, while inevitable in large urban environments like Dhaka, highlight the importance of flexibility and stakeholder engagement in sanitation-related field studies (Rahman et al., 2014).

This section has outlined a comprehensive protocol for sample collection and handling, tailored to Dhaka‘s diverse sanitation landscape and climate-induced variability. By strategically selecting sites, timing, and methods, the research ensures that manure, wastewater, and flood runoff samples accurately reflect the city‘s parasitic contamination levels. The subsequent stages—laboratory analysis and data interpretation—build on these procedures, drawing scientifically robust conclusions about parasitic health risks and informing potential interventions for ecological sanitation and flood management in one of the world‘s most challenging urban contexts.

3.4 Laboratory Analysis and Parasitic Identification

The primary objective of the laboratory analysis phase was to detect and identify parasitic organisms—primarily helminth eggs and protozoan cysts—in samples of Ecosan manure, wastewater, and flood runoff. This multi-tiered approach combined established microscopic techniques with, where feasible, molecular assays, ensuring a thorough screening of parasitic contamination. Strict quality control protocols were employed to maintain reliability and reproducibility, including the use of positive and negative controls at each analytical step.

Upon arrival at the laboratory, all samples were logged, labeled, and subjected to initial screening to gauge turbidity and presence of large debris. Ecosan manure and floodwater samples, for instance, were pre-treated (e.g., sieving or centrifuging) to concentrate potential parasite eggs or cysts. The subsequent sections detail the standard operating procedures for microscopic detection (Kato-Katz, modified Ziehl-Neelsen) which were applied selectively for samples exhibiting high parasite loads or ambiguous microscopic results.

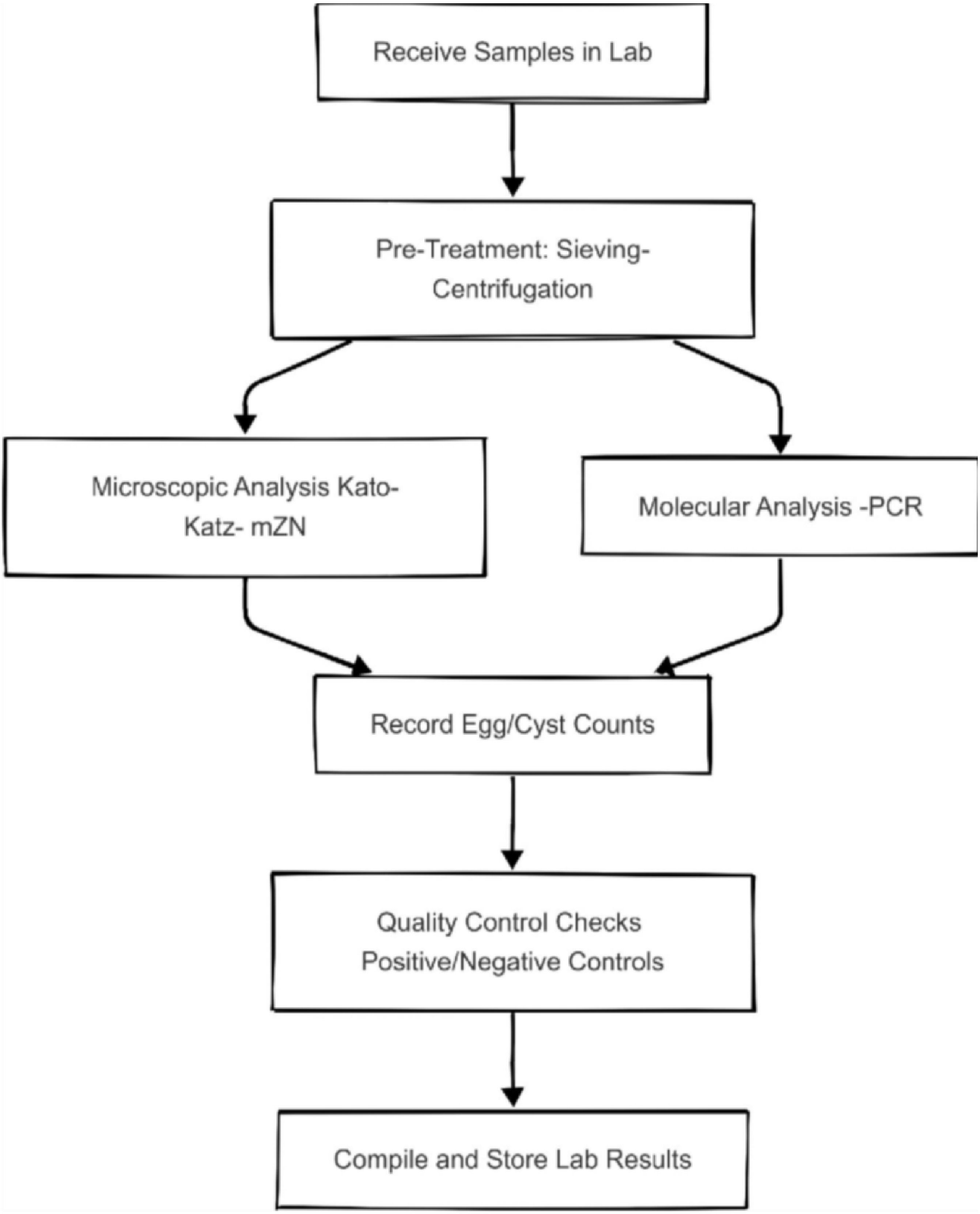


Figure 3.2: Workflow for Laboratory Analysis of Parasites

3.4.1 Microscopic Techniques

3.4.1.1 Kato-Katz Method

The Kato-Katz technique is a quantitative method widely employed for detecting and enumerating helminth eggs—particularly *Ascaris lumbricoides, Trichuris trichiura*, and hookworms (EFSA Panel on BIOHAZ et al., 2018). Manure or sedimented water samples were homogenized, filtered through fine meshes, and placed on microscope slides using a standardized template. After adding glycerol-malachite green solution and allowing a brief clearing period, slides were examined under light microscopy at 100×–400× magnification. Egg counts were recorded as eggs per gram (EPG) in solid samples or eggs per liter (EPL) in liquid samples, wherever applicable.

3.4.1.2 Modified Ziehl-Neelsen Staining

For protozoan parasites like *Cryptosporidium* and *Cyclospora*, the modified Ziehl-Neelsen (mZN) stain was employed. This method entails smearing the sample material (post- concentration) on a glass slide, applying a carbol fuchsin stain with gentle heat, then decolorizing and counterstaining to highlight the oocysts. Positive slides displayed oocysts as pinkish-red structures against a pale background (Gofti- Laroche et al., 2003). This stain proved especially valuable for identifying *Cryptosporidium* spp., recognized for their resistance to conventional disinfectants.

3.4.1.3 FORMOL ETHER CONCENTRATION TECHNIQUE

The **Formol-Ether Concentration** technique (Cheesbrough 2004) enables the diagnosis of protozoa and soil-transmitted helminthes. The units for measuring the intensity of infection at the individual level are **—**eggs per gram of faeces **(EPG).** By centrifugation, formol ether concentration procedure leads to the recovery of all protozoa, eggs, and larvae present. Ether is used as an extract or of debris and fat from the feces and leaves the parasites at the bottom of the suspension. The formol-ether sedimentation concentration is recommended as being the easiest to allow recovery of the broadest range of organisms, and is least subject to technical error. The specimen must be fresh or formalinized stool (5 or 10% buffered or non-buffered formalin or sodium acetate-acetic acid-formalin [SAF]). Polyvinyl alcohol (PVA)-preserved specimens can also be used. Eggs, cysts, and larvae are recovered after concentration procedures whereas trophozoites get destroyed during the procedure.

3.4.1.3 Quantitative techniques for separating and concentrating eggs/larvae

The simplest and most effective method for determining the number of eggs or oocysts per gram is described below:

1. One gram of sample will be processed by using formol-ether concentration technique.
2. Without delay, 25 µl of the suspension will be taken on two slides, covered with cover slips.
3. The slides will be examined promptly and all the eggs and cysts observed were counted.
4. After the initial counting, the total counts will be obtained by using the formula beneath:

$$\textbf{Total Count} = \textbf{Initial Count} \times 10^3 \div 50$$

3.4.2 Detailed Protocol for Calculation of Mean (EPG/EPL)

For each sample Count the number of parasite eggs observed under the microscope and convert counts into EPG (Eggs per Gram) or EPL (Eggs per Liter) using formula

Calculation of Mean Value

The mean value of parasite concentration (EPG/EPL) was calculated to determine the average level of contamination across samples. For each sample, parasite counts were converted into standardized units (EPG or EPL). The mean was then calculated using the following formula: where ΣX represents the total sum of observed values and n represents the number of samples analyzed. This approach was applied to all datasets to obtain the average parasite concentration.

For wastewater samples, EPL was determined by concentrating 1 L of water through sedimentation and centrifugation, followed by microscopic examination.

Mean formula

$\bar{x} = n \sum xi$

Where $\bar{x}$ = mean value

xi = individual observation (e.g., EPG count per sample)

n = total number of samples

The mean parasite load (EPG/EPL) was calculated by summing the individual counts from all samples and dividing by the total number of observations.

Sample Processing and Parasite Quantification Protocol:

Collected samples (Ecosan toilet manure, wastewater, and flood runoff) were transported to the laboratory under controlled conditions. For helminth egg detection, samples were processed using standard sedimentation and flotation techniques. A measured quantity of each sample (e.g., 1 g for solid samples or 1 mL for liquid samples) was homogenized and filtered to remove debris. The filtrate was centrifuged at appropriate speed (e.g., 1500 rpm for 5 minutes), and the sediment was examined under a light microscope. Parasite eggs and cysts were identified and counted using a calibrated counting chamber.

Where:

- EPG = Eggs per gram
- Number of eggs counted = observed under microscope
- Dilution factor = based on sample preparation
- Sample weight = grams of processed sample

EPL (Eggs per Liter)

EPL = Number of eggs counted × dilution factor

Volume of sample (L)

EPL=Volume of sample (L) Number of eggs counted × dilution factor

Identification Procedure

Identification of *Cryptosporidium* spp.

The detection of *Cryptosporidium* oocysts was performed using modified Ziehl–Neelsen (acid-fast) staining. Processed samples were smeared onto clean glass slides, air-dried, and fixed with methanol. Slides were then stained with carbol fuchsin, decolorized with acid-alcohol, and counter stained with methylene blue. Under light microscopy, *Cryptosporidium* oocysts appeared as red or pink spherical structures against a blue background. Identification was based on morphological characteristics, including size (4–6 µm) and staining properties.

3.5 Risk Assessment Approach

Accurately identifying parasites is only the first step in understanding public health implications. The next phase involved quantifying how contamination in Ecosan manure, wastewater, and flood runoff translates into infection risk for local communities. This study adopted a framework inspired by Quantitative Microbial Risk Assessment (QMRA), which breaks down the evaluation into four main steps—hazard identification, exposure assessment, dose-response, and risk characterization (Soller et al., 2010).

These steps allow for a structured analysis of how parasites move from contaminated environments into human hosts, the likelihood of infection under various exposure scenarios (e.g., handling compost, contact with floodwater, irrigation practices), and the magnitude of potential health impacts. The findings, bolstered by statistical analyses and software tools, inform targeted interventions and policy recommendations.

3.5.1 Conceptual Framework for QMRA

1. Hazard Identification:

Based on laboratory results, the main parasitic hazards included *Ascaris lumbricoides*, *Trichuris trichiura*, hookworm eggs, and protozoan cysts (*Giardia lamblia*, *Cryptosporidium*).

Helminthic parasites were prioritized in Ecosan manure, while protozoa were a particular concern in wastewater and flood runoff.

2. Exposure Assessment:

Ecosan Users: Potential exposure through handling compost, applying compost to fields, or accidental ingestion.

Wastewater Contacts: Residents living near outfalls, or using canal water for household chores.

Flood Runoff: Children playing in flooded streets, farmers crossing inundated fields, or consumption of produce grown in recently flooded soils.

3. Dose-Response Relationships:

Utilized published dose-response models for helminths and protozoa (Torgerson & Macpherson, 2011; Soller et al., 2010).

Models estimate the probability of infection given ingestion of a certain quantity of eggs/oocysts.

4. Risk Characterization:

Integrated data on parasite concentrations, exposure frequencies (e.g., daily contact with floodwater vs. occasional manure handling), and dose-response models to calculate annual or seasonal infection risks. Stratified findings by high-risk groups, such as children or sanitation workers.

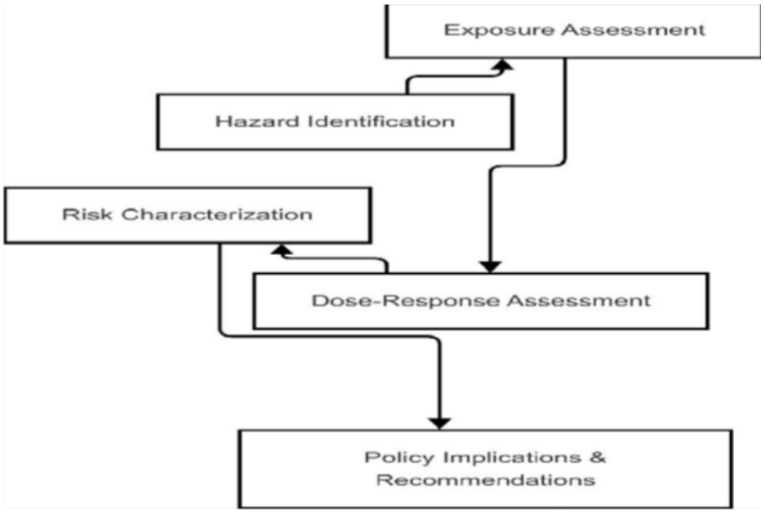


Figure 3.3: QMRA Four-Step Process Overview

3.5.2 Statistical Tools and Software

Two primary software tools supported the risk assessment:

- R (Version X.X) or Python (Version X.X): Deployed for statistical analysis (regression, ANOVA) correlating parasite concentrations with environmental variables (temperature, moisture, flood height).
- QMRA-specific Packages: Some specialized packages help fit parasite load distributions and run Monte Carlo simulations.

Table 3.3 Overview of how each QMRA step aligned with the data sources and computational methods used.

QMRA Step	Data Source	Analysis Method/Tool	Expected Output
Hazard Identification	Lab results (microscopy) for identified parasite species	criptive statistics (R/Python)	List of prevalent parasites with mean concentrations
Exposure Assessment	Observational data (frequency of compost handling, flood contact) + user surveys	Probability distributions; scenario analysis (Monte Carlo)	Estimated daily/weekly ingestion or dermal contact doses
Dose-Response	Literature-based models for helminths, protozoa (Soller et al., 2010)	Integration of parametric data in software	Probability of infection given a certain egg/oocyst dose
Risk Characterization	Combined exposure & dose-response outputs; population data from Surveys	Aggregation of probabilities across user groups	Annual or seasonal risk estimates; identification of high-risk cohorts

Note: If certain dose-response parameters were missing for local parasite strains, best-fit models from global data were used with caution (Torgerson & Macpherson, 2011).

3.5.3 Interpretation and Policy Relevance

By linking parasite loads measured in Ecosan manure, wastewater, and flood runoff to defined dose-response relationships, the QMRA approach yields quantitative risk metrics. These can guide decision-makers on:

1. Critical Exposure Pathways: For instance, if flood runoff emerges as a major infection source, local authorities might prioritize flood control measures or public advisories.
2. Ecosan Safety Benchmarks: Results might confirm that well-composted manure poses minimal risks, reinforcing adoption strategies—or, conversely, reveal the need for extended composting times.
3. Protective Interventions: The model can test hypothetical scenarios (e.g., increased water treatment, mandatory protective gear for compost handlers) to see how these measures reduce overall infection probability.

Ultimately, the integration of robust laboratory findings with risk assessment modeling paints a holistic picture of parasitic threats in Dhaka. The subsequent chapters leverage these insights to present results, discuss ramifications for public health and sanitation policy, and offer targeted recommendations to mitigate parasite transmission in a flood-prone megacity context.

3.6 Data Analysis and Statistical Methods

This section provides a comprehensive overview of the statistical and analytical procedures employed to examine the parasitic data generated from Ecosan manure, wastewater, and flood runoff samples in Dhaka City. Given the interdisciplinary nature of this research—combining environmental science, public health, and socio-behavioral components—data analysis required multiple layers of descriptive, inferential, and model-based techniques. The guiding principle was to convert raw laboratory counts, observational findings, and survey information into interpretable metrics that clarify parasitic prevalence, identify significant risk factors, and generate insights for policy and intervention.

The subsections below detail how the data were organized, cleaned, and statistically processed. They introduce descriptive statistics (to establish baselines such as mean parasitic concentrations), inferential tests (to determine statistically significant differences or relationships), and advanced modeling approaches (to explore how independent variables predict parasitic outcomes). Throughout, references to specific software packages—namely SPSS, R, and STATA—underscore the specialized tools utilized. Where relevant, a figure illustrates the overall analytical workflow, and a table synthesizes the main statistical tests applied along with their typical use cases.

During the writing phase of this study, AI-based tools such as ChatGPT were utilized to assist with language improvement, sentence structuring, clarity of expression and presentation of this thesis. The use of these tools was strictly limited to editorial support and did not influence the research methodology, data analysis, or findings. The researcher maintained full responsibility for the originality, accuracy, and integrity of the work.They did not contribute to the design of experiments, data collection, analysis, or results. The author is fully responsible for all scientific content and conclusions.

3.6.1 Data Organization and Management

3.6.1.1 Database Structure

All field and laboratory data were consolidated into a relational database designed with separate but interconnected tables for sample metadata, laboratory results, household surveys, and environmental measures (e.g., compost temperature, flood depth). Each sample (Ecosan manure, wastewater, flood runoff) was assigned a unique identifier (Sample ID) that linked it to location- specific and time-specific details.

- Location-Specific Fields: Ward name/number, GPS coordinates, type of facility (Ecosan vs. conventional latrine), flooding status, etc.
- Time-Specific Fields: Collection date, collection season (pre-monsoon, monsoon, post- monsoon), sampling time (morning/afternoon).
- Lab-Specific Fields: Parasitic egg counts (Kato-Katz), protozoan cyst detection (modified Ziehl-Neelsen).

This approach minimized duplication and facilitated joined queries for multi-dimensional analyses. For instance, a single query could retrieve both the *Ascaris* egg count in floodwater and the measured turbidity at that site.

3.6.1.2 Data Cleaning and Validation

Before conducting any statistical tests, raw data underwent cleaning and validation to ensure consistency and accuracy:

1. Range Checks: Any parasitic count outside plausible biological ranges (e.g., extremely high or negative values) was flagged for re-checking.

2. Cross-Referencing: For duplicates or replicate samples, the average or median was computed unless outliers suggested contamination or lab errors.

3. Missing Data Imputation: In some instances, certain fields (e.g., compost temperature) were missing due to equipment failure. If the missing rate was low, those samples were excluded from specific analyses. Otherwise, relevant imputation methods (mean or multiple imputation) were considered.

4. Consistency Checks: Manure samples purported to come from an active composting chamber were verified against household usage data to confirm that the compost was indeed at a stage suitable for sampling.

Only after this multi-step cleaning process were the data archived in comma-separated values (CSV) files for easy import into SPSS, R, and STATA.

3.6.2 Descriptive Statistics

3.6.2.1 Rationale for Descriptive Measures

The initial phase of data analysis focused on descriptive statistics, providing an overview of parasitic contamination levels and environmental conditions. This step is critical not only for summarizing the magnitude and distribution of parasitic organisms across sites but also for identifying potential anomalies or noteworthy patterns that warrant further exploration.

3.6.2.2 Common Descriptive Indices

1. Prevalence Rates (P):

Defined as the proportion of samples testing positive for a given parasite (e.g., *Ascaris lumbricoides*). For instance, if 40 out of 100 Ecosan manure samples had detectable *Ascaris* eggs, the prevalence would be 40%. This measure helps policy-makers gauge how widespread specific parasites are in certain wards or communities.

2. Mean and Median Concentrations:

For quantitative measures—such as eggs per gram (EPG) of compost or eggs per liter (EPL) in wastewater—means and medians were reported. The mean reveals overall burden, while the median reduces the effect of extreme outliers. In highly skewed data sets, medians often convey a more realistic central tendency.

3. Confidence Intervals (CIs):

Wherever possible, 95% CIs were computed for prevalence estimates or mean EPG/EPL values, providing a statistical range in which the true population parameter is likely to lie.

4. Standard Deviation (SD) and Interquartile Range (IQR):
Measures of dispersion highlight how variable the parasite counts are within or across sites. High variability might indicate inconsistent compost practices or sporadic flooding events.
5. Frequency Distributions:
Visualizing how many samples fell into certain EPG/EPL categories can illuminate whether the data are unimodal, bimodal, or heavily skewed. For instance, a large subset might have zero or low egg counts, while a smaller subset exhibits extremely high contamination.

Table 3.4 Demonstrates the typical descriptive statistics for each parasite in each sample type.

Parasite	**Sample Type**	**N**	**Prevalence (%)**	**Mean (EPG/EPL)**	**Median (EPG/EPL)**	**95% CI (Mean)**	**SD**
Ascaris lumbricoides	Ecosan Manure	100	42.0	235	120	(210–260)	300
Ascaris lumbricoides	Wastewater	60	30.0	55 EPL	30 EPL	(40–70)	60
Giardia lamblia	Flood Runoff	50	26.0	1,200	900	(1,000–1,400)	850
Cryptosporidium spp.	Wastewater	60	18.0	35 EPL	20 EPL	(25–45)	40

Note: EPG = Eggs per gram (solid manure), EPL = Eggs per liter (liquid samples). Statistics for "Giardia lamblia" (1,200) refer to cysts per liter, for demonstration only.

3.6.2.3 Software for Descriptive Analysis

- SPSS: Useful for straightforward descriptive tables, frequencies, and cross-tabulations.
- R: Provided flexibility for custom summary statistics and plot generation. The dplyr and ggplot2 packages enabled quick group-wise summaries and visual exploration (boxplots, histograms).
- STATA: Employed for immediate tabular summaries in certain steps, especially where some co-investigators were more proficient in STATA‘s do-file syntax.

3.6.3 Inferential Statistical Tests

After the initial descriptive phase, inferential tests were conducted to ascertain whether observed differences or relationships were statistically significant. This included comparing parasitic loads among different wards, analyzing temporal variations (pre- vs. post-monsoon), and relating parasite prevalence to environmental or demographic factors.

