Access to Safe Water and Sanitation in Gazipur, Bangladesh: Advancing the Targets towards Sustainable Development Goal 6

A THESIS WORK BY

AMIR UDDIN AHMED

(200051203)

MAHIBUR ALAM (200051229)

MD.FARHAN RAFIQ

(200051131)

A THESIS SUBMITTED TO THE DEPARTMENT OF CIVIL AND
ENVIRONMENTAL ENGINEERING

ISLAMIC UNIVERSITY OF TECHNOLOGY, GAZIPUR.

IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE
DEGREE OF
BACHELOR OF SCIENCE IN
CIVIL AND ENVIRONMENTAL ENGINEERING
2025

PROJECT REPORT APPROVAL

It is hereby certified that the work presented in this thesis was carried out by the following final year students of session 2021-2022 under the direct supervision of Dr. Md. Rezaul Karim, Professor of Civil and Environmental Engineering (CEE), Dean of Faculty of Science and Technical Education, Islamic University of Technology, Gazipur, Dhaka.

Supervisor

Prof. Dr. Md. Rezaul Karim

Professor of Civil and Environmental Engineering

Islamic University of Technology, Gazipur, Dhaka.

DECLARATION

It is hereby declared that this entitled “Access to Safe Water and Sanitation in Gazipur:In the Context of Sustainable Development Goal 6” thesis/project report or any part of it has not been submitted elsewhere for the award of any Degree or Diploma (except for publication).

Amir Uddin Ahmed
Student ID: 180051203

Mahibur Alam
Student ID: 180051229

Md. Farhan Rafiq
Student ID: 200051131

Supervisor

Prof. Dr. Md. Rezaul Karim
Professor of Civil and Environmental Engineering
Islamic University of Technology, Gazipur, Dhaka.

DEDICATION

WE WOULD LIKE TO DEDICATE THIS THESIS WORK TO **OUR PARENTS AND FAMILY.** ***WE WANT TO SHOW OUR UTMOST GRATITUDE AND RESPECT FOR THEIR CONTINUOUS SUPPORT THROUGHOUT OUR LIFE.***

WE ALSO WANT TO EXPRESS UTMOST RESPECT TO OUR THESIS SUPERVISOR PROFESSOR DR. MD. REZAUL KARIM.

ACKNOWLEDGEMENTS

“In the name of Allah, Most Gracious, Most Merciful”

By the name of God, the All Mighty, God, the All Beneficent, and God, the Merciful, the author express deep gratitude and loyalty for their assistance in allowing him to successfully finish the study. This achievement would not have been feasible, worthy and completed without the guidance of a number of different people who indirectly or directly contributed and extended their significant support in the preparation and completion of this research work.

The author is indebted to Dr. Md. Rezaul Karim, Professor of the Department of Civil and Environmental Engineering, for his consistent support, direction, and passionate efforts in explaining things articulately, as well as for his inspiration at every level of this work. The author expresses his most profound and heartfelt thanks to Dr. Md. Rezaul Karim.

The author would like to convey his heartfelt appreciation to every single member of the department's faculty for the aid and support they have provided right from the start.

The authors would also want to extend their thanks to their elders, particularly Md. Rahadujjaman ,Rakibul Hassan and Kazi Sakib Shariar for their unwavering support. And special thank you to our junior Ahid Ashraf for providing his helping hand in our thesis.

Authors are obligated, as a last step, to express their thanks to the author's parents, who not only supported and encouraged the author throughout his life, but also provided him with the chance to get a superior education from one of the nation's most prestigious educational institutions.

Table of Contents

List of Figures

List of Tables

ABSTRACT

Safe drinking water and basic sanitation remain major concerns in rapidly growing urban areas of Bangladesh. In this study, household water quality and sanitation conditions in eight unions of Gazipur were assessed with reference to SDG 6. Two hundred samples were taken from households during the dry (December-February) and wet (March-August) seasons, and 14 physio-chemicals and microorganisms were analyzed. The storage practices, cleaning frequency of the tanks, access to sanitation and hygienic practices were recorded using a structured questionnaire. Results were presented with the Integrated Water Quality Index (IWQI) and differences among seasons were determined by Wilcoxon signed-rank test, relationship between practices was tested with Pearson's chi-square tests and correlations between parameters analyzed. The outcome revealed that Microbiological contamination (E. coli) was a common problem for all seasons where manganese and to less extent iron often exceeded guideline. Dissolved salt generally reduced during monsoon while turbidity and risk towards microbial were high keeping IWQI classes lower than dry season. A strong association was also found with infrequent cleaning of tanks and E. coli presence, highlighting an intervention point. Overall, the results indicate that pre monsoon tank management, first flush diversion, point of use disinfection and focused heavy metal control including Fe and Mn can improve household water quality to contribute to achieving SDG 6 in Gazipur.