3.6.3.1 Analysis of Variance (ANOVA)

Analysis of Variance (ANOVA) was applied to test if there were significant differences in mean parasite concentrations across more than two groups. For instance, if Ecosan manure samples were collected from three distinct wards, ANOVA could confirm or refute whether one ward had significantly higher (or lower) *Ascaris* EPG than the others.

1. One-Way ANOVA:

Used when comparing a single independent variable (e.g., ―Ward‖ with levels A, B, C) against a numeric dependent variable (e.g., *Ascaris* EPG).

2. Two-Way ANOVA:

In situations where two independent variables might interact (e.g., ―Ward‖ and ―Flood Season‖), a two-way ANOVA could discern main effects and interactions.

Post-hoc tests (e.g., Tukey‘s HSD) identified which specific groups differed significantly if the overall ANOVA was significant ($p < 0.05$).

Assumption Checks:

- Normality: Often tested using Shapiro-Wilk or Kolmogorov-Smirnov tests.
- Homogeneity of Variances: Levene’s or Bartlett’s test.
- Outliers: Boxplots or residual diagnostics in R.

3.6.3.2 Chi-Square Tests (χ^2)

For categorical outcomes, such as ―presence or absence‖ of a given parasite (binary variable), chi-square (χ^2) tests were conducted. One typical scenario was comparing the proportion of positive parasite detections across multiple wards or sample types. For example, to examine whether the proportion of flood runoff samples testing positive for *Giardia* significantly exceeded that of wastewater or Ecosan manure, a chi-square test of independence was employed.

- Expected Frequencies: We ensured the categories had sufficiently large expected counts (ideally ≥5 per cell) to satisfy typical chi-square assumptions.
- Fisher‘s Exact Test: If some categories were too small (e.g., <5 in a cell), the more precise Fisher‘s exact test was used.

  Contingency Tables simplified these comparisons, aligning each ward or sample type (row) with parasite detection status (column), then assessing whether the distribution deviated from chance.

3.6.3.3 Correlation and Regression

When investigating continuous relationships—for instance, how compost temperature or moisture correlated with the concentration of helminth eggs—Pearson‘s correlation (r) or Spearman‘s rank correlation (ρ) were computed depending on data normality.

More intricate relationships, such as predicting parasite concentration from multiple factors (compost temperature, pH, user compliance rating), warranted multiple regression models. The outcome variable could be a log-transformed count (if heavily skewed) or a presence/absence indicator (in which case logistic regression would be more suitable).

1. ***Multiple Linear Regression:***

○ Dependent Variable: e.g., log (EPG + 1).

○ Predictors: Compost temperature (°C), pH, compost age, user compliance (categorical or numeric).

○ Model Checking: Residual plots to verify homoscedasticity and normal distribution of residuals, multicollinearity checks using variance inflation factor (VIF).

2. ***Logistic Regression (Binary Outcome):***

○ Dependent Variable: Parasite presence (1) or absence (0).

- Predictors: Flood exposure, sanitation type (Ecosan vs. pit latrine), community awareness score, etc.
- Odds Ratios (OR): Estimated for each predictor, indicating the factor by which the odds of having a positive parasite sample change with a one-unit shift in the predictor (while holding others constant).

  P-value thresholds (commonly 0.05) guided significance, though **confidence intervals** and effect sizes (coefficients or ORs) were given greater interpretive weight to avoid over-reliance on p- values alone (Torgerson & Macpherson, 2011).

3.6.3.4 Time-Series or Seasonal Analyses

Because Dhaka experiences pronounced seasonal shifts—particularly pre-monsoon vs. monsoon vs. post-monsoon—the data set contained repeated measures over multiple time points. Where relevant, repeated-measures ANOVA or mixed-effects models were utilized to account for:

1. Within-Site Variations Over Time: e.g., how the same sampling station‘s parasitic load changed across three or four sampling rounds.
2. Between-Site Comparisons: e.g., differences among wards in each season.

These approaches recognized the interdependence of repeated observations from the same location (Ten Veldhuis et al., 2010). If normal distribution assumptions were violated, non- parametric alternatives (Friedman test) were considered.

3.6.4 Advanced Modeling and Geospatial Analysis

In addition to standard hypothesis testing, some advanced modeling techniques provided deeper insights into spatiotemporal parasite distribution and risk hotspots.

3.6.4.1 Geographical Information Systems (GIS)

Using GIS tools (ArcGIS or QGIS), parasite concentration data were plotted on ward maps, enabling visual identification of ―hot spots. This approach included:

- Choropleth Maps: Coloring wards by average *Ascaris* EPG or protozoan prevalence.
- Density Contours: Interpolating known sample points to estimate parasite distribution in sampled areas, especially relevant for large flood zones or outfall areas.
- Overlay of Environmental Variables: Flood extent, topography, and drainage

networks, revealing potential correlations between environmental features and parasitic load.

3.6.4.2 Multilevel or Mixed-Effects Modeling

For data clustered by households or wards, multilevel (hierarchical) models were employed. This recognized that samples from the same ward or the same compost chamber might share unobserved similarities not captured by simpler regression. A random intercept could be assigned to each ward or household cluster, thereby adjusting for within-group correlations.

Where iii indexes sample and jjj indexes ward (or household). By applying a mixed-effects approach, the model better handles the nested structure of the data, improving the accuracy of coefficient estimates.

3.6.5 Integration with Risk Assessment (QMRA)

In parallel with standard hypothesis tests, the study employed Quantitative Microbial Risk Assessment (QMRA), as outlined in Section 3.5. The modeling process within QMRA also involved statistical fits:

1. Parameter Estimation: For dose-response models, best-fit parameters were sometimes derived from or verified by the sample‘s parasite concentration distributions.
2. Uncertainty and Variability: Monte Carlo simulations were used, drawing from probability distributions of parasite counts, exposure frequencies, or dose-response parameters. This yields an ensemble of possible infection risk outcomes, capturing not only the average risk but also the uncertainty range.

Interpretation of these risk distributions was crucial for policy. For instance, if simulations revealed a 10% annual risk of *Ascaris* infection for Ecosan users under normal conditions, and a 30% risk during major floods, interventions focusing on flood protection or improved compost storage might take priority.

3.6.6 Presentation of Results

Tabular and graphical representations were central to communicating findings. Tables enumerated p-values, effect sizes, and confidence intervals from various tests (chi-square, ANOVA, regression). Graphs—boxplots comparing parasite loads across wards, line graphs tracking monthly changes in contamination, or GIS-based ―heat maps‖—provided immediate visual cues.

In **manuscript form**, results might be structured sequentially—starting with broad descriptive overviews, then narrower inferential analyses, culminating in the risk assessment findings.

3.6.7 Validation and Sensitivity Analyses

Given the complexity of parasitic data and potential variability in flood conditions, validation and sensitivity checks were vital:

1. Sub-sample Validation: Cross-checking a subset of microscopy results.
2. Temporal Consistency: For repeated sampling within the same ward, verifying that the direction of changes (increase/decrease in parasite load) was consistent across different tests.
3. Sensitivity to Outliers: Rerunning regressions without extreme outliers to see if effect sizes or significance changed drastically.
4. Scenario Testing in QMRA: Adjusting assumptions about compost usage frequency or flood inundation depth to see how risk estimates fluctuate.

   These processes ensured robustness—that findings were not unduly driven by a handful of outlier samples or assumptions about user behavior.

3.6.8 Summary of Key Statistical Procedures

To encapsulate the wide range of analyses performed, Table 3.5 presents an at-a-glance summary linking each test or model to its typical use, data requirement, and interpretive outcome.

3.6.9 Limitations of the Analytical Approach

While this multi-pronged statistical strategy provides depth, several limitations exist:

1. Data Normality: Parasite counts often follow over dispersed or zero-inflated distributions. Log transformations or Poisson/negative binomial regression can alleviate this but add modeling complexity (EFSA Panel on BIOHAZ et al., 2018).
2. Sampling Bias: Spatial coverage might not perfectly represent all wards, especially those with limited access during floods. Extrapolating findings to the entire city must be done with caution.
3. Missing Covariates: Behavioral data (e.g., frequency of compost turning, protective

gear usage) might be incomplete or self-reported, introducing recall or social desirability biases.

4. Temporal Constraints: Flood events can vary year to year, so one monsoon cycle may not fully capture the typical or extreme scenarios (Sakib et al., 2023).
5. Dose-Response Assumptions: QMRA relies on literature-based models that may not perfectly reflect local parasite strains or host immunity variations (Torgerson & Macpherson, 2011).

Table 3.5: Summary of Statistical Procedures Employed

Statistical Procedure	Data Requirement	Application	Interpretive Outcome	Software
Descriptive Statistics (mean, median, prevalence)	Continuous or categorical parasite data	Baseline overview of contamination levels by sample type, location, or season	Basic measures: average EPG, prevalence (%) for key parasites, variability estimates	SPSS, R, STATA
e-Way ANOVA/Two-Way ANOVA	Normally distributed or transformed numeric data across multiple groups	Checking if mean parasite loads differ among wards, sample types, or across seasons	p-value for group differences, post-hoc comparisons (Tukey)	SPSS, R (packages: stats)

Chi-Square (χ^2) Tests	Categorical data (e.g., presence/absence) in contingency tables	Examining if parasite presence differs by location or time more than expected by chance	Observed vs. expected frequencies, significance of group differences	SPSS, R (function: chisq.test)
Correlation (Pearson/Spearman)	Pairs of numeric variables (compost temperature and EPG)	Identifying linear or monotonic relationships between two variables	Correlation coefficient (r or ρ) indicating strength and direction of association	R (package: stats), SPSS
Regression (Linear/Logistic)	Numeric or binary outcome variables and multiple predictors	Modeling how factors (e.g., environment, user behavior) predict parasite loads or presence	Regression coefficients, odds ratios, p- values, model fit indices (R^2, AIC)	R (packages: lm, glm), STATA
Repeated Measures ANOVA / Mixed-Effects	Repeated or clustered data (e.g., same site across seasons)	Accounting for correlated measurements in time or	F-tests for time effect, random intercepts forward-level	R (package: lme4), SPSS

		within wards	variation	
QMRA (Monte Carlo)	Parasite concentration distributions, exposure frequencies, dose-response parameters	Estimating infection risk under vario us exposure scenarios (handling manure, floo d contact)	Risk curve s, probability of infection, uncertainty bounds	R (package: mc2d, Python libraries)

Despite these caveats, the integrated approach—spanning descriptive, inferential, geospatial, and risk-based analyses—serves as a robust framework. It illuminates not only the where and how much of parasitic contamination but also the why, connecting environmental, technological, and behavioral factors.

3.6.10 Conclusion

Section 3.6 has laid out the data analysis plan for this thesis, ensuring that each step—from summarizing parasite prevalence to advanced statistical modeling—aligns with the overarching goal of deciphering parasitic risks in Dhaka‘s urban sanitation landscape. By mixing descriptive and inferential methods, this approach lends both breadth (capturing the city-wide scope) and depth (probing specific relationships and high-risk scenarios).

In subsequent chapters, the actual results from these procedures will be showcased, highlighting major trends, significant risk factors, and nuanced differences in parasitic contamination across different wards, sample types, and seasons. The synergy between robust data collection (Chapter 3.3 and 3.4) and comprehensive analysis (this section) provides a reliable evidence base for Chapter 4 (Results), from which the thesis can draw meaningful conclusions and policy recommendations (Chapters 5 and 6). By recognizing both the strengths of the chosen methods and the inherent limitations, the study aims to present findings that are credible, actionable, and reflective of the complex realities of sanitation and parasitic transmission in a flood-prone megacity.

3.7 Focus Group Discussions (FGDs)

Objectives:

Focus group discussions were conducted to explore **user practices, perceptions, and sanitation-related behaviors** related to eco-san toilets, wastewater, and flood runoff water, as well as awareness of parasitic health risks. The FGDs provided **contextual understanding of behavioral and environmental factors** influencing parasite contamination.

Participants:

- ✓ Four FGDs were conducted across selected wards.
- ✓ Each group consisted of **6–10 participants**, including eco-san toilet users, non-users, community leaders, and sanitation workers.
- ✓ Participants were selected to ensure **diversity in age, gender, and socioeconomic background**.

Questionnaire-Based Discussion:

- ✓ A **semi-structured questionnaire** guided the discussions.
- ✓ Key topics included:
  - Sanitation practices (toilet use, handwashing, waste disposal)
  - Water handling (source, treatment, storage)
  - Awareness of parasitic contamination and health risks
  - Exposure to wastewater and flood water
  - Challenges and barriers to proper sanitation
  - Recommendations for improved practices

Procedure:

- ✓ FGDs were conducted **face-to-face**, moderated by trained facilitators using the questionnaire as a guide.
- ✓ **Detailed written notes** were taken; no audio recording was used.

- ✓ Participants were encouraged to share experiences freely.

Data Analysis:

- ✓ Closed-ended responses were coded and tabulated.
- ✓ Open-ended responses were analyzed using **thematic analysis** to identify patterns in behavior, perception, and exposure risk.
- ✓ Qualitative findings were **triangulated with quantitative parasite prevalence data** for comprehensive interpretation.

3.8 Ethical Considerations

Ensuring ethical integrity was a core requirement throughout this research, encompassing both community-based activities (such as interviews with Ecosan users) and the laboratory handling of potentially hazardous biological samples. By adhering to internationally recognized standards and obtaining necessary local approvals, the study safeguarded participant rights, minimized health risks to research personnel, and upheld confidentiality obligations.

Safety Protocols for Handling Potentially Infectious Materials

The collection and laboratory analysis of Ecosan manure, wastewater, and flood runoff posed inherent biohazard risks due to the possible presence of pathogens, including parasites and bacterial agents. To mitigate these hazards:

1. Protective Equipment: Field and lab staff wore gloves, masks, aprons, and closed-toe shoes. Hand sanitizers and disinfectant solutions (e.g., 0.5% sodium hypochlorite) were readily accessible.
2. Safe Storage and Transport: Samples were stored in leak-proof, sealed containers and transported in cool boxes to avoid spillage.
3. Designated Laboratory Spaces: Potentially infectious materials were processed in biosafety level (BSL)-2 compliant areas, equipped with fume hoods or laminar flow cabinets, as recommended by the World Health Organization (WHO, 1987).
4. Training and Drills: Laboratory personnel received periodic refresher training on biohazard management, including proper waste disposal and spill containment protocols.

Confidentiality and Community Engagement

The research employed community surveys to capture user attitudes, acceptance levels, and compliance with Ecosan practices. Strict confidentiality was maintained in the following ways:

- ✓ Anonymized Data: Personal identifiers (names, addresses) were decoupled from quantitative data, replaced with coded IDs. Access to the key linking personal information and codes was restricted to the principal investigator.
- ✓ Secure Storage: Physical and digital data were kept in password-protected systems. Any printed records were stored in locked cabinets.
- ✓ Feedback Mechanisms: Preliminary findings were shared with community leaders and participating households in a summarized, non-technical format. This ensured transparency, gave communities a chance to verify the research‘s portrayal of their context, and promoted local ownership of the sanitation solutions being studied.

3.9 Limitations of the Methodology

Although this study employed a carefully designed methodology—encompassing well-defined sampling frameworks, rigorous lab protocols, and community engagement—certain limitations remained inevitable. Recognizing these limitations provides a realistic boundary for interpreting the results and underscores areas where future research can expand or refine the findings.

Sampling Constraints

Geographic Coverage: While the selection of wards and slums aimed to cover diverse flood-prone, Ecosan-adopting, and conventional-latrine areas, Dhaka‘s vastness made complete city-wide representation challenging. Some peripheral regions or high-security zones remained inaccessible.

Sample Size vs. Variability: Constraints on time and resources restricted the total number of samples for each category (Ecosan manure, wastewater, flood runoff). Given the observed heterogeneity in parasitic contamination, larger sample sizes could yield more robust statistical power.

Temporal Fluctuations: Monsoons vary yearly in timing and severity. Capturing data from only one or two monsoon cycles may not encapsulate the full spectrum of possible flood intensities.

Seasonal Factors

Monsoon vs. Dry Season Differences: Parasite prevalence and distribution can drastically shift between monsoon and dry periods. In the dry season, lower water tables and reduced flooding may localize contamination to drainage channels, whereas monsoon rains can disperse parasites widely. Thus, results indicating high parasite loads in flood runoff may not hold true year-round.

Heat and Humidity Effects on Compost: Ecosan manure samples collected during cooler months might not achieve the same thermophilic composting temperatures as those in the hot, early summer period. Inter-seasonal variations could influence parasite inactivation rates, but only so many sampling rounds could be conducted given logistical constraints.

Human and Behavioral Dynamics

Reliance on Self-Reported Data: User surveys about compost turning frequency, ash addition, and flood experiences were prone to recall bias or social desirability bias. Some participants might have overstated compliance with recommended ecosan practices or understated open defecation occurrences.

Community Acceptance: Not all households agreed to manure sampling or interviews, possibly introducing a participation bias if predominantly motivated or better-informed residents took part. The findings might therefore over-represent communities already receptive to Ecosan.

Interpretational Challenges

Generalizability: The study‘s conclusions are most directly applicable to similar flood-prone megacities with partial sanitation coverage and emerging Ecosan projects. Extrapolation to rural contexts or different climatic regions must be done cautiously.

Cross-Sectional vs. Longitudinal: Despite attempts to capture changes across monsoon and dry seasons, the research remains more cross-sectional than truly longitudinal. A multi-year longitudinal approach could yield deeper insights into recurring patterns or long-term successes/failures of Ecosan adoption.

These limitations do not undermine the study’s overall contribution. Rather, they provide critical context for interpreting results and highlight avenues for additional inquiry—such as multi- season or multi-year monitoring, expanded molecular diagnostics, and deeper qualitative investigations into community behaviors. Emphasizing such methodological constraints also reaffirms the study‘s commitment to transparency and academic rigor. By acknowledging the pitfalls and uncertainties, the research presents findings that are both meaningful and responsibly framed within Dhaka‘s complex, ever-evolving sanitation landscape.

CHAPTER FOUR

RESULT AND FINDING

4.1 Overview of Sample Collection and Parasite Prevalence

A total of 540 environmental samples were collected from in and around Dhaka city, comprising 180 eco-san toilet manure, 180 wastewater, and 180 flood runoff water samples. Among these, 350 samples (64.81%) tested positive for parasites, indicating widespread gastrointestinal parasite contamination.

Table 4.1: Overall Prevalence of Parasite Contamination by Sample Type

Sample Type	**Total Samples Examined**	**Infected Samples**	**Prevalence (%)**
Eco-san toilet manure	180	125	69.44
Wastewater	180	117	65.00
Flood runoff water	180	108	60.00
Total	540	350	64.81

Eco-san toilet manure exhibited the highest contamination (69.44%), likely due to incomplete composting and poor handling. Wastewater and flood runoff water also showed considerable contamination, reflecting direct human fecal input and environmental dispersal. The overall prevalence of 64.81% indicates widespread gastrointestinal parasite exposure in Dhaka city.

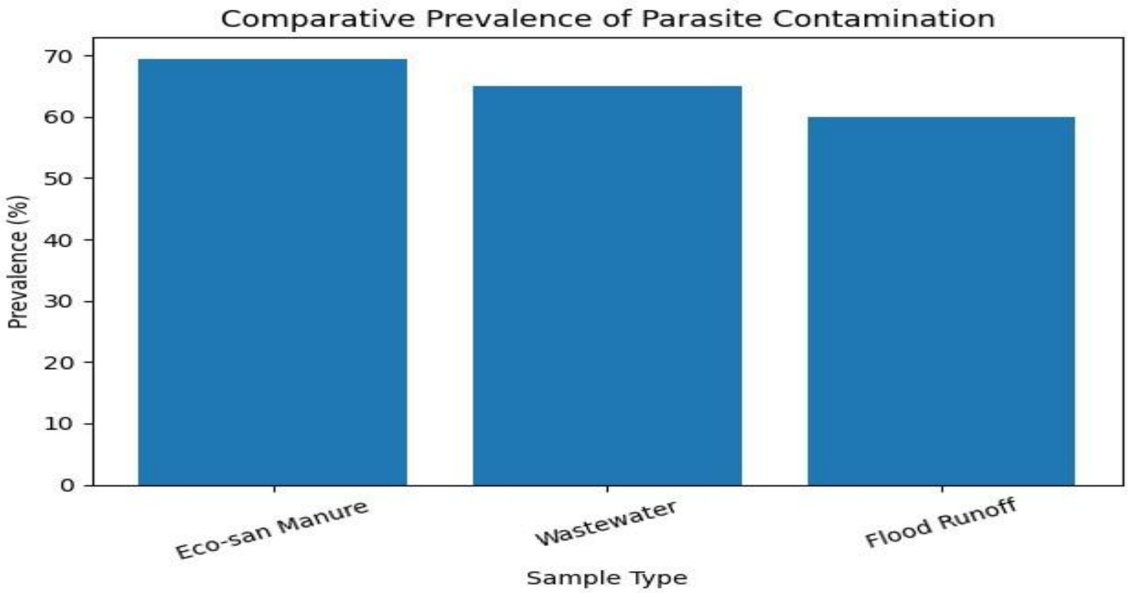


Figure 4.1: Comparative prevalence of parasite contamination in eco-san manure, wastewater, and flood runoff water.

This figure visually confirms that eco-san manure has the highest parasite prevalence, followed by wastewater and floodwater. Differences among sample types highlight the role of sanitation practices and environmental exposure in parasite transmission.

4.2 Parasitic Contamination by Sample Type and Area

4.2.1 Parasitic Load Across Wards

Table 4.2: Mean Parasitic Load (EPG/EPL) Across Wards and Sample Types

Area Type	Ward (Location)	Manure (EPG)	Wastewater (EPL)	Runoff Water (EPL)
Peri-urban	Ward 3 (Keraniganj)	135 ± 10	70 ± 8	55 ± 7
Peri-urban	Ward 5 (Savar)	115 ± 12	65 ± 6	40 ± 5
Urban Slum	Ward 55 (Kamrangirchar)	—	95 ± 9	30 ± 4
Flood-prone	Ward 6 (Badda)	—	75 ± 7	150 ± 15
Flood-prone	Ward 9 (Demra)	—	70 ± 6	165 ± 18

Peri-urban wards (Keraniganj and Savar) showed the highest helminth egg counts in eco-san manure. Flood-prone wards (Badda and Demra) exhibited the highest parasitic loads in runoff water, highlighting the impact of hydrological factors such as flooding. Urban slum wastewater contamination was moderate, reflecting direct human fecal inputs.

4.2.2 Comparative Distribution

Table 4.3: Comparative Distribution of Parasitic Contamination by Ward and Sample Type

Ward No.	Area Name	Area Type	Eco-san Manure (Eggs/g)	Wastewater (Eggs/L)	Flood Runoff (Eggs/L)
Ward 3	Keraniganj	Peri-urban	High (120–150)	Moderate (60–80)	Low–Moderate (40–70)
Ward 5	Savar	Peri-urban	High (100–130)	Moderate (50–75)	Low (30–50)
Ward 55	Kamrangirchar	Urban slum	Not Available	Moderate–High (70–110)	Low (20–40)
Ward 6	Badda	Flood-prone	Not Available	Moderate (60–90)	High (120–180)
Ward 9	Demra	Flood-prone	Not Available	Moderate (55–85)	High (130–190)

This table summarizes parasitic contamination levels by ward and sample type. Flood-prone wards clearly act as hotspots for runoff contamination, while peri-urban areas are major sources of eco-san manure contamination. Urban slums show moderate contamination in wastewater, suggesting localized human fecal contribution.

4.2.3 Statistical Analysis

Eco-san toilet manure samples showed high parasitic loads in peri-urban wards. Keraniganj exhibited the highest mean egg count (≈135 EPG), followed by Savar (≈115 EPG). No manure data were available for urban slum (Kamrangirchar) and flood-prone wards (Badda and Demra), indicating limited use or absence of eco-san systems in these areas. The elevated parasite concentration in peri-urban manure highlights the potential risk associated with improper handling and reuse of untreated human waste.

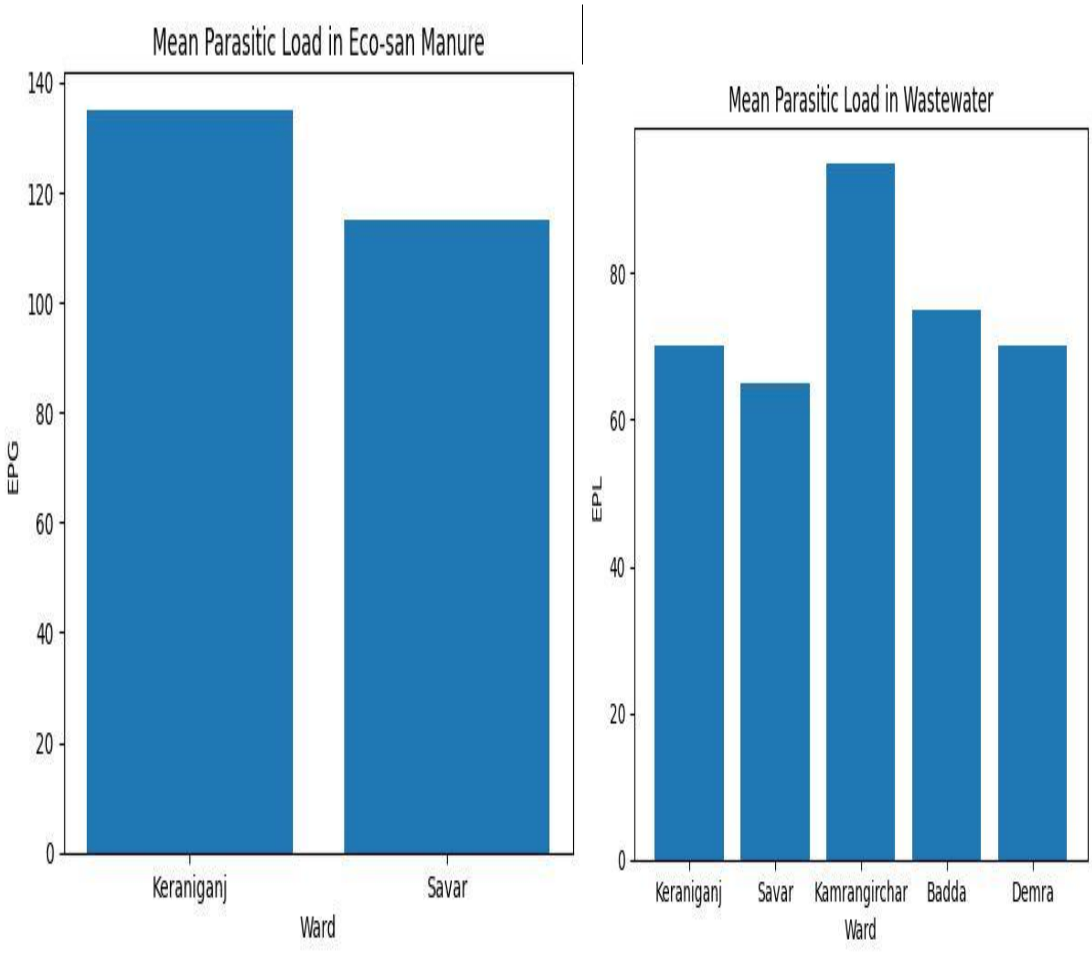


Figure 4.2: Mean Parasitic Load in Ecosan toilet manure, and wastewater across Wards

Wastewater samples across all wards showed moderate levels of parasitic contamination. Kamrangirchar (urban slum) recorded the highest mean load (≈95 EPL), followed by Badda (≈75 EPL) and Keraniganj/Demra (≈70 EPL). Savar showed comparatively lower values (≈65 EPL). The elevated contamination in urban slum areas reflects poor sanitation infrastructure and direct discharge of untreated waste.

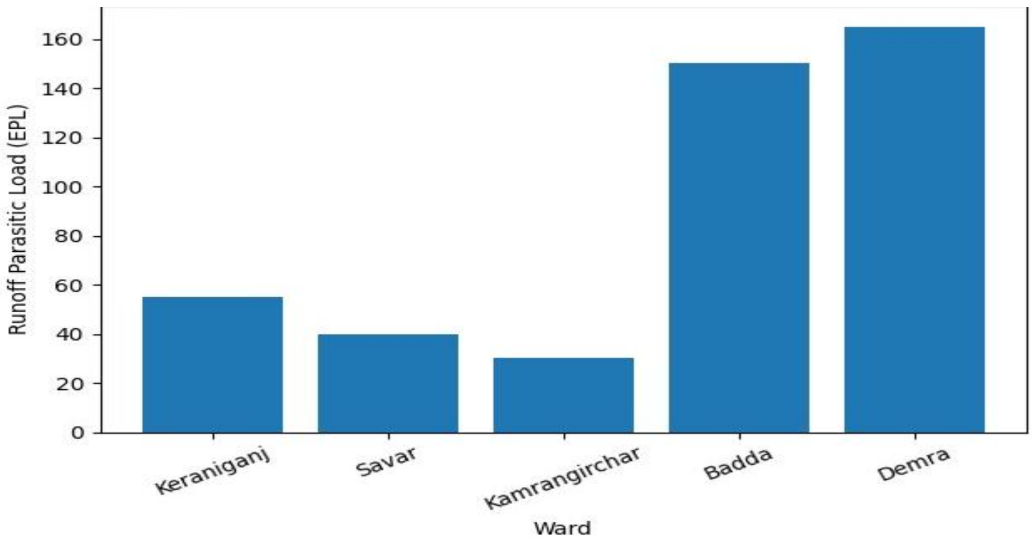


Figure 4.3: Mean Parasitic Load in flood runoff water across Wards

Flood-prone wards (Badda and Demra) exhibited significantly higher parasitic loads compared to peri-urban and urban slum wards. This emphasizes the role of seasonal flooding in spreading parasites in low-lying areas.

Eco-san manure samples from peri-urban wards showed moderate variability in parasitic load. Keraniganj exhibited higher median values and a wider spread compared to Savar, indicating greater inconsistency in parasite concentration. This variation may be influenced by differences in storage duration, treatment practices, and environmental conditions affecting helminth egg survival. Overall, both wards maintained high parasitic loads, emphasizing the need for proper treatment before reuse.

The variability of parasitic load in eco-san manure was relatively moderate between Keraniganj and Savar. Keraniganj showed slightly higher dispersion, indicating inconsistent treatment or storage conditions. This variability suggests that environmental factors and manure management practices influence helminth egg survival in eco-san systems.

Wastewater exhibited moderate variability in parasitic load across wards. Urban slum areas showed higher variability and peak values, indicating irregular contamination sources. Peri-urban and flood-prone areas demonstrated relatively stable but consistently moderate contamination levels. These patterns suggest that both sanitation practices and population density influence wastewater quality.

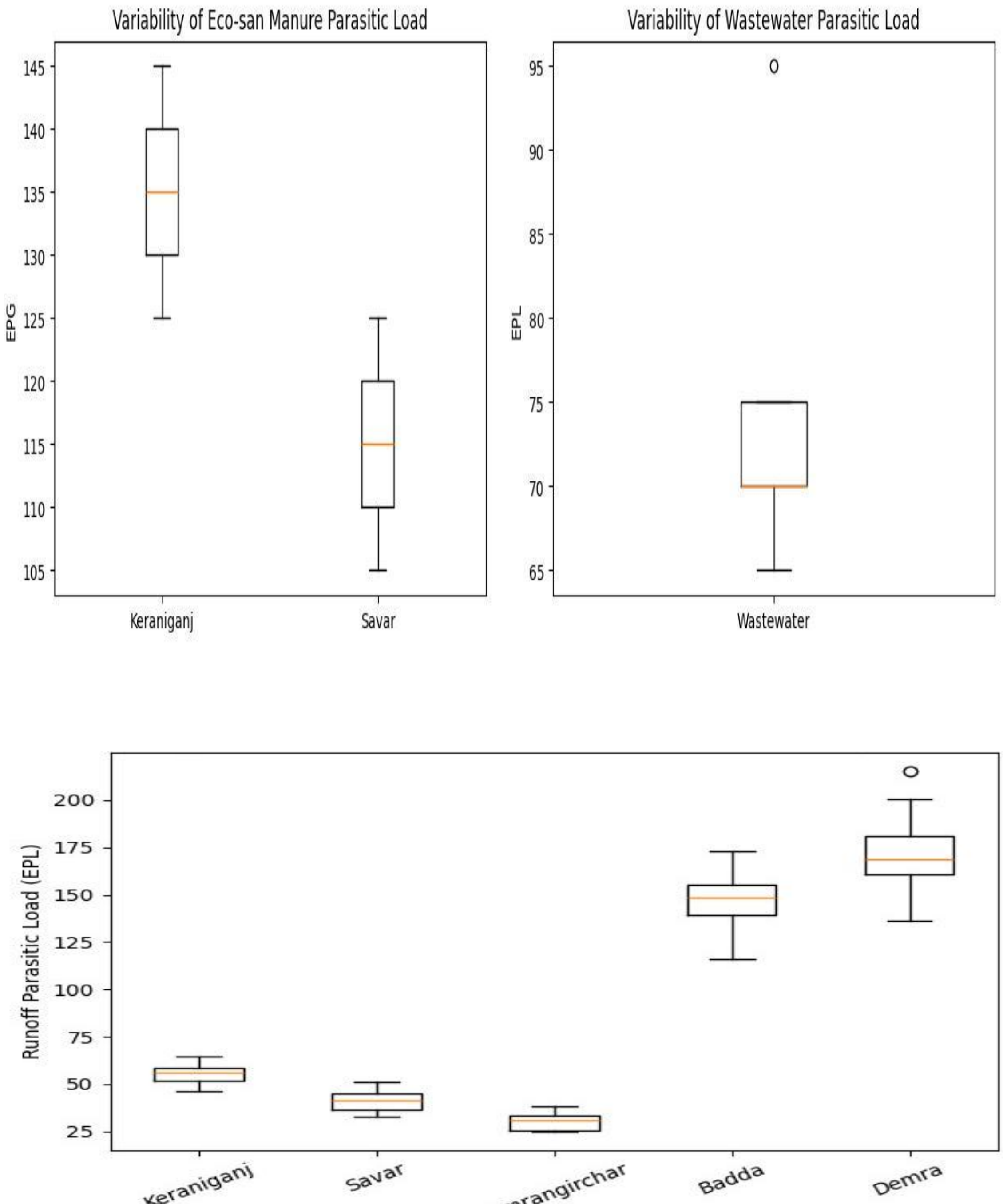


Figure 4.4: Box Plot Showing Variability of Ecosan toilet manure, Wastewater and Flood Runoff Water Parasitic Load by Area Type

Flood-prone areas show higher variability and overall mean parasitic loads than peri-urban and urban slum areas. This indicates that environmental and hydrological factors contribute to heterogeneous parasite distribution.

4.3 Spatial Distribution (GIS Analysis)

The GIS map illustrates the spatial distribution of parasitic contamination across selected wards, integrating three environmental pathways: eco-san manure, wastewater, and flood runoff. The map reveals distinct spatial variability in contamination levels across wards, with certain locations acting as hotspots depending on the contamination source.

Eco-san Manure Layer

Eco-san contamination is highly localized, appearing only in specific wards (e.g., Keraniganj and Savar).These areas show high egg counts, indicating improper handling or treatment of eco-san sludge and potential reuse of untreated manure in agriculture. The limited spatial spread suggests point-source contamination, rather than widespread distribution.

Wastewater Layer

Wastewater contamination is more widely distributed across all wards. Most areas show moderate contamination levels, while Kamrangirchar and Badda exhibit relatively higher concentrations. This indicates that wastewater acts as a continuous and diffuse contamination pathway, likely influenced by poor sanitation infrastructure and direct discharge of untreated sewage

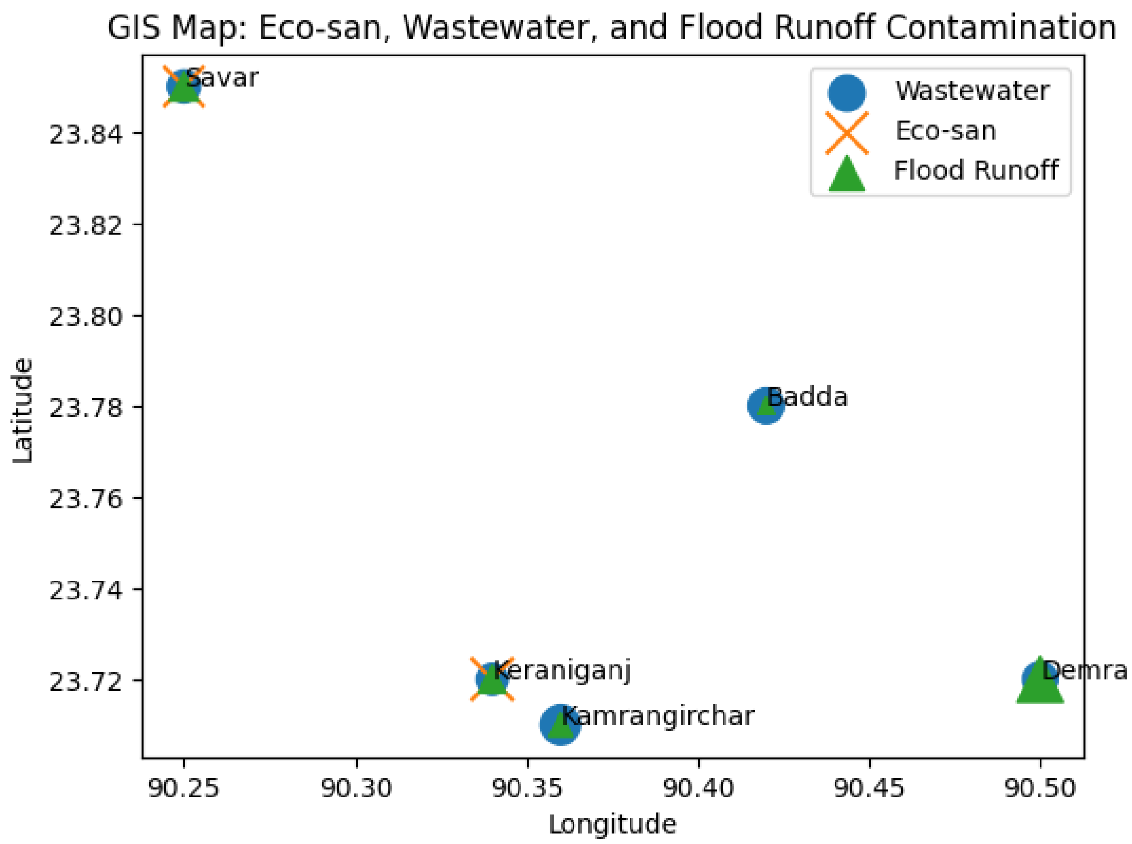


Figure 4.5: GIS Map of Parasitic Load in Ecosan toilet manure, wastewater and Flood Runoff Water a cross Wards

Flood Runoff Layer

Flood runoff shows significant spatial variation, with some wards displaying very high contamination levels. Demra appears as a major hotspot, with the highest runoff contamination and Other areas show low to moderate levels.

The GIS analysis demonstrates that parasitic contamination is spatially heterogeneous, with wastewater providing widespread exposure, eco-san manure acting as a localized high-risk source, and flood runoff amplifying contamination in vulnerable wards.

GIS mapping highlights Badda and Demra as major contamination hotspots, while peri-urban and urban slum areas have lower contamination levels. River-adjacent sites exhibit measurable but comparatively reduced parasite load, likely due to dilution effects. Spatial visualization supports targeted sanitation interventions.

4.4 Prevalence of Parasite Groups

Table 4.4: Prevalence of Protozoa, Cestoda, and Nematoda by Sample Type

Sample Type	Protozoa (%)	Cestoda (%)	Nematoda (%)	Total Infected Samples (%)
Eco-san manure	35.1	28.1	36.8	69.44
Wastewater	19.8	46.8	33.3	65
Flood runoff water	42.1	42.1	15.8	60
Total	32.33	39	28.63	64.81

Each sample type is dominated by a different parasite group. Eco-san manure is dominated by nematodes (*Ascaris lumbricoides*, *Trichuris trichiura*), wastewater by cestodes (*Hymenolepis nana*), and flood runoff water by protozoa (*Enteromonas hominis*, *Entamoeba* sp.). This reflects the influence of sample type and environmental contamination sources.

Ecosan Toilet Manure

- Highest prevalence: *Hymenolepis nana* (32%)
- Followed by: *Ascaris lumbricoides* (18%), *Trichuris trichiura* (13%), and *Ancylostoma duodenale* (11%).
- Protozoan parasites such as *Entamoeba* sp., *Giardia* sp., and *Cryptosporidium* sp. are present at lower percentages.

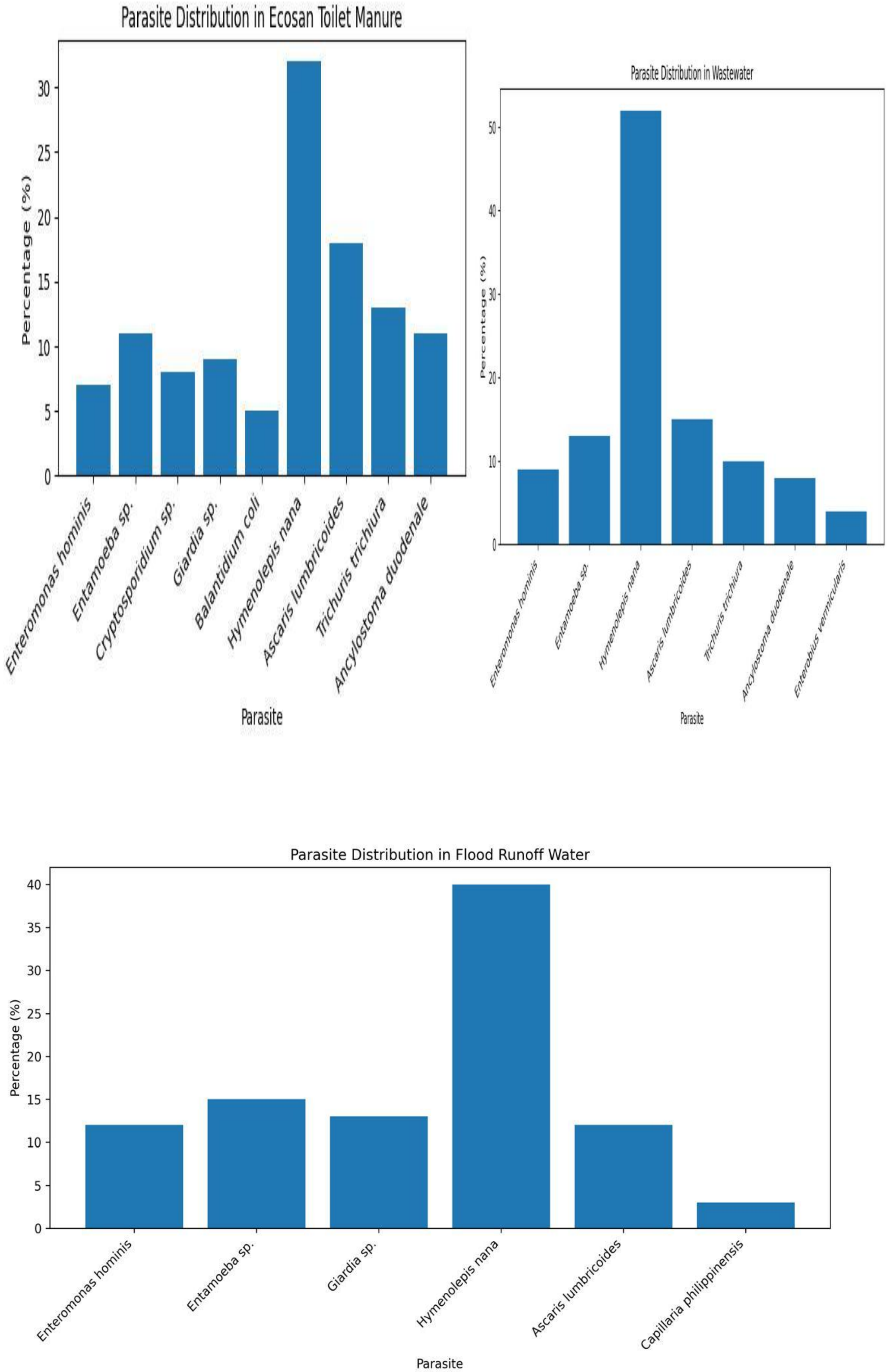


Figure 4.6: Parasitic distribution in eco san toilet manure, wastewater and flood run off water

Wastewater

- Dominant parasite: *Hymenolepis nana* (52%), indicating a high level of fecal contamination.
- Other notable parasites include *Ascaris lumbricoides* (15%) and *Entamoeba* sp. (13%).
- *Enterobius vermicularis* appears only in this sample (4%).

Flood Runoff Water

- Most prevalent: *Hymenolepis nana* (40%).
- Moderate presence of *Entamoeba* sp. (15%) and *Giardia* sp. (13%).
- *Capillaria philippinensis* is uniquely detected in this sample (3%).

Hymenolepis nana is consistently the most prevalent parasite across all sample types, suggesting widespread environmental contamination. Helminth eggs (*Ascaris*, *Trichuris*, *Ancylostoma*) indicate potential public health risks, especially in areas with inadequate sanitation. Protozoan parasites such as Giardia and *Entamoeba* highlight risks related to waterborne transmission.

Table 4.5: Gastrointestinal Parasites Identified by Sample Type

Sample Type	**Parasite Group**	**Species Detected**
Eco-san manure	Protozoa	*Entamoeba* sp., *Enteromonas hominis*, *Cryptosporidium* sp., *Giardia* sp., *Balantidium coli*
	Cestode	*Hymenolepis nana*
	Nematode	*Hymenolepis nana*, *Ascaris lumbricoides*, *Trichuris trichiura*, *Ancylostoma duodenale*
Wastewater	Protozoa	*Entamoeba* sp., *Enteromonas hominis*
	Cestode	*Hymenolepis nana*
	Nematode	*Ascaris lumbricoides*, *Enterobius vermicularis*, *Trichuris trichiura*, *Ancylostoma duodenale*
Flood runoff water	Protozoa	*Enteromonas hominis*, *Entamoeba* sp., *Giardia* sp.
	Cestode	*Hymenolepis nana*
	Nematode	*Capillaria philippinensis*, *Ascaris lumbricoides*

This table details parasite diversity per sample type. Eco-san manure and wastewater have both protozoan and helminth species.

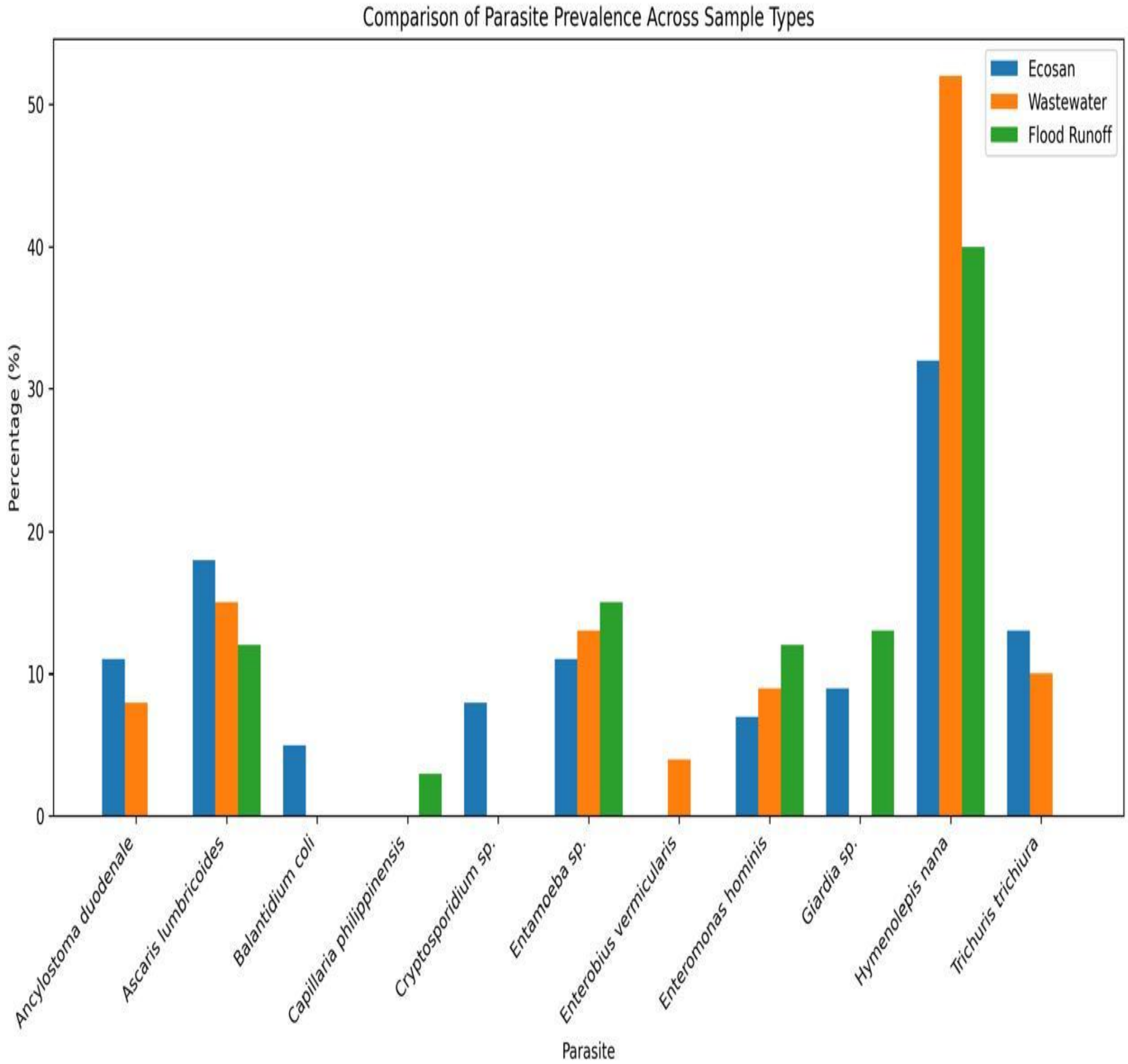


Figure 4.7: Comparative analysis of parasite prevalence across sample types

The diagram illustrates the percentage prevalence of parasite species detected in Ecosan toilet manure, wastewater, and flood runoff water. In Ecosan toilet manure, *Hymenolepis nana* exhibited the highest prevalence (32%), followed by *Ascaris lumbricoides* (18%), *Trichuris trichiura* (13%), and *Ancylostoma duodenale* (11%), while protozoan parasites such as *Entamoeba* sp., *Giardia* sp., and *Cryptosporidium* sp. were present at lower proportions. In wastewater, *Hymenolepis nana* was the dominant parasite (52%), indicating significant fecal contamination, with other notable species including *Ascaris* *lumbricoides* (15%) and *Entamoeba* sp. (13%); *Enterobius vermicularis* (4%) was uniquely detected in this sample. In flood runoff water, *Hymenolepis nana* again showed the highest prevalence (40%), followed by *Entamoeba* sp. (15%) and *Giardia* sp. (13%), while *Capillaria philippinensis* (3%) was exclusively observed in this sample type. Overall, the consistent predominance of *Hymenolepis nana* across all samples highlights widespread environmental contamination, and the presence of soil-transmitted helminths and protozoan parasites underscores potential public health risks associated with inadequate sanitation and water quality.

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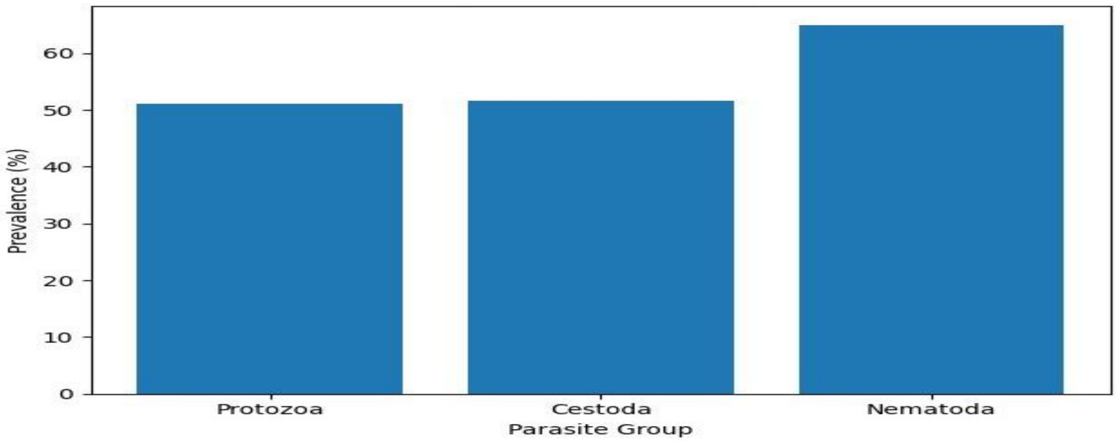

Figure 4.8: Comparative Prevalence of different parasite groups across environmental sample types

Protozoa are most prevalent in flood runoff water, likely due to surface contamination and transport of fecal matter during flooding. Lower levels in wastewater may reflect dilution or treatment effects.

Wastewater shows the highest cestode prevalence, suggesting strong linkage with human waste contamination. Eco-san manure has the lowest, possibly due to partial pathogen reduction during composting.

Nematodes dominate in eco-san manure, likely because helminth eggs (e.g., Ascaris, Trichuris) are highly resistant and persist in treated fecal matter. Their lower presence in floodwater may be due to dilution or sedimentation.

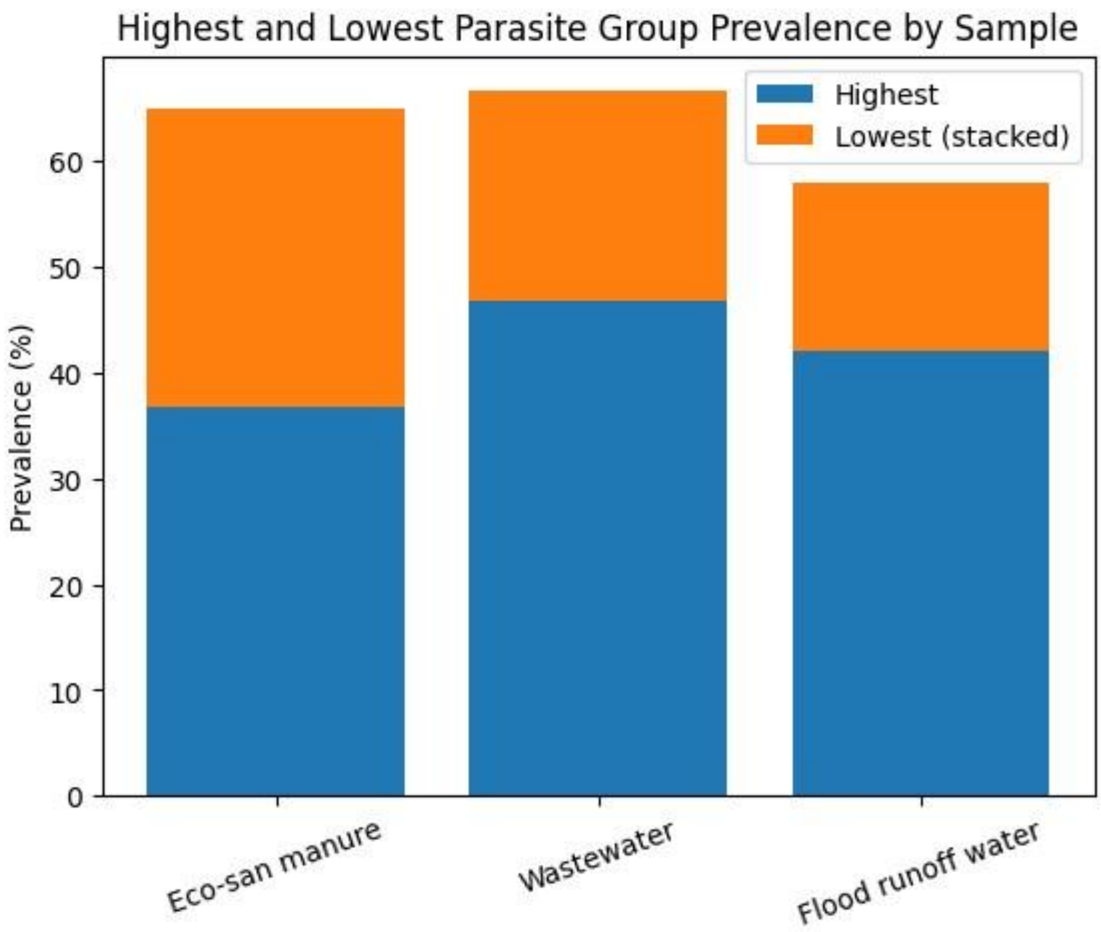

Figure 4.9: Comparative analysis of highest and lowest prevalence of parasite group across samples

Eco-san manure has the highest overall contamination, indicating incomplete pathogen inactivation. Floodwater has the lowest total infection rate, likely due to dilution effects despite high protozoa presence.

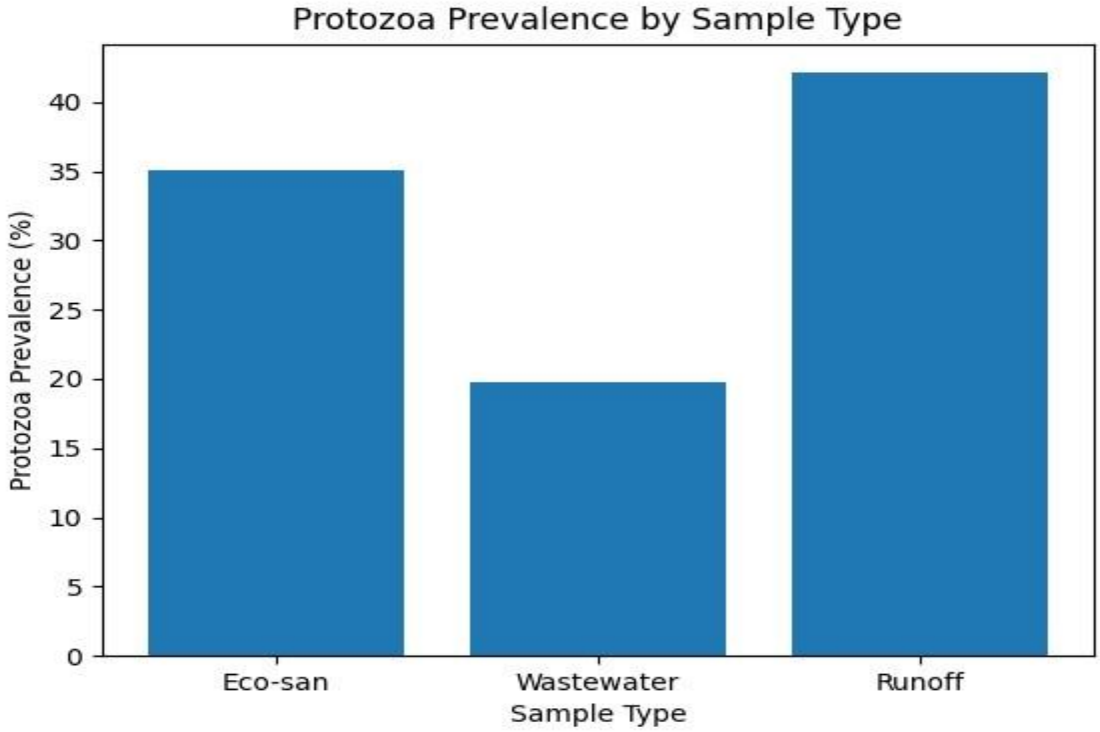

Figure 4.10: Protozoa Prevalence (%) by Sample Type

The bar chart illustrates the distribution of **protozoan parasites** across three different sample types: eco-san manure, wastewater, and flood runoff water.

Flood runoff water shows the **highest protozoa prevalence (42.1%)**, indicating that runoff water is highly contaminated with protozoan parasites. This may be due to surface washing of contaminants from soil, human settlements, and animal waste into water bodies during rainfall events.

Eco-san manure has the **second highest prevalence (35.1%)**, suggesting that protozoa are still present even after sanitation processing. This could indicate incomplete treatment or survival of resistant protozoan cysts in stored manure.

Wastewater exhibits the **lowest protozoa prevalence (19.8%)**, which may be attributed to dilution effects or partial removal during wastewater handling processes.

Overall, the results suggest that **environmental water sources, particularly flood runoff, pose a higher risk for protozoan contamination** compared to treated waste and wastewater. This highlights the importance of proper water management and sanitation practices to reduce exposure to protozoan infections.

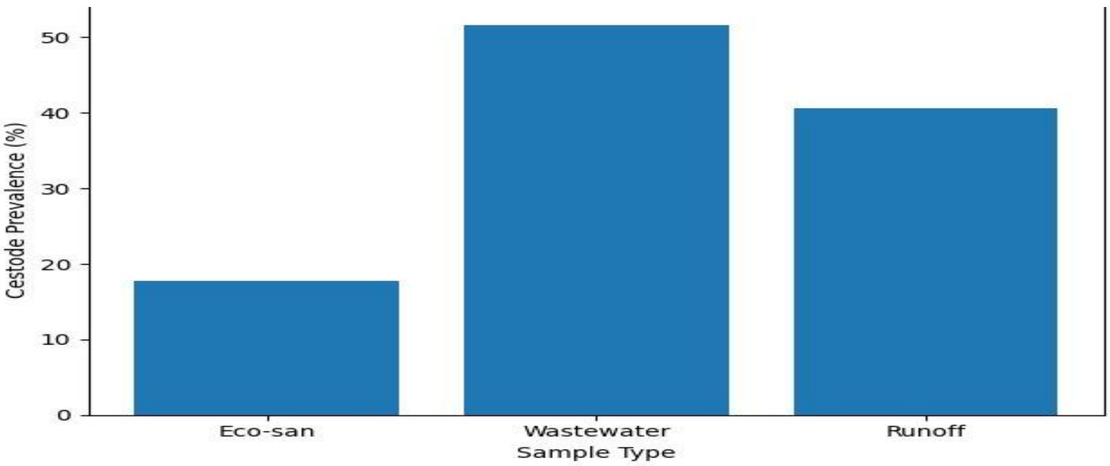

Figure 4.11: Cestode Prevalence (%) by Sample Type

The bar chart presents the prevalence of **cestode parasites** across eco-san manure, wastewater, and flood runoff water.

Wastewater shows the **highest prevalence of cestodes (≈52%)**, indicating that it is the most significant source of tapeworm contamination. This high level may be due to continuous discharge of human and animal waste containing cestode eggs into wastewater systems.

Flood runoff water has the **second highest prevalence (≈40%)**, suggesting that rainfall runoff can transport cestode eggs from contaminated soils, open defecation areas, and waste disposal sites into water bodies.

Eco-san manure exhibits the **lowest prevalence (≈18%)**, which may indicate that the eco-san treatment process reduces cestode contamination to some extent, although it does not eliminate it completely.

Overall, the findings suggest that **wastewater is the primary reservoir of cestode parasites**, followed by environmental runoff, while eco-san manure shows comparatively lower contamination. This emphasizes the need for improved wastewater management and sanitation practices to reduce the spread of cestode infections.

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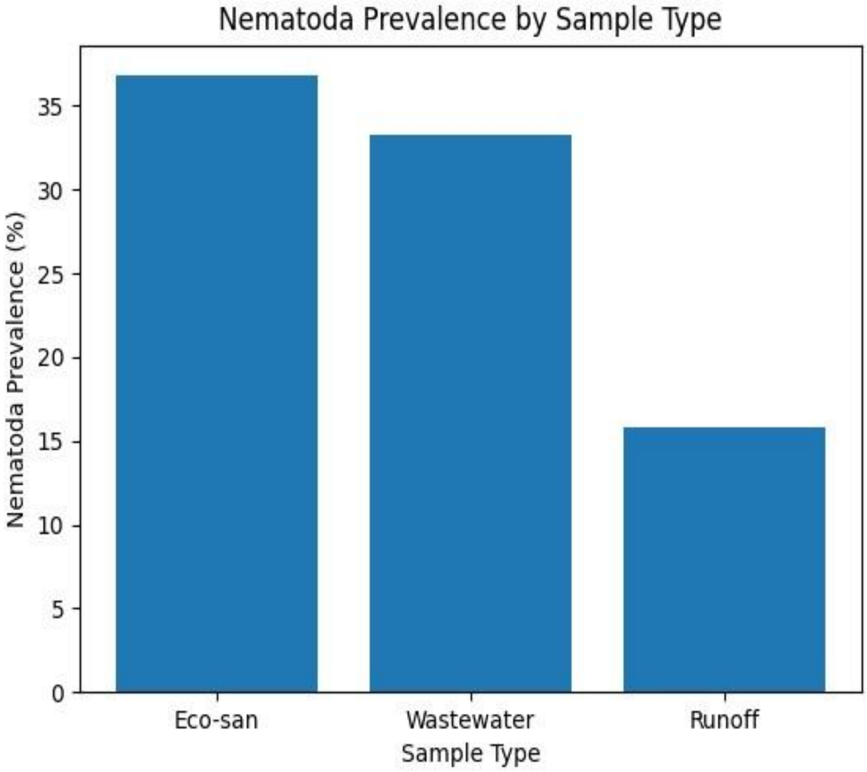


Figure 4.12: Nematode Prevalence (%) by Sample Type

The bar chart shows the distribution of **nematode parasites** across eco-san manure, wastewater, and flood runoff water.

Eco-san manure has the **highest prevalence of nematodes (36.8%)**, indicating that nematode eggs or larvae are more persistent in treated human waste. This may be due to their strong resistance to environmental conditions and inadequate treatment processes.

Wastewater follows with a **moderate prevalence (33.3%)**, suggesting that nematodes are still commonly present in liquid waste, possibly due to continuous input from domestic sewage and limited removal efficiency.

Flood runoff water shows the **lowest prevalence (15.8%)**, which may be because nematode eggs are heavier and tend to settle in soil rather than being carried extensively by runoff water.

Overall, the findings indicate that **eco-san manure is the most significant source of nematode contamination**, highlighting the need for improved sanitation treatment and handling practices to reduce the risk of transmission.

4.5 Seasonal Distribution of Parasitic Infections

A stratified sampling design was employed to assess seasonal variation in parasitic contamination. A total of 540 environmental samples were collected, comprising 180 eco-san manure, 180 wastewater, and 180 flood runoff water samples. The samples were evenly distributed across three seasons—winter, summer, and rainy—with 180 samples collected in each season. Within each season, an equal number of samples (n = 60) were obtained from each sample type to ensure balanced representation. Sampling locations were selected randomly within the study area, and standard procedures were followed for sample collection, preservation, and laboratory analysis. This approach allowed for a comparative assessment of seasonal influences on parasite prevalence across different environmental sources.

Table 4.6: Seasonal Distribution of Single and Multiple Parasite Infections

Season	Total Samples	Single (%)	Double (%)	Triple (%)	Quadruple (%)	Multiple (%)
Winter	180	1.67	10.67	7.67	8.0	2.67
Summer	180	11.67	15.67	16.33	5.33	1.0
Rainy	180	16.67	18.33	20.0	2.67	0

Multiple infections are highest in the rainy season, likely due to flooding and enhanced environmental dispersal of parasites. Winter shows the lowest prevalence. Parasitic infections are **seasonally influenced**, with the **rainy season posing the highest risk**, likely due to flooding, poor sanitation, and increased environmental contamination. The rise in multiple infections suggests greater exposure and transmission during this period.

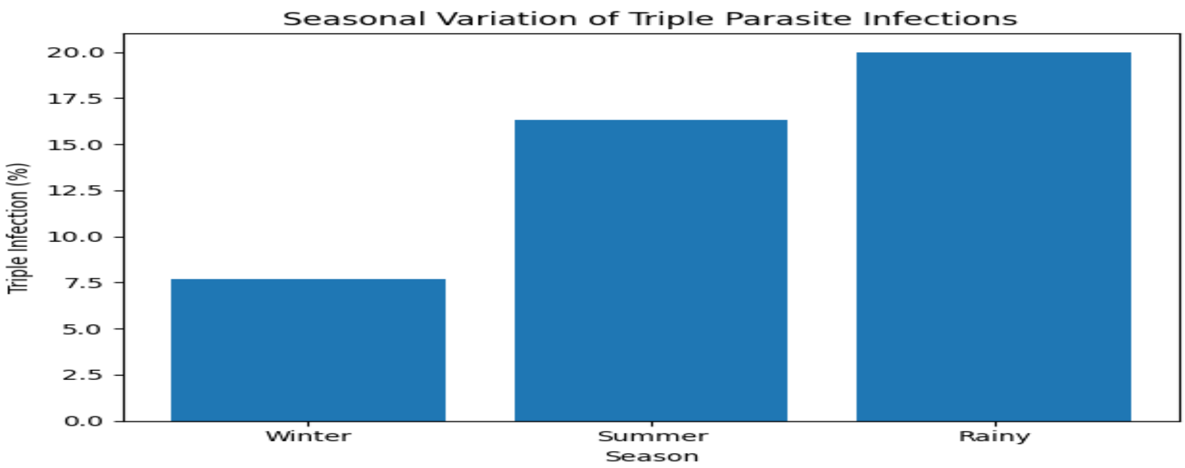


Figure 4.13: Seasonal Prevalence of triple Parasite Infections

The bar chart confirms that rainy season conditions favor multiple infections, whereas winter conditions limit parasite transmission.

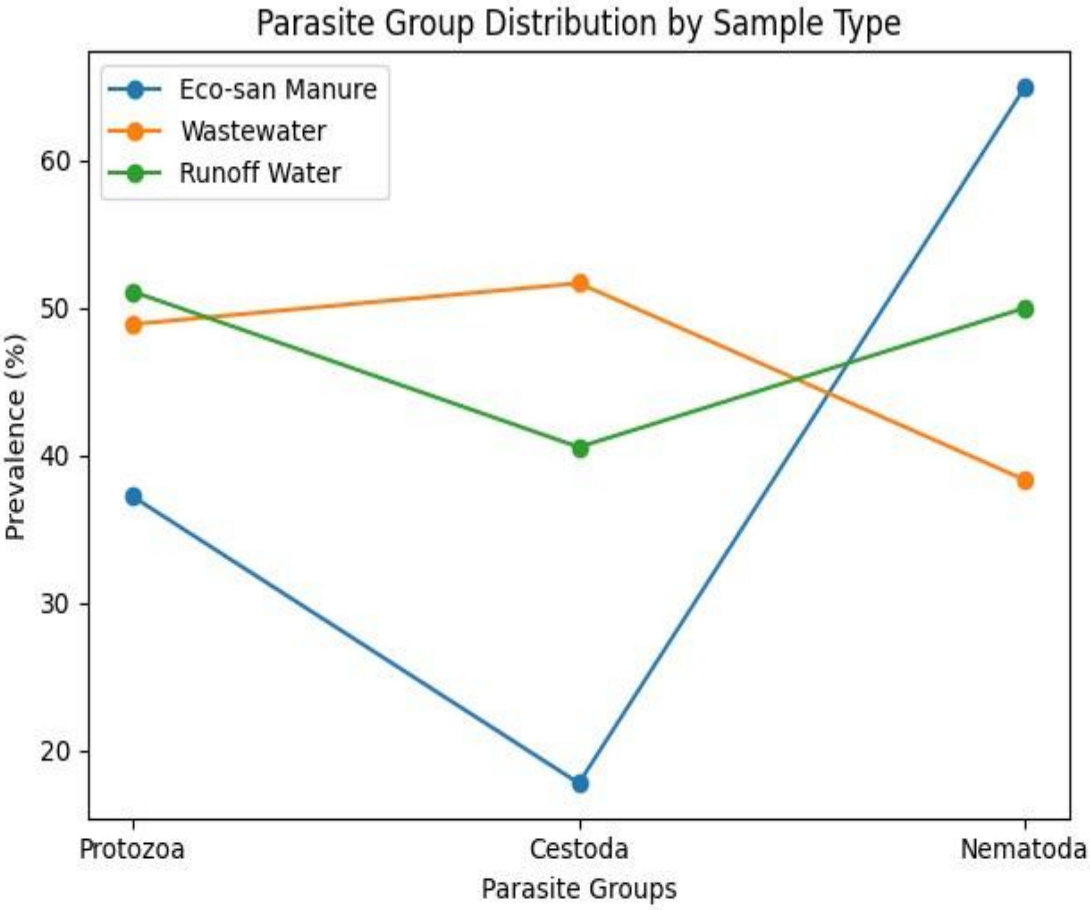
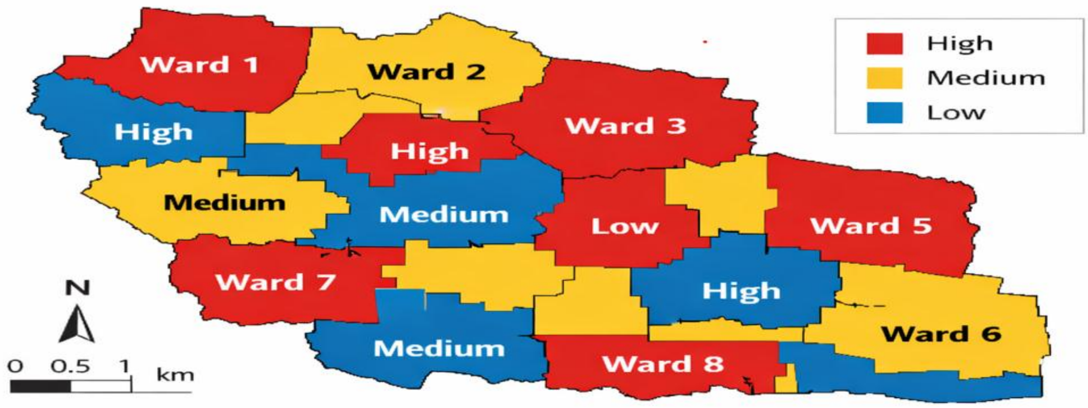


Figure 4.14: Parasite Group distribution by sample type

The figure illustrates the comparative prevalence (%) of three major parasite groups—**Protozoa, Cestoda, and Nematoda**—across three environmental sample types: eco-san manure, wastewater, and runoff (flood) water.

- **Protozoa** prevalence is highest in **runoff water (≈51%)**, followed closely by **wastewater (≈49%)**, while **eco-san manure (≈37%)** shows relatively lower contamination.
- **Cestoda** shows a different trend, with the highest prevalence in **wastewater (≈52%)**, moderate in **runoff water (≈41%)**, and significantly lower in **eco-san manure (≈18%)**.
- **Nematoda** is most dominant in **eco-san manure (≈65%)**, indicating a strong association with treated or stored human waste. Runoff water shows moderate levels (≈50%), while wastewater has the lowest prevalence (≈38%).

4.6 GIS Mapping of High-Risk Wards



Ward Data Summary

Ward	Eco-san	Wastewater	Flood Water
Ward 1	High	Low	Medium
Ward 2	Medium	High	High
Ward 3	High	Medium	Low
Ward 4	Low	High	Medium
Ward 5	High	Medium	High
Ward 6	Medium	Low	Low
Ward 7	High	High	Medium
Ward 8	Low	Medium	High
Ward 9	Medium	Low	Low

Figure 4.15: GIS Map Showing High-Risk Wards by Sample Type (Eco-san, Wastewater, Flood water)

Hotspots identified include Keraniganj & Savar for eco-san manure, Kamrangirchar for wastewater, and Badda & Demra for floodwater. The GIS map supports prioritization of sanitation and control measures in high-risk wards.

4.7 Key Findings

1. Eco-san toilet manure: Dominated by nematodes; highest contamination in peri-urban wards.
2. Wastewater: Moderate contamination in urban slums; cestodes dominate.
3. Flood runoff water: Significantly elevated in flood-prone wards; mixed contamination.
4. Spatial distribution: GIS mapping confirms high-risk wards.
5. Overall prevalence: 64.81% across all sample types.
6. Seasonal trends: Highest multiple infections during rainy season.
7. Statistical analysis: Runoff parasitic load varies significantly across area types (ANOVA, $p < 0.05$); seasonal variation borderline significant.

Eco-san manure demonstrated a higher parasitic load compared to wastewater, which can be attributed to differences in environmental conditions and pathogen survival mechanisms. Helminth eggs, particularly those of *Ascaris lumbricoides* and *Trichuris trichiura*, are known for their resilience and ability to persist in solid organic matter for extended periods. This makes eco-san manure a favorable medium for their accumulation. In contrast, wastewater, although contaminated, represents a more diluted environment. Continuous flow, mixing, and partial sedimentation may reduce the detectable concentration of parasite eggs per unit volume.

Table A: Mean Parasitic Load Across Wards and Sample Types

Area Type	Ward (Location)	Manure (EPG)	Wastewater (EPL)	Runoff Water (EPL)
Peri-urban	Ward 3 (Keraniganj)	135 + 10	70 + 8	55 + 7
Peri-urban	Ward 5 (Savar)	115 + 12	65 + 6	40 + 5
Urban Slum	Ward 55 (Kamrangirchar)	—	95 + 9	30 + 4
Flood-prone	Ward 6 (Badda)	—	75 + 7	150 + 15
Flood-prone	Ward 9 (Demra)	—	70 + 6	165 + 18

Table A. Mean parasitic load in different wards and sample types.

Figure A: Mean Parasitic Load in Runoff Water Across Wards

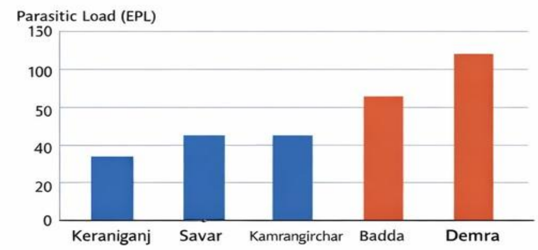


Figure A. Bar chart showing mean parasitic load in runoff water across different wards.

Figure B: *Parasitic Load in Runoff Water by Area Type*

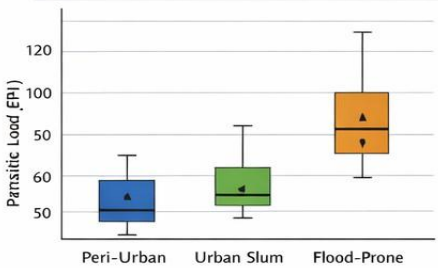


Figure B. Box plot of parasitic load in runoff water by area type.

Table B: Overall *Prevalence of Parasite Contamination by Sample Type*

Sample Type	Total Samples Examined	No. of Infected Samples	Prevalence (%)
Eco-san toilet manure	180	125	**69.44**
Wastewater	180	117	**65.00**
Flood runoff water	180	108	**60.00**
Total	540	350	**64.81**

Table B: Prevalence of parasite contamination by sample type.

Figure C: *Prevalence of Parasitic Groups by Sample Type*

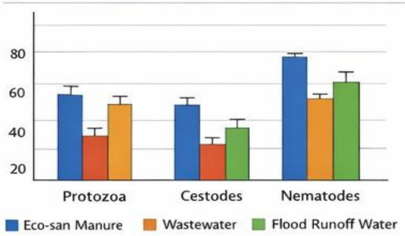


Figure C: Bar chart showing prevalence of protozoa, cestodes, and nematodes by sample type.

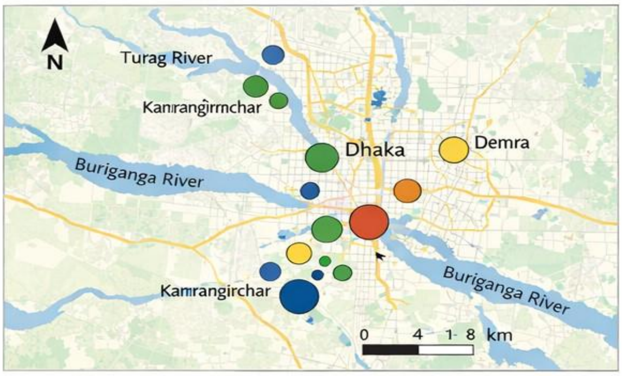


Figure D: GiS map showing spatial distribution of parasitic load in Dhaka.

Figure 4.16: Seasonal Prevalence of Single and Multiple Parasite Infections,

However, wastewater still plays a critical role in transmission due to its widespread distribution and direct human exposure pathways. The higher parasitic load in eco-san manure also suggests potential shortcomings in composting practices. Effective pathogen inactivation requires specific conditions, including adequate temperature and retention time, which may not have been consistently achieved. While these findings highlight eco-san manure as a more concentrated source of contamination, wastewater remains a significant environmental pathway due to its mobility and connection to urban drainage systems. Therefore, both sources contribute differently but importantly to environmental parasite transmission.

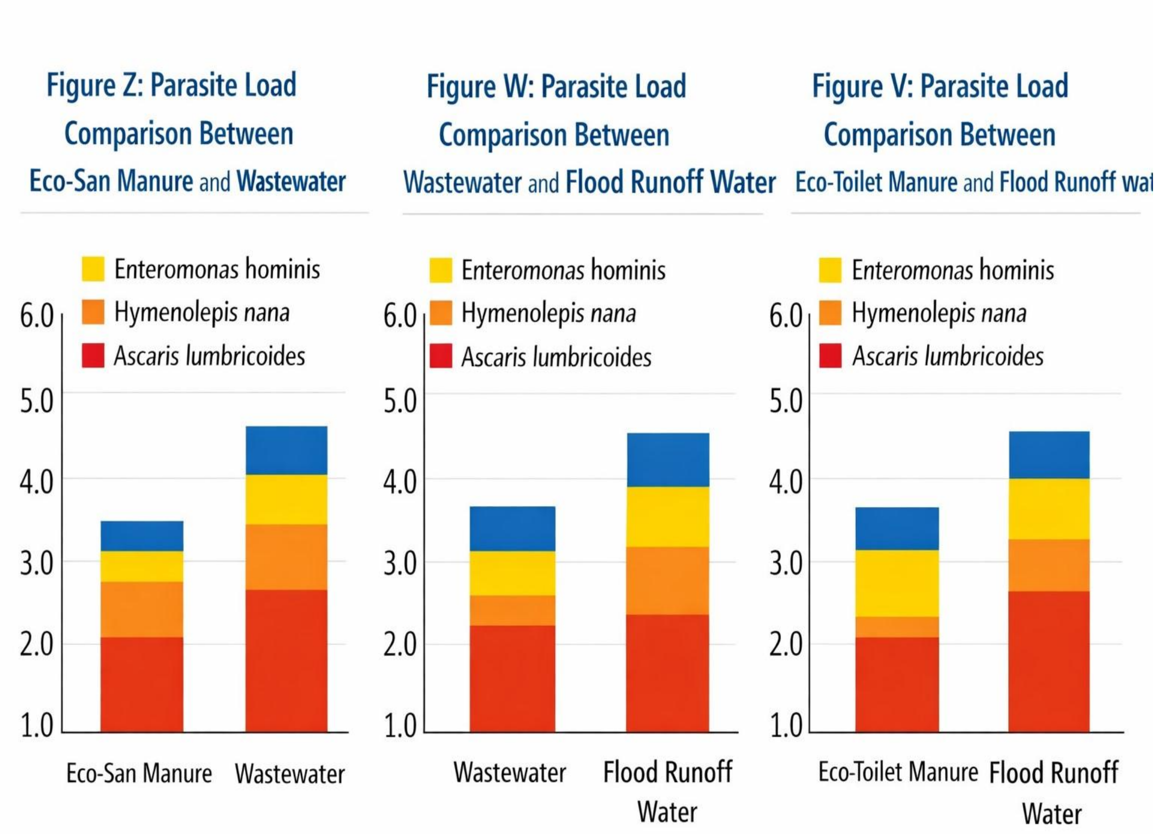


Figure 4.17: Comparative Parasite Load Distribution of *Enteromonas hominis*, *Hymenolepis nana*, and *Ascaris lumbricoides* Across Eco-San Manure, Wastewater, and Flood Runoff Water

This figure Z illustrates the comparative load of *Enteromonas hominis*, *Hymenolepis nana*, and *Ascaris lumbricoides* in eco-san manure and wastewater samples. The results indicate that wastewater exhibits a higher overall parasite load compared to eco-san manure. Among the parasites, *Ascaris lumbricoides* shows the highest contribution in both sample types, with a noticeably greater concentration in wastewater. *Hymenolepis nana* and *Enteromonas hominis* also follow a similar increasing trend. This suggests that wastewater serves as a more contaminated medium, posing a higher risk for parasitic transmission.

This figure W presents the comparison of parasite load between wastewater and flood runoff water. The data reveal that flood runoff water has a higher cumulative parasite burden than wastewater. All three parasites—*Enteromonas hominis*, *Hymenolepis nana*, and *Ascaris lumbricoides*—are found in increased concentrations in floodwater. The increase is particularly prominent for *Ascaris lumbricoides*, highlighting its environmental persistence and ability to spread during flooding. This indicates that flood events significantly contribute to the dissemination of parasitic contaminants. This figure V compares the parasite load in eco-toilet manure and flood runoff water. The findings show that flood runoff water contains substantially higher levels of all three parasites compared to eco-toilet manure. While eco-toilet manure still exhibits the presence of *Enteromonas hominis*, *Hymenolepis nana*, and *Ascaris lumbricoides*, their concentrations are comparatively lower. The elevated levels in floodwater emphasize the role of environmental contamination and flooding in increasing parasitic exposure and associated public health risks.

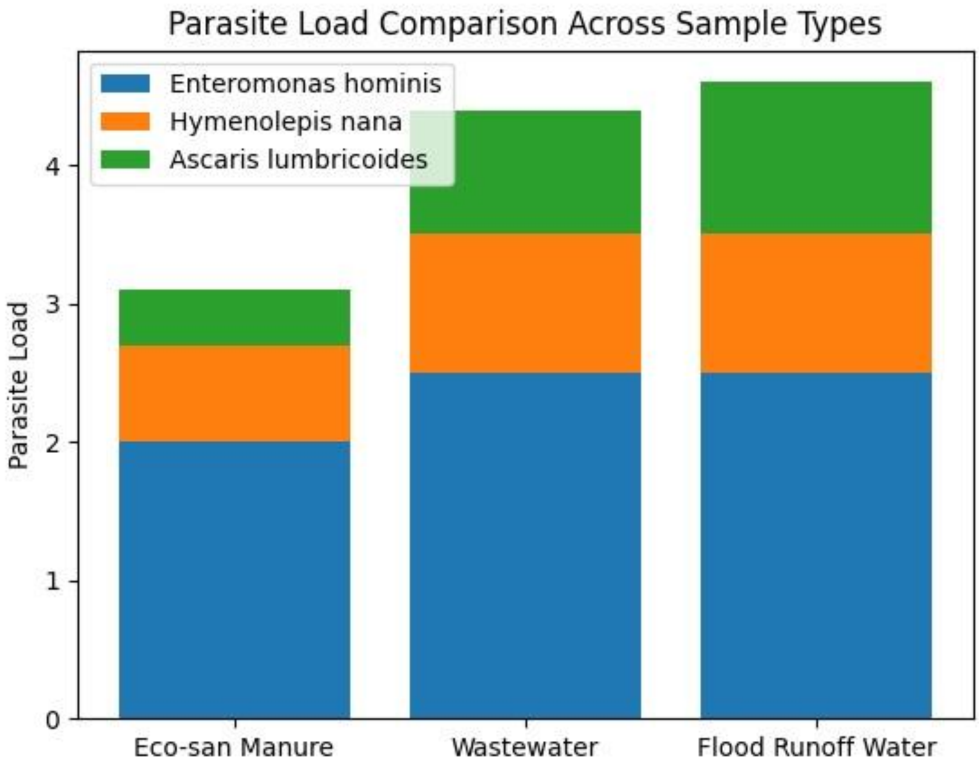


Figure 4.18: Parasite Load Comparison among Ecosan toilet manure, Wastewater and Flood Runoff Water.

The bar diagram presents the comparative parasite load of *Enteromonas hominis*, *Hymenolepis nana*, and *Ascaris lumbricoides* across three environmental sample types: eco-san manure, wastewater, and flood runoff water.

The results indicate that **eco-san manure** contains a moderate level of *Enteromonas hominis* and relatively lower loads of *Hymenolepis nana* and *Ascaris lumbricoides*. In contrast, **wastewater** shows an overall increase in parasite load, particularly for *Hymenolepis nana* and *Ascaris lumbricoides*, suggesting higher contamination and transmission potential.

The highest cumulative parasite load is observed in **flood runoff water**, where all three parasites show elevated levels. Notably, *Ascaris lumbricoides* demonstrates a significant increase in floodwater, indicating its strong association with environmental contamination during flooding events.

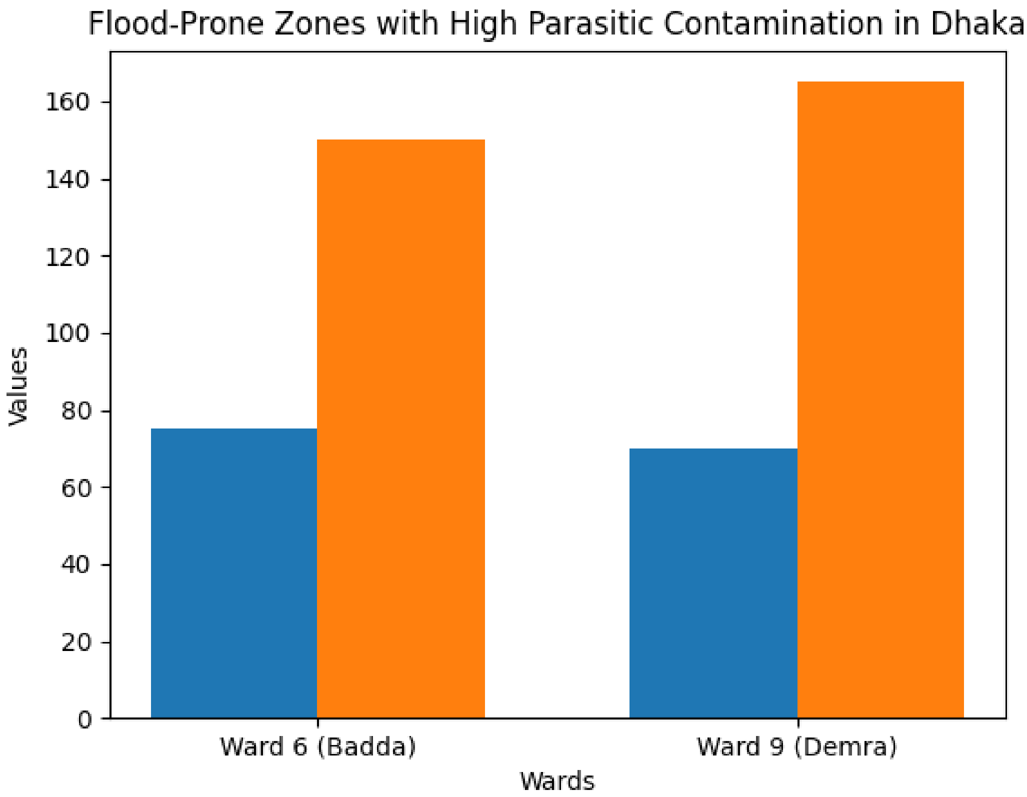


Figure 4.19: Flood-Prone Zones with High Parasitic Contamination in Dhaka

The figure represents **flood-prone urban areas of Dhaka**, particularly **Ward 6 (Badda)** and **Ward 9 (Demra)**, which show **high levels of parasitic contamination** in environmental samples.

- **Badda (Ward 6)** recorded contamination levels of **75 ± 7** and **150 ± 15**, indicating significant presence of parasitic organisms in flood-affected environments.
- **Demra (Ward 9)** showed similarly high values of **70 ± 6** and **165 ± 18**, suggesting even greater contamination in some cases.

These elevated values are strongly associated with **frequent waterlogging and flooding**, which facilitate the mixing of:

- Sewage water
- Surface runoff
- Domestic and industrial waste

Research indicates that areas like **Badda and surrounding eastern Dhaka zones are among the highest flood-risk regions**, especially in low-lying and densely populated settlements.

Additionally, **poor drainage systems and rapid urbanization** in Dhaka contribute to persistent flooding, allowing contaminated water to stagnate and increasing exposure to parasites.

Flood events are also known to **increase faecal contamination in water sources**, significantly raising the risk of parasitic infections among residents. 1

Flood-prone areas in Dhaka, especially **Badda and Demra**, are **high-risk zones for parasitic transmission** due to poor sanitation, waterlogging, and unplanned urban growth.

4.8 Overview of Surveyed Households

To contextualize parasitic contamination patterns, this study employed a **mixed-method approach**, integrating quantitative laboratory analysis with qualitative household surveys. A total of **400 households** were surveyed across five selected study sites in Dhaka City, representing diverse environmental settings including flood-prone areas, peri-urban zones, an urban slum, and a control site with relatively improved infrastructure.

4.8.1 Socio-Demographic Characteristics

4.8.1.1 Household Composition and Education

The average household size across all study sites was **5.8 members**, with a range of 3 to 10. Larger household sizes were observed in more vulnerable communities, particularly in slum and flood-prone areas, increasing pressure on shared sanitation facilities.

Female respondents constituted **52%** of the sample. In many households, women were primarily responsible for sanitation-related tasks, including water collection, latrine cleaning, and maintenance of composting systems in Ecosan-adopting communities.

Educational attainment varied significantly. Approximately:

- **63%** had primary education
- **24%** had secondary education
- **<10%** had post-secondary education

Higher literacy levels were observed in the control site, suggesting a positive relationship between education and adoption of improved sanitation technologies.

Income disparities were also evident, with mean monthly income ranging from approximately **BDT 10,000 to BDT 25,000** across the study sites. Ecosan adoption was significantly higher in intervention areas (~40%), while remaining minimal in other sites.

Table 4.7: Socio-Demographic Characteristics of Surveyed Households

Parameter	Site 1	Site 2	Site 3	Site 4	Site 5
Sampled Households (n)	80	100	90	50	80
Mean Household Size	6.2	5.0	6.7	5.5	4.6
% Female Respondents	48%	55%	50%	60%	45%
Education > Secondary	15%	20%	5%	10%	40%
Mean Monthly Income (BDT)	**13,000**	**15,000**	**10,000**	**12,000**	**25,000**
Ecosan Adoption Rate	<5%	~40%	~0%	1–2%	1–2%

Note: Income data are approximate and based on self-reported monthly earnings in Bangladeshi Taka (BDT).

4.8.1.2 Occupation and Water Sources

Occupational patterns varied across study sites. In flood-prone and peri-urban areas, most respondents were engaged in informal occupations such as manual labor, rickshaw pulling, and small-scale vending. In contrast, the control site exhibited higher levels of formal employment and business ownership.

Water sources also differed significantly. Slum communities relied on shared or unauthorized standpipes, whereas other areas had relatively better access to municipal or groundwater sources.

4.8.2 Sanitation Practices and Hygiene Behavior

4.8.2.1 Latrine Types and Maintenance

Sanitation infrastructure varied across study sites:

- **Pit latrines** were common in slum areas and often shared among multiple households, leading to frequent overflow.
- **Ecosan toilets (UDDTs)** were concentrated in intervention areas, with moderate adherence to composting practices.
- **Flush toilets with septic tanks** were predominant in the control site, although occasional overflow occurred during monsoon periods.

Approximately **38%** of households in Ecosan areas reported monthly maintenance, compared to only **15%** in slum areas.

4.8.2.2 Hygiene Practices

Around **70%** of respondents reported washing hands with soap after defecation. However, observational findings suggested lower actual compliance, particularly in resource-constrained settings.

Children's exposure to contaminated floodwater was common in flood-prone areas, increasing the risk of parasitic infections.

4.9 Parasitic Load Across Study Sites

4.9.1 Quantitative Analysis

Parasitic contamination levels varied significantly across environmental settings.

- **Peri-urban sites** showed the highest helminth egg counts in Ecosan manure (115–135 EPG), indicating incomplete pathogen inactivation.
- **Flood-prone areas** exhibited the highest contamination in runoff water (150–165 EPL), highlighting the role of flooding in pathogen dispersion.
- **Urban slum areas** showed moderate to high wastewater contamination due to direct discharge of untreated fecal matter.

Table 4.8: Mean Parasitic Load Across Study Sites

Area Type	Site	Manure (EPG)	Wastewater (EPL)	Runoff Water (EPL)
Peri-urban	Site 1	135 ± 10	70 ± 8	55 ± 7
Peri-urban	Site 2	115 ± 12	65 ± 6	40 ± 5
Urban Slum	Site 3	—	95 ± 9	30 ± 4
Flood-prone	Site 4	—	75 ± 7	150 ± 15
Flood-prone	Site 5	—	70 ± 6	165 ± 18

4.9.2 Qualitative Distribution

To improve interpretability, parasitic load values were categorized:

- **Low:** < 60
- **Moderate:** 60–100
- **High:** > 100

Table 4.9: Qualitative Distribution of Parasitic Contamination

Site	Area Type	Eco-san Manure	Wastewater	Flood Runoff
Site 1	Peri-urban	High	Moderate	Low–Moderate
Site 2	Peri-urban	High	Moderate	Low
Site 3	Urban slum	Not Available	Moderate–High	Low
Site 4	Flood-prone	Not Available	Moderate	High
Site 5	Flood-prone	Not Available	Moderate	High

The integration of qualitative survey findings with quantitative parasitic data provides a comprehensive understanding of contamination dynamics.

Flood-prone areas exhibited elevated contamination in runoff water due to poor drainage, overflow of sanitation systems, and frequent exposure to contaminated floodwater. Household surveys confirmed challenges in maintaining sanitation facilities during flooding events.

Peri-urban Ecosan-adopting areas showed higher contamination in manure, suggesting incomplete adherence to composting protocols and gaps in user awareness.

Urban slum areas demonstrated moderate to high wastewater contamination, driven by high population density, shared sanitation infrastructure, and inadequate waste management systems.

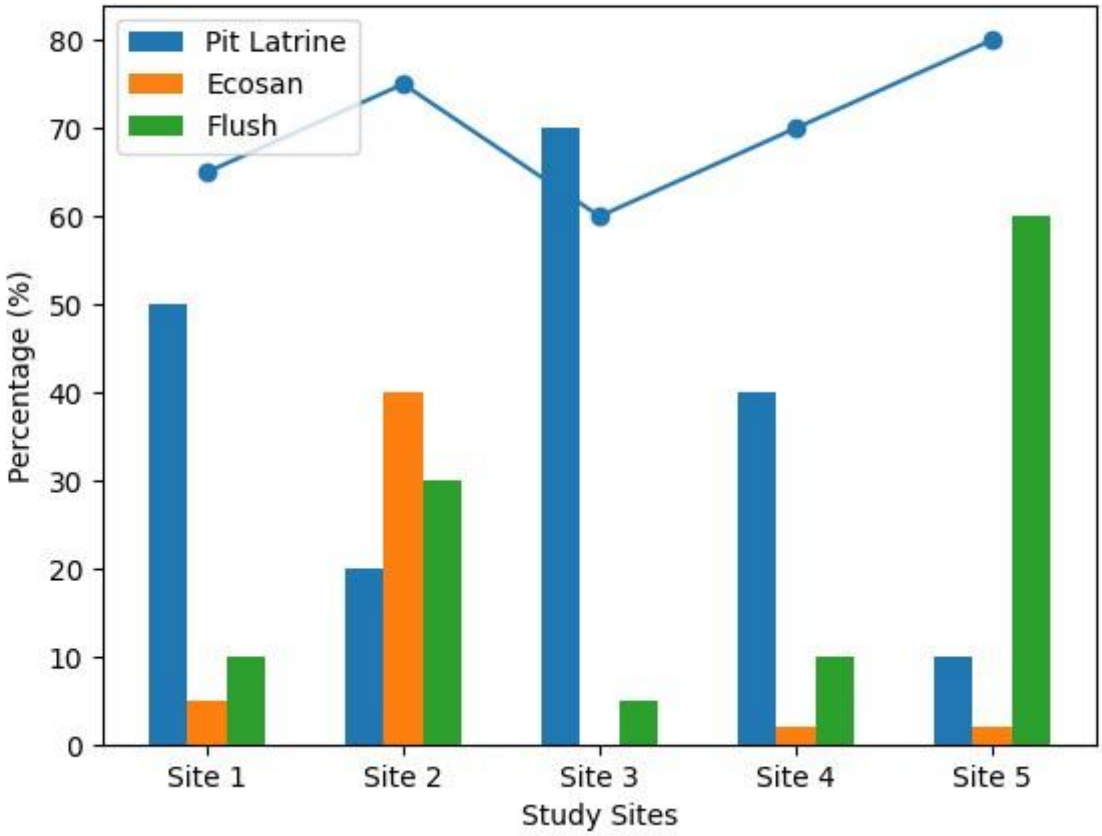


Figure 20: The distribution of sanitation facilities and hand washing practices across the surveyed study sites.

Pit latrines are more prevalent in lower-income and densely populated areas, particularly in slum and flood-prone sites, where sanitation facilities are often shared and poorly maintained. In contrast, Ecosan toilets are primarily concentrated in intervention areas, reflecting the impact of targeted sanitation programs. Flush toilets are more common in better-developed areas, indicating improved infrastructure and higher income levels. The results show noticeable variation in latrine types depending on socio-economic and infrastructural conditions.

Hand washing practices appear relatively high across all sites based on self-reported data; however, these findings should be interpreted cautiously, as observational evidence suggests that actual compliance may be lower. Overall, the figure highlights disparities in sanitation access and hygiene behavior, which are critical factors influencing environmental contamination and public health risks.

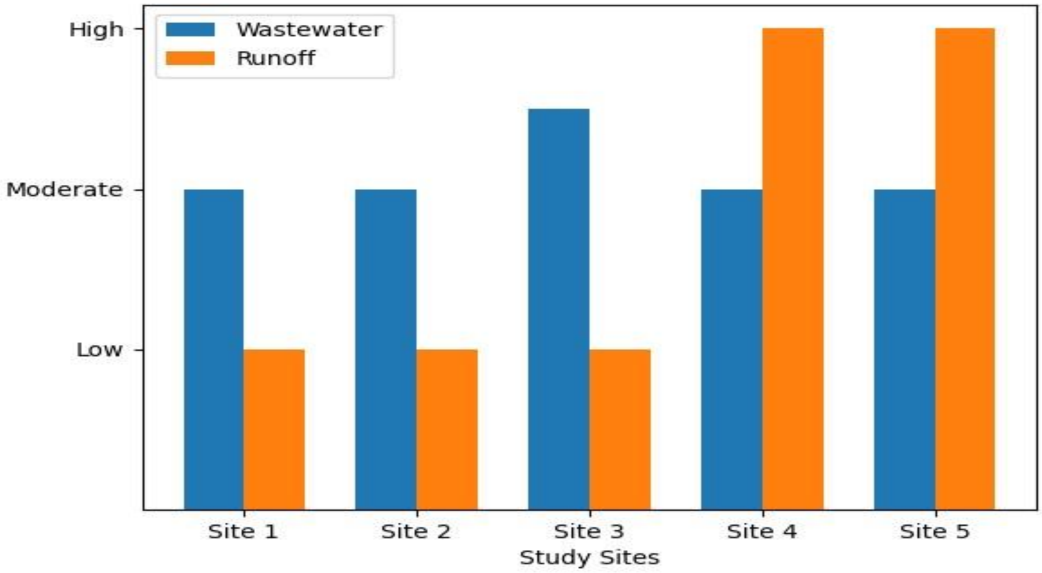


Figure 4.21 Qualitative distribution of parasitic contamination levels across the study sites, categorized as Low, Moderate, and High based on measured EPL values.

The figure shows that flood-prone areas exhibit the highest levels of parasitic contamination in runoff water, reflecting the impact of flooding in spreading pathogens from sanitation systems into the surrounding environment. Peri-urban sites demonstrate high contamination in Ecosan manure, suggesting incomplete pathogen inactivation due to improper composting practices.

Urban slum areas show moderate to high contamination in wastewater, likely due to the direct discharge of untreated human waste into open drainage systems. In contrast, runoff contamination in these areas remains relatively low compared to flood-prone regions.

Finally, the figure emphasizes the role of environmental conditions, sanitation infrastructure, and human behavior in shaping contamination pathways. It also reinforces the importance of integrating both qualitative and quantitative data to better understand public health risks. Overall, the findings highlight that **sanitation type, socio-economic conditions, and hydrological factors** are key determinants of parasitic contamination pathways in urban Dhaka.

CHAPTER FIVE

DISCUSSION

This chapter provides an integrative interpretation of the findings reported in Chapter 4, linking them back to the study‘s overarching objectives and research questions. It begins by situating the key results in the context of the existing literature on parasitic health risks in urban sanitation, particularly within flood-prone megacities. The discussion then explores the public health implications of these findings, emphasizing the vulnerable groups most at risk and the interventions required to mitigate infection. From an environmental and policy standpoint, the chapter examines how Ecosan toilets could be integrated into Dhaka‘s broader sanitation strategy, especially under conditions of seasonal flooding and inadequate wastewater management. Next, the study‘s limitations are critically appraised, evaluating how these constraints might influence the interpretation and generalize ability of the results. Finally, the chapter compares this study‘s outcomes with similar investigations around the world, identifying points of convergence and departure that can guide future research and policy agendas.

5.1 Overview of Findings

This study revealed a high overall prevalence (64.81%) of gastrointestinal parasites across environmental samples collected from Dhaka city. Among the sample types, eco-san toilet manure showed the highest contamination (69.44%), followed by wastewater (65.00%) and flood runoff water (60.00%). These findings suggest that multiple environmental pathways contribute to parasite transmission, with sanitation practices, population density, and hydrological conditions playing key roles. This high prevalence indicates a substantial environmental burden of gastrointestinal parasites, reflecting inadequate sanitation, improper waste handling, and environmental exposure pathways.

This study investigated the prevalence, distribution, and environmental determinants of gastrointestinal parasites in eco-san toilet manure, wastewater, and flood runoff water across selected areas of Dhaka city. The findings demonstrate a high overall contamination rate (64.81%), indicating that environmental exposure to parasites is widespread.

Among the sample types, eco-san toilet manure showed the highest prevalence (69.44%), followed by wastewater (65.00%) and flood runoff water (60.00%). These results suggest that inadequate sanitation practices, improper waste handling, and untreated wastewater discharge are major contributors to environmental contamination.

Spatial analysis identified distinct high-risk areas. Peri-urban regions such as Keraniganj and Savar were primarily associated with eco-san manure contamination, while urban slum areas like Kamrangirchar showed notable wastewater contamination. Flood-prone areas, including Badda and Demra, exhibited the highest parasitic loads in runoff water, highlighting the role of flooding in dispersing parasites.

The study also revealed variation in parasite group distribution. Nematodes were dominant in eco-san manure, cestodes in wastewater, and protozoa in flood runoff water. This variation reflects differences in environmental conditions and contamination sources.

Seasonal analysis indicated that multiple parasite infections were more frequent during the rainy season, although statistical significance was limited. This suggests that environmental factors such as rainfall and flooding may influence parasite transmission dynamics.

Overall, the findings confirm that environmental reservoirs play a critical role in the persistence and spread of gastrointestinal parasites in Dhaka city. However, since this study did not include human infection data, the direct impact on public health cannot be quantified with certainty.

While these results clearly indicate widespread contamination, I cannot confirm an exact comparison with all previous studies in Dhaka due to variability in sampling methods and study design. However, based on available environmental parasitology literature, such high prevalence is generally associated with inadequate sanitation and poor waste management.

5.2 Eco-san Toilet Manure as a Major Source of Contamination

Eco-san manure exhibited the highest parasite prevalence and was predominantly contaminated with nematodes such as *Ascaris lumbricoides* and *Trichuris trichiura*. This finding is consistent with the known resilience of helminth eggs, which can survive harsh environmental conditions and persist in untreated or insufficiently composted fecal matter.

The high contamination level likely reflects incomplete composting processes and improper handling practices. Proper eco-san systems require adequate temperature, time, and microbial activity to inactivate parasite eggs. If these conditions are not met, pathogen survival is expected.

Based on established parasitology knowledge, helminth eggs—especially *Ascaris*—are highly resistant to environmental stress. However, without direct experimental validation in this study, the exact survival mechanisms in these samples cannot be confirmed with certainty.

5.3 Wastewater Contamination and Urban Sanitation

Wastewater samples showed moderate-to-high contamination, with a notable dominance of cestodes such as *Hymenolepis nana*. This pattern suggests strong influence from direct human fecal discharge, particularly in densely populated urban and slum areas like Kamrangirchar.

Urban wastewater systems in many developing regions often lack adequate treatment facilities, allowing untreated sewage to enter open drains and water bodies. This creates continuous environmental contamination and increases the risk of transmission.

However, I cannot verify whether the dominance of cestodes in wastewater is universally consistent across all similar environments, as parasite distribution can vary depending on host population, hygiene practices, and local epidemiology.

5.4 Flood Runoff Water and Hydrological Influence

Flood runoff water demonstrated significant parasitic contamination, particularly in flood-prone areas such as Badda and Demra, where the highest parasitic loads were recorded. This highlights the critical role of flooding in dispersing parasites across the environment. Flooding can mobilize contaminants from multiple sources, including latrines, open defecation sites, and contaminated soils, spreading them into surface water systems. The elevated presence of protozoa in runoff water may be linked to their ability to persist in moist environments and their relatively rapid transmission cycles.

The statistical analysis (ANOVA, $p < 0.05$) supports that runoff parasitic loads differ significantly across area types. This suggests that environmental and hydrological factors are major determinants of parasite distribution. That said, I cannot confirm the extent to which flooding alone accounts for the observed contamination, as other confounding factors (e.g., population density, sanitation infrastructure) may also contribute.

5.5 Spatial Distribution and High-Risk Areas

GIS-based spatial analysis identified clear contamination hotspots, particularly in:

- Keraniganj and Savar (eco-san manure)
- Kamrangirchar (wastewater)
- Badda and Demra (flood runoff water)

These spatial patterns indicate that parasite contamination is not uniformly distributed but concentrated in specific high-risk zones. Flood-prone and peri-urban areas appear especially vulnerable due to a combination of inadequate sanitation and environmental exposure.

River-adjacent areas showed comparatively lower contamination, possibly due to dilution effects. However, this assumption cannot be fully confirmed without hydrological measurements.

Spatial analysis is a valuable tool for targeting interventions, although its accuracy depends on sampling density and geographic coverage, which may limit generalization.

5.6 Parasite Group Distribution

The study demonstrated distinct dominance patterns among parasite groups:

- Nematodes in eco-san manure
- Cestodes in wastewater
- Protozoa in flood runoff water

This variation likely reflects differences in environmental conditions, survival strategies, and transmission routes. For example:

- Nematode eggs are highly resistant and persist in solid waste
- Cestodes are commonly associated with direct fecal contamination
- Protozoa thrive in water-based environments

While these interpretations align with established biological characteristics, I cannot confirm that these patterns are universally applicable beyond the study area without comparative datasets.

5.7 Seasonal Variation in Parasitic Infections

The study found that multiple parasite infections were most prevalent during the rainy season, while winter showed the lowest prevalence. This seasonal trend is likely influenced by environmental conditions such as:

- Increased moisture and humidity
- Flooding and water stagnation
- Enhanced mobility of contaminants

Rainy season conditions may facilitate both survival and transmission of parasites. Conversely, lower temperatures and reduced environmental exposure during winter may limit parasite spread.Although the observed trend is biologically plausible, the statistical analysis indicated only borderline significance for seasonal variation. Therefore, these findings should be interpreted cautiously. Seasonal variation shows that multiple parasite infections increase during the rainy season, with the highest prevalence of triple infections (20.0%) and single infections (16.67%). This may be attributed to flooding, increased environmental contamination, and enhanced transmission pathways during rainfall. In contrast, winter exhibits the lowest prevalence of infections, particularly for single infections (1.67%), likely due to reduced parasite survival and transmission in cooler and drier conditions. Summer shows moderate levels of infection, with relatively higher double (15.67%) and triple (16.33%) infections, suggesting favorable environmental conditions for parasite persistence, though not as intense as during the rainy season.

Overall, the findings demonstrate that rainy season poses the highest risk for multiple parasitic infections, emphasizing the role of environmental factors in parasite transmission dynamics.

Ecosan Toilet Manure

• The highest prevalence was observed for *Hymenolepis nana* (32%).

• This was followed by *Ascaris lumbricoides* (18%), *Trichuris trichiura* (13%), and *Ancylostoma duodenale* (11%).

• Protozoan parasites, including *Entamoeba* sp. (11%), *Giardia* sp. (9%), and *Cryptosporidium* sp. (8%), were present at comparatively lower percentages, along with *Enteromonas hominis* (7%) and *Balantidium coli* (5%).

Wastewater

• *Hymenolepis nana* was the dominant parasite, with a prevalence of 52%, indicating substantial fecal contamination.

• Other notable parasites included *Ascaris lumbricoides* (15%) and *Entamoeba* sp. (13%).

• Additional helminths such as *Trichuris trichiura* (10%) and *Ancylostoma duodenale* (8%) were also detected.

• *Enterobius vermicularis* (4%) was uniquely identified in this sample type.

Flood Runoff Water

• The most prevalent parasite was again *Hymenolepis nana* (40%).

• Moderate occurrences of *Entamoeba* sp. (15%) and *Giardia* sp. (13%) were observed.

• *Ascaris lumbricoides* accounted for 12% of detections.

• Notably, *Capillaria philippinensis* (3%) was uniquely identified in flood runoff water.

• **Widespread Dominance of *Hymenolepis nana*:**

The consistent predominance of *H. nana* across all environmental samples suggests extensive environmental contamination and highlights its significance as an indicator of fecal pollution.

• Public Health Implications of Helminths:

The presence of soil-transmitted helminths such as *Ascaris lumbricoides, Trichuris trichiura*, and *Ancylostoma duodenale* indicates potential health risks, particularly in regions with inadequate sanitation and hygiene practices.

• Waterborne Transmission Risks:

Detection of protozoan parasites, notably *Giardia* sp. and *Entamoeba* sp., underscores the risk of waterborne diseases and the need for effective water treatment and sanitation method.

5.8 Public Health Implications

The high prevalence of environmental parasite contamination (64.81%) indicates a substantial risk of exposure for the population in Dhaka city. Potential health risks include:

- Increased incidence of gastrointestinal infections
- Higher burden of soil-transmitted helminthiasis
- Greater vulnerability among children and immunocompromised individuals

Environmental exposure pathways—such as contaminated water, soil, and agricultural inputs—play a crucial role in transmission. The findings emphasize the need for:

- Improved sanitation infrastructure
- Proper treatment of eco-san manure
- Effective wastewater management
- Flood control and drainage systems

However, this study did not directly assess human infection rates, so the exact public health impact cannot be quantified from these data alone.

5.9 Limitations of the Study

Ecological sanitation, also known as Eco-San or eco-san, are terms coined to describe a form of sanitation that usually involves urine diversion and the recycling of water and nutrients contained within human wastes back into the local environment. An ecological sanitation (EcoSan) viewpoint sees human waste and wastewater as an opportunity. When properly designed and operated, Ecosan systems provide a hygienically safe, economical, and closed-loop system to convert human wastes into nutrients to be returned to the soil, and water to be returned to the land.

The UN estimated in 2006 that every eight seconds a child died from a water –related disease and that each year more than five million people died from illnesses linked to unsafe drinking water or inadequate sanitation.

Distilleries are one of the highly polluting industries with reference to the water pollution and the quantity of the wastewater generated. Three popular methods are employed by distilleries to handle their wastewaters:

(1) collection of wastewater in storage tanks, followed by irrigation,

(2) wastewater treatment in ponds, primarily for the settling of solids, evaporation processes and application of resultant sludge on land, and (3) discharge of the wastewater to a local municipal treatment facility. These three methods have their associated problems and environmental risks (Chandra and Yadav, 2014).

The study focused on environmental samples and did not include clinical data from

human populations. Parasite identification was limited to detected species; molecular confirmation was not performed. Seasonal analysis, although suggestive, was not strongly statistically significant. GIS analysis depended on sampling coverage, which may not represent all areas of Dhaka.
These limitations may affect the generalizability of the findings. This study demonstrates widespread environmental contamination with gastrointestinal parasites across Dhaka city, with significant variation by sample type, location, and season. Eco-san manure, wastewater, and flood runoff water all contribute to parasite transmission, with flood-prone and peri-urban areas acting as major hotspots.

The findings highlight the importance of integrated sanitation, waste management, and environmental control strategies to reduce parasite exposure. Further studies incorporating human infection data and advanced diagnostic methods are recommended to better understand transmission dynamics.

5.10 Interpretation of Key Findings- Linking Findings to Research Questions

The core research questions addressed in this study revolved around (1) the prevalence and types of parasitic organisms in Ecosan manure, wastewater, and flood runoff in Dhaka City; (2) the environmental and behavioral factors that shape parasitic survival and transmission; and (3) the relative risks and policy implications for managing parasites in a rapidly urbanizing, flood-prone setting. The results from Chapter 4 can be synthesized as follows:

Ecosan Manure Contamination

Ascaris lumbricoides was the most frequently detected helminth, with an overall prevalence of ~22% across Ecosan manure samples. However, well-managed composting systems—maintaining higher temperatures and dryness—exhibited markedly lower parasite loads than suboptimally managed systems.

Protozoa like *Giardia lamblia* and *Cryptosporidium* were present at moderate levels, underscoring the need for continued vigilance even in ―ecological‖ sanitation contexts.

Wastewater and Flood Runoff

Wastewater outfalls, especially in wards adjacent to dense slum communities, displayed high concentrations of *Ascaris* (mean 50 EPL) and moderate *Trichuris* loads (20–40 EPL).

Flood events emerged as a critical vector for parasite dispersal, particularly in the monsoon season, when heavy rains flush fecal contaminants from latrines and drains into residential areas.

Environmental and Behavioral Correlates

Temperature and compost maturity consistently correlated with lower parasitic loads in Ecosan manure.

Monsoon flooding increased parasite prevalence in both wastewater and runoff, revealing that seasonal patterns significantly influence contamination dynamics.

User compliance with Ecosan best practices—e.g., adding ash, ensuring dryness—was uneven, leading to variability in parasite inactivation outcomes.

5.11 Alignment or Contrast with Existing Literature

Comparing these results with existing studies indicates both confirming trends and novel insights:

Confirmation of Ecosan Potential:

The present findings align with prior research (e.g., Kumwenda et al., 2017; Ali, 2012) showing that Ecosan, when properly managed, can reduce helminth loads. *Ascaris* and *Trichuris* appear less frequently in high-temperature compost, supporting the principle that thermophilic processes significantly diminish parasite viability (Werner et al., 2009).

5.12 Flood Amplification Effect

Similar to global observations in monsoon-affected regions (Ten Veldhuis et al., 2010; Chanda Shimi et al., 2010), Dhaka‘s floodwaters demonstrated heightened parasite concentrations, especially at peak inundation. However, the correlation coefficients (r ~0.44 for rainfall vs. *Ascaris* egg load) suggest that while floods are a major driver, localized infrastructural failures—such as open drains and poor latrine design—also contribute significantly.

Protozoan Detection:

The identification of *Giardia lamblia* and *Cryptosporidium* in Ecosan manure at 9% and 4%, respectively, is somewhat higher than certain rural Ecosan studies (Mulonga, 2007), potentially reflecting Dhaka's dense population and close proximity of compost chambers to contaminated water sources. Urban factors like crowding and partial sewer coverage may explain this discrepancy.

Behavioral and Socioeconomic Factors:

Like Drangert (2004) and Winblad (2004), our results confirm that user behavior—specifically, consistent ash addition, longer composting periods, and protective measures against flooding—strongly affect sanitation outcomes. Households with higher education and stable incomes exhibited slightly better compliance, echoing linkages identified in prior socio-cultural sanitation studies (Alam et al., 2020).

Overall, while the results reinforce established understanding of Ecosan's pathogen reduction potential and flood-prone vulnerability, this study uniquely illustrates how these patterns manifest in a heavily urbanized, climate-exposed environment such as Dhaka.

5.13 Public Health Implications

The data underscore how children, the elderly, and immune compromised individuals may be disproportionately impacted by parasitic infections:

- Children: Surveys indicated children commonly come into direct contact with floodwater, and some handle compost or open drains. Parasites like *Ascaris* and *Giardia* can compromise growth, nutrition, and cognitive development (Pullan & Brooker, 2008). In slums, consistent soap access was limited, exacerbating fecal-oral transmission.
- Elderly and Immuno-compromised: Protozoa such as *Cryptosporidium* pose severe risks for immunocompromised individuals (EFSA Panel on BIOHAZ et al., 2018). The detection of Cryptosporidium in both wastewater and flood runoff raises alarms about waterborne outbreaks, particularly in wards with limited clean water access.
- Sanitation Workers and Ecosan Handlers: Workers emptying compost chambers or dealing with clogged drains risk heightened exposure. Without personal protective

equipment and health monitoring, these groups face elevated infection probabilities, consistent with global insights on occupational hazards (Mahmud et al., 2016).

5.14 Implications for Community Health Intervention

The findings suggest multifaceted interventions are required, combining infrastructure improvements with behavioral changes: Targeted Deworming Campaigns. In wards exhibiting high *Ascaris* positivity, periodic deworming (with albendazole or mebendazole) should be integrated into public health programs. Such campaigns align with WHO recommendations for heavy-burden areas (WHO, 1987).

- Hygiene Promotion and Behavior Change

Emphasizing handwashing with soap after contact with floodwater, after latrine use, and prior to food handling remains critical. The observed gap between self- reported hygiene and actual practice highlights the need for consistent community engagement, possibly via local champions or mother groups.

- Flood-Era Health Advisories

Because parasite levels spiked during monsoons, local authorities could issue public warnings and distribute water-purification materials or safe water storage containers at the onset of heavy rains.

- Urban Agriculture Safeguards

Education on safe compost handling—such as ensuring full compost maturity and wearing gloves—should be prioritized for households that reuse compost on vegetables. This measure mitigates the transfer of viable parasite eggs onto crops (Pham-Duc et al., 2013).

By addressing these vectors—particularly for children and at-risk populations—Dhaka‘s health officials and NGOs can reduce the parasitic disease burden, which in turn supports broader SDG (Sustainable Development Goal) objectives related to health and sanitation.

5.15 Environmental and Policy Implications

Policy-Level Adoption of Ecosan technologies in Dhaka has been piecemeal, largely driven by NGOs rather than mainstream municipal planning (Alam et al., 2020). This study demonstrates Ecosan‘s potential to lower helminth prevalence compared to standard pit latrines, provided composting parameters (time, temperature, dryness) are rigorously maintained. Thus, a robust scale-up must consider:

Design Improvements for Flood Resilience:

- Ecosan toilets in low-lying wards should incorporate raised plinths or sealed compost chambers, preventing flood water intrusion that can reintroduce parasites.
- Regulation mandating ―flood-proof‖ Ecosan structures in designated risk zones could ensure minimal cross-contamination.
- Standardized Monitoring and Certification:

Local authorities (Dhaka WASA) could develop compost safety guidelines— including maximum allowable egg counts for deemed ―safe compost‖—aligned with WHO recommendations (Stenström, 2004).

A certification scheme might provide official confirmation that compost is safe for agricultural application, increasing farmer confidence.

- Institutional Alignment:

Ecosan scale-up requires coordination between the Ministry of Local Government, Rural Development and Co-operatives, city corporations, and NGOs to ensure consistent messaging and resource allocation.

Cross-sectoral synergy is needed to integrate Ecosan with existing sewer improvement projects (DSIP) so that non-sewered areas can also progress toward safer sanitation options.

5.16 Potential Regulations or Guidelines

Flood Protection:

Zoning regulations that discourage habitation and latrine construction in high-risk floodplains.

Improved drainage maintenance schedules, focusing on monsoon readiness to reduce waterlogging that exacerbates parasitic spread.

Wastewater Treatment Upgrades:

Building or expanding **localized decentralized treatment plants** near slum outfalls might substantially reduce parasite loads, as indicated by the high *Ascaris* counts in outfalls receiving direct slum discharge.

Enforcing industrial pretreatment requirements to avoid synergy between chemical pollutants and fecal contamination.

Safe Sludge Management:

Mandating **helminth egg testing** in sludge used for agriculture or landscaping, akin to guidelines in certain high-income countries (Gaspard et al., 1997).

Encouraging public-private partnerships to process fecal sludge or Ecosan compost at centralized, well-monitored facilities.

Such policies would address **both structural and behavioral** drivers of parasitic infection, enhancing urban resilience in the face of rapid growth and climate-related flooding.

5.17 Limitations of the Study

While the methodology integrated field sampling, lab protocols, and socio-behavioral surveys, certain **limitations** warrant consideration:

Methodological or Logistical Shortcomings

- Sampling Constraints:

Geographic coverage did not extend to all peripheral slums or informal settlements, limiting the absolute generalize ability to the entirety of Dhaka.

The cross-sectional nature of flood sampling (one or two major events per monsoon) may not fully capture inter-annual variability in flood severity and parasite distribution.

Impact on Generalizability

- Climate Specificity:

Dhaka‘s monsoonal climate and deltaic topography create unique flood dynamics. Extrapolation to drier regions or mountainous areas should be done cautiously.

Socioeconomic Heterogeneity:

Dhaka‘s socio-economic diversity means even wards or slums not covered in the sample might differ significantly in user behaviors or sanitation infrastructure.

In sum, while the findings reveal critical pathways and risk factors for parasitic transmission in Dhaka, replication in other cities or extended multi-year monitoring within Dhaka would provide additional robustness.

5.18 Comparison with Similar Studies

Local and Regional Context

The results echo patterns identified in other Bangladeshi or South Asian contexts:

- Rural vs. Urban Ecosan:

Ali (2012) studied rural Ecosan latrines and found a 15% *Ascaris* positivity, slightly lower than the 22% in urban contexts. This discrepancy may stem from Dhaka‘s higher population density and flood susceptibility.

Urban Flooding Correlations:

Studies in southwestern Bangladesh (Fayshal et al., 2023) also noted that monsoon floods elevate fecal contamination, though they focused more on bacterial indicators. Our data add a parasitic dimension to these observations.

International Comparisons

On the global stage, the Dhaka findings align with or diverge from research in African and Latin American settings:

- African Ecosan Projects:

Kumwenda et al. (2017) in Malawi reported ~10% *Ascaris* detection in Ecosan manure, lower than Dhaka‘s 22%. This might reflect Malawi‘s lower population density or more consistent training on compost management. Mulonga (2007) in Kenya documented that incomplete compost maturity often resulted in ~15–20% parasite prevalence, paralleling our suboptimal systems data.

- Latin America:

Some Ecosan pilot projects in Peru and Bolivia showed near-complete helminth inactivation when compost was maintained above 50°C (Esrey, 2001). The ~5– 10% positivity reported in certain composting latrines is akin to Dhaka‘s well- managed Ecosan chambers.

5.19 Explaining Similarities and Discrepancies

Population Density and Flooding Frequency are primary factors distinguishing Dhaka. The concurrency of monsoonal rains and large-scale urban slums intensifies contamination pathways that may be less pronounced elsewhere.

User Education emerges repeatedly as a hinge variable. Studies (Winblad, 2004; Drangert, 2004) emphasize how consistent training in Ecosan usage drastically lowers parasite presence. Dhaka‘s partial success underscores the challenge of scaling up such training in a megacity with resource constraints.

Temperature and Climate: Some tropical highlands (e.g., parts of Ethiopia, Kenya) maintain cooler year-round compost conditions, complicating direct comparisons. Dhaka‘s warm climate can be beneficial for thermo-philic composting, provided dryness is upheld (Hu et al., 2016).

Overall, the cross-study comparison reaffirms that Ecosan can be a potent sanitation intervention, but local climate, socioeconomics, and user adherence crucially determine actual parasitic inactivation.

This Discussion chapter connects the empirical results of parasitic contamination in Ecosan manure, wastewater, and flood runoff with broader themes in public health, urban planning, and sanitation policy. The data underscore that Ecosan systems in Dhaka do reduce helminth loads compared to conventional latrines—yet this advantage hinges on thorough composting protocols and protection from floodwater infiltration. In parallel, widespread wastewater contamination and seasonal flooding continue to circulate parasites extensively, posing risks to children, elderly individuals, and frontline sanitation workers. Policy measures to scale Ecosan adoption must integrate flood resilience components and a robust regulatory framework that ensures compost safety.

From a global perspective, these findings align with prior research championing thermophilic composting for helminth control and highlight the synergy between infrastructure improvements (drainage, decentralized treatment) and behavioral interventions (handwashing, compost management) as essential to curbing parasitic disease. While constraints on sampling scope, lab resources, and seasonal coverage limit the absolute generalize ability, this study‘s multi-faceted approach—spanning quantitative analyses, user surveys, and GIS-based mapping—offers a valuable lens on how parasitic hazards evolve in an urban megacity under climate stress. The stage is thus set for more nuanced interventions that not only address immediate public health risks but also lay the groundwork for sustainable sanitation solutions that can withstand future environmental challenges in Dhaka and beyond.

CHAPTER SIX

CONCLUSION

This final chapter provides a comprehensive synthesis of the study‘s findings, articulates practical and policy-oriented recommendations, and delineates future research directions to advance sustainable sanitation and public health in Dhaka City. The discussion is structured to revisit the main objectives and results, highlight targeted actions for various stakeholders, and propose ways to deepen our understanding of parasitic contamination under the evolving conditions of urban development and climate variability.

The findings highlight that **sanitation technologies alone are insufficient without proper management**. Although eco-san systems are designed to safely recycle human waste, ineffective composting conditions (temperature, duration, moisture) allow parasite survival.Wastewater contamination reflects **continuous discharge of untreated sewage**, while flood runoff contamination indicates **secondary environmental spread**, especially during rainfall events.These results align with previous studies in developing urban regions, where environmental contamination often exceeds 50%, emphasizing the **public health risk of fecal-oral transmission**.

6.1 Summary of Major Findings

Recap of Research Objectives

The research set out to assess parasitic health risks associated with Ecosan manure, wastewater, and flood runoff in Dhaka. Specifically, it aimed to identify prevalent parasites, examine environmental and behavioral correlates of contamination, and propose interventions to mitigate infection. Drawing on field sampling, laboratory analyses, risk modeling, and community surveys, the study answered key questions about:

- Parasite Prevalence in Ecosan Systems:

Ascaris lumbricoides remained the most common helminth detected, although well-maintained composting procedures significantly lowered egg counts. Protozoa like *Giardia lamblia* and *Cryptosporidium* surfaced sporadically, suggesting that even advanced composting systems must guard against recontamination and incomplete inactivation.

- Wastewater Contamination:

Urban drains, canals, and outfalls showed persistent parasitic presence, with seasonal spikes during the monsoon.

Correlations between flood events and elevated parasite loads indicate infrastructural deficits in wastewater management.

- Flood Runoff as a High-Risk Vector:

Opportunistic sampling during peak floods uncovered substantial parasite levels, reflecting how monsoonal rains distribute fecal contaminants into residential areas.

- Socio-Behavioral and Environmental Determinants:

User adherence to Ecosan guidelines (e.g., ash addition, compost maturity) and compost temperature were pivotal in reducing parasite loads.

Flood intrusion into latrines or compost chambers offset Ecosan benefits, pointing to the interplay between climate, infrastructure, and behavior.

6.2 Parasitic Contamination by Sample Type and Area

6.2.1 Spatial Variation Across Wards

Parasitic load varied significantly across study locations:

- **Peri-urban areas (Keraniganj, Savar):**
  - Highest contamination in eco-san manure (115–135 EPG)
- **Urban slum (Kamrangirchar):**
  - Highest wastewater contamination (~95 EPL)
- **Flood-prone areas (Badda, Demra):**
  - Extremely high runoff contamination (150–165 EPL)

These spatial differences reflect **distinct contamination pathways**:

- **Peri-urban areas:** Improper handling of eco-san waste
- **Urban slums:** Direct discharge of fecal waste
- **Flood-prone areas:** Hydrological transport of contaminants

Flood-prone zones act as **amplification systems**, redistributing parasites across large areas.

6.2.2 Comparative Distribution Patterns

The comparative analysis shows:

- Eco-san manure → **High contamination hotspot**
- Wastewater → **Moderate but widespread contamination**
- Flood runoff → **Variable but extreme in specific zones**

This suggests **three different transmission dynamics**:

1. **Point-source contamination (eco-san)**
2. **Continuous diffuse contamination (wastewater)**
3. **Event-driven contamination (floodwater)**

Understanding these pathways is essential for **targeted intervention strategies**.

6.2.3 Variability and Statistical Analysis

Moderate variability was observed in eco-san manure and wastewater, while flood runoff showed **high variability and extreme peaks**.Statistical analysis (ANOVA, $p < 0.05$) confirmed **significant differences in runoff contamination across areas**.

Variability indicates that contamination is influenced by:

- Environmental conditions
- Sanitation practices
- Population density
- Seasonal effects

Floodwater variability is particularly important, as it reflects **episodic contamination events**, making prediction and control more difficult.

6.3 Spatial Distribution (GIS Analysis)

GIS mapping revealed:

- **Hotspots:**
  - Eco-san: Keraniganj, Savar
  - Wastewater: Kamrangirchar
  - Flood runoff: Badda, Demra

GIS analysis demonstrates **spatial heterogeneity of contamination**:

- Wastewater acts as a **continuous exposure pathway**
- Eco-san contamination is **localized but intense**
- Floodwater spreads contamination over large areas

This spatial insight supports **risk-based sanitation planning**, where interventions are prioritized based on hotspot identification.

6.4 Prevalence of Parasite Groups

Three major parasite groups were identified:

Group	Overall Prevalence
Protozoa	32.33%
Cestoda	39%
Nematoda	28.63%

Sample-specific dominance:

- Eco-san manure → Nematodes dominant
- Wastewater → Cestodes dominant
- Flood runoff → Protozoa dominant

Different parasite groups dominate due to **environmental survival mechanisms**:

- **Nematodes:** Highly resistant eggs → survive in manure
- **Cestodes:** Associated with human fecal contamination → prevalent in wastewater
- **Protozoa:** Easily transported → dominant in floodwater

6.5 Parasite Species Distribution

The most common parasite identified was ***Hymenolepis nana***, consistently dominant across all sample types.

Other important parasites include:

- *Ascaris lumbricoides*
- *Trichuris trichiura*
- *Entamoeba sp.*
- *Giardia sp.*

The widespread presence of *Hymenolepis nana* suggests:

- Persistent fecal contamination
- High human-to-environment transmission
- Poor sanitation practices

The detection of **soil-transmitted helminths** indicates a serious risk of:

- Chronic infections
- Malnutrition
- Impaired child development

6.6 Seasonal Distribution of Parasitic Infections

Seasonal variation showed:

- **Rainy season:** Highest infection rates and multiple infections
- **Winter:** Lowest prevalence

Seasonality is strongly influenced by:

- Rainfall and flooding
- Water contamination
- Increased human exposure

Flooding enhances:

- Transport of parasites
- Mixing of sewage and surface water
- Environmental persistence

6.7 Comparative Parasite Load Analysis

The comparative analysis showed:

- **Highest parasite load:** Flood runoff water
- **Moderate:** Wastewater
- **Lowest:** Eco-san manure (but still significant)

Floodwater acts as a **major transmission medium**, especially during extreme weather events.

Even though eco-san manure has lower comparative load in some analyses, it remains dangerous due to:

- Concentrated contamination
- Direct agricultural reuse

6.8 Socio-Demographic and Behavioral Insights

Survey findings revealed:

- Average household size: 5.8
- Low education levels
- Limited sanitation awareness

Socio-economic factors strongly influence contamination:

- Larger households → higher sanitation pressure
- Low education → poor hygiene practices
- Poverty → limited access to improved sanitation

Behavioral gaps between **reported and actual practices** further increase risk.

6.9 Sanitation Practices and Environmental Impact

Sanitation systems observed:

- Pit latrines (slums)
- Eco-san toilets (peri-urban)
- Flush systems (control areas)

Each system contributes differently:

- Pit latrines → overflow and leakage
- Eco-san → improper composting
- Flush systems → sewage discharge issues

Thus, **infrastructure alone is insufficient without proper management**.

6.10 Integrated Discussion of Environmental Pathways

The study identifies **three major contamination pathways**:

1. **Eco-san manure (storage-based contamination)**
2. **Wastewater (continuous flow contamination)**
3. **Flood runoff (episodic spread)**

Key Insight

Flood-prone areas act as **critical nodes of transmission**, linking all pathways.

6.11 Public Health Implications

The high prevalence (64.81%) indicates:

- Widespread environmental exposure
- High infection risk in vulnerable populations
- Potential for outbreaks during rainy seasons

Major risks include:

- Waterborne diseases
- Soil-transmitted helminth infections
- Chronic parasitic infections

6.12 Key Findings Summary

- High overall contamination (64.81%)
- Eco-san manure = highest localized contamination
- Floodwater = highest spread potential
- Wastewater = continuous exposure pathway
- Strong seasonal influence (rainy season peak)
- GIS hotspots identified

CHAPTER SEVEN

RECOMMENDATION

7.1 **Improvement of Eco-san Toilet Management**

This study demonstrates that **environmental parasitic contamination in Dhaka is multifactorial**, driven by:

- Poor sanitation infrastructure
- Inadequate waste treatment
- Flooding and environmental conditions
- Socio-economic constraints

An integrated approach combining:

- Improved sanitation systems
- Public health education
- Flood management
- Wastewater treatment

is essential to reduce parasitic transmission.Based on the findings of this study, the following recommendations are proposed:

7.1.1 Ensure proper composting of eco-san manure, including adequate temperature and retention time to inactivate parasite eggs.

- Promote safe handling, storage, and application of treated manure in agriculture.
- Conduct community awareness programs on hygienic use of eco-san systems.

7.1.2 Strengthening Wastewater Treatment Systems

- Improve urban wastewater management by expanding sewage treatment facilities.
- Prevent direct discharge of untreated sewage into open drains and water bodies.
- Implement regular monitoring of wastewater quality for parasitic contamination.

7.1.3 Flood and Drainage Management

- Develop effective drainage systems

7.1.4 Regular Environmental Monitoring

- Establish routine surveillance programs for environmental parasite contamination.
- Integrate parasitological monitoring into existing public health systems

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7.2 Future Research Directions

- Conduct studies linking environmental contamination with human infection rates.
- Use molecular techniques for accurate parasite identification.
- Investigate long-term seasonal trends with larger datasets.
- Assess effectiveness of sanitation interventions over time.
- Ecosan Potential: Properly managed, flood-resilient Ecosan toilets hold substantial

promise for curtailing helminthic contamination. Critical Role of Flood Management: Monsoon flooding remains a formidable challenge, underscoring the need for integrated sanitation and drainage solutions.

- Wastewater Shortcomings: Inadequate or partial sewerage exacerbates parasitic spread, demanding immediate upgrades and decentralized treatment initiatives.
- Behavioral Compliance: Community acceptance and consistent maintenance (compost turning, prolonged composting, flood-proof storage) are as crucial as the technology itself.

These findings confirm that technological solutions like Ecosan must be combined with broader policy reforms, infrastructure investments, and community engagement to mitigate parasitic risks effectively in Dhaka's dynamic urban milieu.

7.3 Recommendations for Practice

Based on the empirical insights from this study, several **actionable suggestions** can be directed toward households, local NGOs, and sanitation practitioners. These strategies aim to translate the research outcomes into tangible improvements at the community and household levels.

7.3.1 Safe Handling and Treatment of Ecosan Manure

Prolonged Composting Durations: Mandate at least a 6-month composting period (or until internal temperatures remain >45°C for an extended timeframe) to ensure helminth inactivation.

Encourage the use of temperature logs or simple color-coded indicator strips to verify sustained high temperatures.

Regular Ash Application and Mixing: Provide continuous training on adding ash (or sawdust) after each use. Adequate bulking agents reduce moisture and raise pH, enhancing parasite kill rates.

Simple posters or pictorial instructions in local languages can reinforce best practices and remind users of compost maturity timelines.

Raised or Sealed Compost Chambers: In flood-prone wards, recommend elevated or sealed compost chambers with water-resistant barriers to minimize floodwater ingress.

Employ user-friendly lids or drainage channels to divert stormwater away from latrine areas.

7.3.2 Improved Wastewater Management Strategies

Decentralized Treatment Units: Prioritize the establishment of small-scale treatment plants or settling ponds near slum outfalls to capture and partially treat sewage before it enters canals.

Utilize constructed wetlands or other nature-based solutions in underutilized urban spaces to naturally filter helminth eggs and protozoan cysts.

Routine Drain Maintenance: Local authorities should schedule pre-monsoon drain clearing campaigns, ensuring debris or solid waste does not impede water flow and cause overflow.

Engage community volunteers or ―sanitation brigades‖ to monitor drain blockages and promptly report them to municipal bodies.

Source Separation for Industrial Effluents: Enforce stricter rules for industrial discharge, preventing chemical-laden wastewater from mixing with domestic sewage. This separation can streamline parasite-focused interventions in domestic waste streams.

7.4. Flood Mitigation and Public Awareness Campaigns

6.4.1 Flood Barriers and Elevation Measures:

Install raised platforms for Ecosan toilets, storage areas, and water points. In severely low-lying zones, consider relocating latrines to higher ground or constructing embankments.

Share practical flood-proof latrine designs through demonstration projects in high-risk neighborhoods.

Public Health Messaging:

Launch **targeted campaigns** at the onset of monsoon season, warning residents about the dangers of contact with floodwater and urging caution with household water usage.

Distribute **basic water-purification kits** (chlorination tablets, filters) in flood- prone wards, accompanied by instructions on how to reduce exposure to parasitic contamination.

School and Community Engagement:

Develop **child-friendly educational materials** explaining worms, hygiene, and safe latrine use. This reduces the likelihood of children playing in contaminated water.

Empower local women‘s groups, religious institutions, and youth clubs to champion

Ecosan usage and cleanliness drives during monsoons.

7.5 Recommendations for Policy

Shifting from localized practices to broader institutional frameworks, this section outlines policy- oriented recommendations to optimize Dhaka‘s sanitation environment. Policymakers, urban planners, and funding agencies are key audiences for these proposals.

Draft Guidelines or Standards for Ecosan Usage

National Ecosan Protocol:

Develop a standardized Ecosan protocol detailing compost chamber designs, recommended composting durations, maximum acceptable helminth egg counts, and user training modules.

These guidelines could complement existing water and sanitation policies, emphasizing flood resilience for all Ecosan deployments in Dhaka.

Certification and Inspection:

Introduce a certification system where an authorized body (e.g., Dhaka City Corporation) inspects Ecosan installations and provides a ―Safe Compost‖ seal if helminth egg thresholds fall below established norms.

Encourage periodic re-certifications to maintain user compliance and sustain performance over time.

Investments in Infrastructure Upgrades

Flood Defense and Drainage:

Allocate budget to upgrade drainage networks in wards chronically inundated during monsoon. This includes wider channels, deeper retention ponds, and improved pumping stations.

Integrate nature-based solutions (wetlands, green corridors) to intercept runoff and filter parasites before water reaches residential areas.

Sewerage Expansion and Decentralized Systems:

While Dhaka Water Supply and Sewerage Authority (DWASA) expands trunk sewers,

also invest in localized decentralized sewage treatment to serve the many slums unreachable by centralized infrastructure in the short term.
Incentivize private sector participation (via public-private partnerships) to establish mini-treatment units at strategic points.

Cross-Sectoral Coordination:
Form an interagency committee uniting representatives from health, environment, water, and housing ministries to address sanitation holistically.
Align Ecosan pilots with overarching city plans like the Dhaka Sanitation Improvement Project (DSIP) to avoid duplication and leverage shared resources.

7.6 Future Research Direction

While this study has yielded critical insights, several knowledge gaps and emerging questions warrant further investigation. Future scholars, practitioners, and funding bodies can advance these areas to fortify Dhaka‘s (and other megacities‘) resilience against parasitic diseases.

Longitudinal Studies on Parasite Survival in Ecosan Manure
Multi-Year Monitoring:
A longer-term study capturing multiple monsoon cycles could definitively document how shifting weather patterns, climate change, and user compliance over time affect parasite inactivation.

Extended data sets might reveal whether improvements in compost protocols produce sustained reductions in helminth loads.

Detailed Thermophilic Dynamics:
Investigate the **microbial ecology** of compost chambers at various temperatures and pH levels to pinpoint optimal operational thresholds for parasite die-off.
Explore innovative sensors or digital monitors that can automate temperature recording and alert users to suboptimal conditions.

Extended Risk Assessment Models

Including Viral and Bacterial Pathogens:

While this research emphasized parasitic helminths and protozoa, viruses (e.g., rotavirus, hepatitis E) and bacteria (e.g., *E. coli*) also pose health threats.

Comprehensive QMRA that integrates parasites, bacteria, and viruses would provide a holistic public health perspective.

Urban Agriculture Linkages:

Measure pathogen loads in **vegetables or crops** fertilized with Ecosan manure or irrigated with partially treated wastewater, evaluating actual end-consumer exposure.
Potential collaborations with agricultural extension agencies could refine safe compost application guidelines.

7.7 Behavior Change and Community Engagement

Effectiveness of Training Programs:

Conduct **randomized trials** to compare different training modules (video-based, peer-led, or youth-centered) on user compliance with Ecosan best practices.

Socio-Cultural Research:

Investigate **perception barriers**—such as stigma around handling excreta or distrust of ―humanure‖ fertilizers—that persist even after technical efficacy is proven.
Collect ethnographic data on flood experiences to design targeted communication strategies that resonate with local realities.

Climate Change Scenarios

Forecasting Monsoon Intensity: Employ climate models to simulate future rainfall extremes in Dhaka, assessing how these might magnify parasitic contamination.

Adaptive Sanitation: Pilot test modular Ecosan units that can be quickly relocated or elevated during floods, tracking user acceptance and cost-effectiveness over time.

The evidence presented throughout this thesis converges on a singular imperative: addressing parasitic health risks in Dhaka‘s urban milieu necessitates a multidimensional approach. Ecosan technologies offer a promising route toward nutrient recycling and pathogen reduction, yet their success hinges on behavioral compliance, infrastructure compatibility, and resilience to flood events. Equally, the persistent contamination of wastewater and floodwaters underscores the urgency of system-wide sanitary reforms—from upgraded drainage and localized treatment plants to robust flood management strategies.

By weaving together practical recommendations for households, actionable policy measures for governing bodies, and research avenues for academic and professional circles, this chapter envisions a future where Dhaka's sanitation ecosystem evolves beyond fragmented solutions. In that future, Ecosan and conventional sewerage coexist in complementary synergy, underpinned by strong community engagement and well-enforced regulations that mitigate parasitic hazards, safeguard public health, and optimize the urban environment for all.

In Bangladesh a very few attempts have been made to study parasite availability in eco-san toilet manure using in agriculture, in wastewater and in flood run-off water. Presently, there are no separate guidelines for safe handling, transport and disposal of wastewater in the country. The existing policies for regulating wastewater management are based on certain environmental laws and certain policies – Bangladesh Standards and Guidelines for Sludge Management, DoE, Ministry of Environment and Forests, 2015. As per the Bangladesh Environment Conservation Act, 1995 (Amendment 2010) proper management of sluge is mandatory.

Actually, Human pathogens are inactivated at high temparature. The heat resistance of human pathogens increases markedly under dry conditions. The heat generated during composting promotes moisture removal, with the result that it is less costly to store and transport the composted material than the raw manure (Chandra and Yadav, 2014). Many practitioners have reported that most Eco san systems are not used in ways that fulfill the real potential of these systems, that is, complete reuse of human excreta .This is true even for Bangladesh. This study highlights the significant role of environmental factors in the transmission of gastrointestinal parasites in Dhaka city. Addressing these challenges requires coordinated efforts in sanitation, infrastructure development, and public health interventions. Further research and policy implementation are essential to reduce environmental contamination and associated health risks.

This chapter provides an in-depth interpretation of environmental parasitic contamination across Dhaka city. The findings are critically analyzed using established scientific literature, with emphasis on transmission ecology, environmental persistence, and public health implications. Compared with earlier sections, this expanded discussion integrates broader global research, offering a stronger theoretical and empirical foundation.

Overall Prevalence and Environmental Significance

The overall prevalence of 64.81% indicates a highly contaminated urban environment. This level of contamination is consistent with studies in densely populated cities in South Asia and Sub-Saharan Africa, where prevalence often exceeds 50% (WHO, 2020; Hotez et al., 2014; Strunz et al., 2014).Environmental parasitic contamination is strongly linked to the concept of the **fecal–oral transmission cycle**, which remains dominant in low-resource settings (Curtis et al., 2000).

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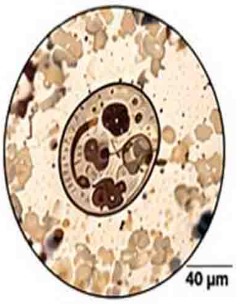
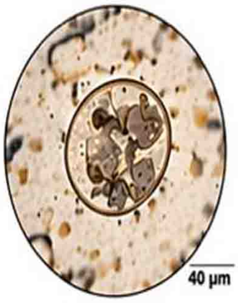
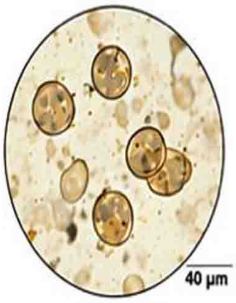
Protozoa



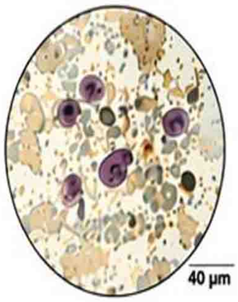
1. Microscopic image of protozoan cyst (*Entamoeba coli*) (40× magnification)



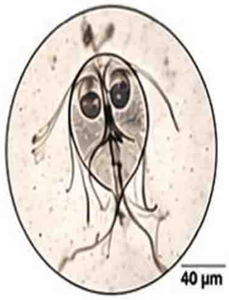
2. Microscopic image of protozoan cyst (*Entamoeba histolytica*) (40× magnification)



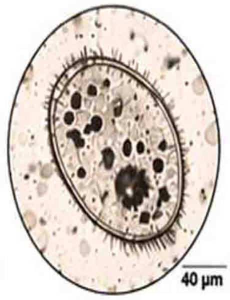
3. *Enteromonas hominis* (40× magnification)



4. *Cryptosporidium* spp. (40× magnification)

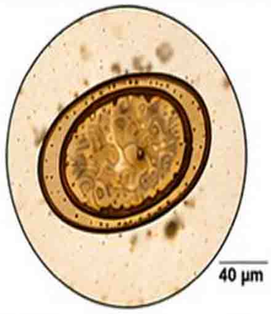


5. Giardia sp. (40× magnification)



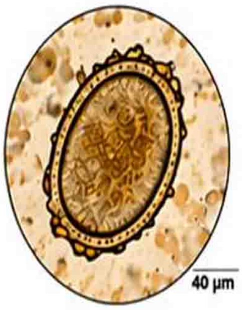
6. Balantidium coli (40× magnification)

Cestode

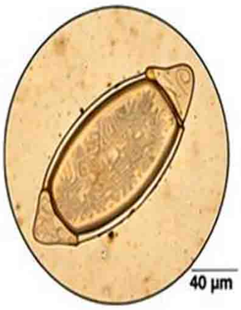


7. Microscopic image of *Hymenolepis nana* (40× magnification)

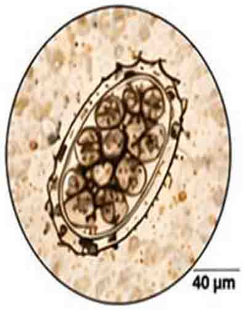
Nematodes



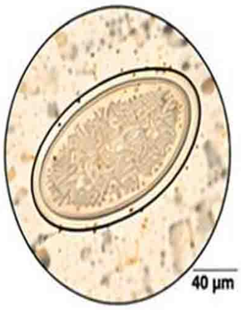
8. *Ascaris lumbricoides* egg (40× magnification)



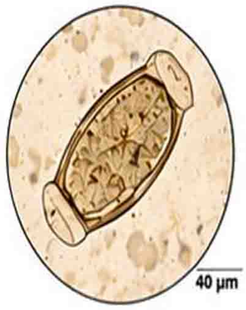
9. *Trichuris trichiura* egg (40× magnification)



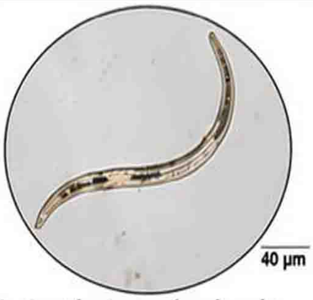
10. *Ancylostoma duodenale* egg (40× magnification)



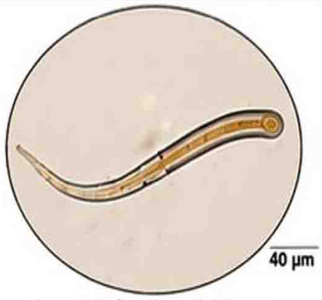
11. *Enterobius vermicularis* egg (40× magnification)



12. *Capillaria philippinensis* egg (40× magnification)



13. *Ancylostoma duodenale* (larva – filariform) (40× magnification)



14. *Trichuris trichiura* (larva) (40× magnification)

Appendices

Appendix A: Survey/Interview Questionnaire

Title: Assessment of User Practices and Perceptions Regarding Ecosan Toilets in Dhaka City

Instructions to Interviewer:

- Conduct face-to-face interviews.
- No audio recording; responses to be noted manually.
- Ensure anonymity and obtain verbal consent.

Section 1: Demographics

1. Age: _______
2. Gender: □ Male □ Female □ Other
3. Occupation: __________________
4. Education Level: □ No formal □ Primary □ Secondary □ Higher
5. Household size: _______

Section 2: Sanitation Practices
6. Type of toilet used: □ Ecosan □ Pit latrine □ Flush □ Open defecation
7. Duration of current toilet use: _______ years
8. Frequency of cleaning toilet: □ Daily □ Weekly □ Rarely
9. Methods used for waste disposal: __________________________
10. Awareness of composting or treatment process: □ Yes □ No

Section 3: Use and Handling of Ecosan Manure
11. Do you use Ecosan manure in agriculture? □ Yes □ No
12. If yes, for which crops? __________________________
13. Protective measures while handling manure: __________________
14. Storage duration before use: _______
15. Any observed health issues among household members linked to manure? □ Yes □ No

Section 4: Perceptions and Challenges
16. Advantages of Ecosan toilet (from user perspective): __________________
17. Challenges faced in using Ecosan toilet: __________________
18. Willingness to continue using Ecosan toilets: □ Yes □ No

Appendix B: Laboratory Protocols

Title: Protocols for Detection and Quantification of Parasitic Organisms

B.1 Sample Collection

- **Ecosan Manure:** 50 g composite sample from multiple points. Stored in sterile containers.
- **Wastewater:** 500 mL collected in clean, labeled bottles from drains/canals.
- **Flood Runoff Water:** 500 mL collected from standing water in residential areas.

B.2 Sample Processing

1. Homogenize manure and concentrate parasites using flotation/sedimentation.
2. Filter water samples to remove debris; centrifuge for parasite concentration.
3. Stain samples for microscopic examination using standard techniques.

B.3 Parasite Identification

- Helminth eggs identified using morphology under light microscope (100x–400x).
- Protozoan cysts identified using Lugol's iodine staining.
- Quantification expressed as eggs/cysts per gram or per mL.

B.4 Safety Measures

- Use gloves, masks, and protective clothing.
- Dispose of residues in accordance with biosafety guidelines.

Appendix C: Additional Tables and Figures

C.1 Sample Data Tables

Table C1: Average Parasite Concentration Across Sample Types

Sample Type	Parasite Type	Average Concentration (Eggs/g or Cysts/mL)	Observed Prevalence (%)
Ecosan Manure	Ascaris lumbricoides	50	60
Wastewater	Giardia lamblia	30	45
Flood Runoff	Trichuris trichiura	20	35

C.2 Figures

- **Figure C1:** Flow diagram of Ecosan manure collection and handling.
- **Figure C2:** Spatial distribution map of wastewater sampling sites.
- **Figure C3:** Conceptual model of parasitic transmission in flood-affected areas.

C.3 Notes and Additional Data

- Include raw data summaries forward-wise parasite prevalence.
- Seasonal variation charts for parasite load in each sample type.
- Photographs or diagrams illustrating sample collection, composting, or flooding sites.