Access to Safe Water and Sanitation in Gazipur: In the context of Sustainable Development Goal SDG 6

Chapter 1: Introduction

1.1 Background of the Study

Ensuring that all people have access to safe water and basic sanitation is still one of the first challenges in the quickly growing world today. Millions continue to be afflicted with water-borne diseases, unsanitary latrines and tainted sources. There are around 663 million people in the world without access to clean water (Ramutsindela & Mickler, 2019). Moreover, worldwide around 2.3 billion people don't have access to essential sanitation service such as toilet and latrine (WHO/UNICEF Joint Monitoring Programme, 2021). It is still more grim in the so-called "developing" world where infrastructure and lack of resources weaken provision for clean water and healthy sanitation. These global disparities in access to and quality of water highlight the importance that local, national and international entities collaborate efforts to characterize, assess and address these issues globally. SIGNIFICANCE Challenge: In the face of these challenges, in 2015 the World adopted the Sustainable Development Goals (SDGs) as a universal call to action to end poverty, protect the planet and ensure that all people enjoy peace and prosperity. Goal 6 is among them the and it focuses directly on water and sanitation with a sub-goal to "achieve access to adequate and equitable sanitation and hygiene for all." won motivation back (United Nations, 2015). Not only is SDG 6 crucial in its own right, it is also a critical enabler for the delivery of other targets under health, education and gender equality, as well as fundamental to delivering a climate resilient future. It centres on achieving universal safe and affordable drinking water, sanitation and hygiene, the protection of freshwater ecosystems, as well as reducing pollution. Without those fundamentals, entire communities are made more vulnerable to becoming sick, poor and polluted.

When the water scarcity became chronic and access to clean drinking water was increasingly a priviledge, not all Puas residents have it. Water is abundant but its quality is degraded in many places, including developing nation Bangladesh. The importance of clean drinking water is immeasurable -- it's integral to good health and economic prosperity. Sanitation facilities that are clean and sanitary matter just as much. Sanitation not only includes access to a toilet, but also safe disposal of human faeces, waste management, waste water and personal hygiene. There exists a causal relationship between inadequate sanitation and various fatal diseases such as cholera, dysentery, typhoid fever and infection with intestinal worms (UNICEF & WHO, 2021). According to the World Health Organization (2020), poor sanitation costs the lives of more than 400,000 people annually most of high percentage being children under five years. And even where it exists, access to clean and safe sanitation facilities is generally not provided for women or children by the most vulnerable in a population this causes by far with a considerable health impact as well as social humiliation of unsecure places (UN Water 2021). In crowded, rapidly industrializing and urban areas like Gazipur the problems of delivering safe sanitation are even more daunting. “It is no news that dirty environment, lack of access to toilet and poor hygiene practices are major contributors to disease outbreaks and environmental degradation can exacerbate public emergency health emergencies but also retard sustainable development (World Bank, 2022).

There are some major problems like the water safety and sanitation, especially in urban- industrial areas including Gazipur (a fast growing metropolitan industrial town of Bangladesh). Catford has 1,741.53 km² area and 31 Mahallas (wards), nine wards; which comprises of municipal area (49.32 km²). Demographics The current population of the city in 2011 is approximately 123,531 with (52.52% male and 47.48% female) and the density of people per square kilometer at almost 2505.00 as per definition r by the government of India Census. km, has received its share of severe environmental issues. The solid waste, industrial effluents and toxic chemicals are discharged indiscriminately and the water bodies are degraded in terms of quality2due to over population and fast industrialisation. These are becoming an environment terror as well as a real threat to health and survival of human beings these days (Islam, Tusher, Mustafa & Mahmud, 2013). In regards to health, particularly chemical pollutants are posing an immediate impact (A.kter.) et.al.,2016). So, Gazipur’s population is increasingly in very unhealthy living conditions.

To overcome this problem, the present study aimed to evaluate the drinking water quality of households situated in Gazipur district on physical, chemical and bacteriological aspects. The sanitation and personal behavior of the populace (for example, frequency with which a water tank is cleaned -condition affecting water quality on the home-side) are also considered.

1.2 Objectives of the Study

The primary objectives of this study are:

- To identify the present status of household drinking water quality in Gazipur district determined by physical, chemical and bacteriological characteristics.

- To normalize the measured parameters with respect to national and international drinking water standards (ECR, 2023; WHO, 2022), depicting the levels of compliance/exceedance in terms of percentage value and seasonal variations (i.e., dry versus wet season) alongside spatial variation across unions, while correlating such gaps with household practices using correlation stats and hypothesis testing.

- To diagnose the systemic shortcomings in water supply, storage and sanitary management within industrialising urban Gazipur as it scales up GTF to prioritize an evidence-based action plan focused on SDG 6 targets (6.1 & 6.2) for improved household level safe water, sanitation and hygiene passage beyond its current informal settlement target groups.

1.3 Scope of the Study

This analysis focuses on the quality of drinking water at household level and hygiene habits, in the Gazipur district, Bangladesh. This study includes all eight unions in Gazipur which gives the sample a wide geographical coverage. In order to keep fair representation about 10 samples were collected from each unionsville and 30 from the Gazipur union in totality (N=100).

The research has a quantitative and qualitative aspect. Physico-chemical analysis for 14 water quality parameters such as turbidity, pH, total dissolved solids (TDS), total suspended solids (TSS), dissolve oxygen (DO) salinity, electrical conductivty (EC.l), chloride. nitrate, color, arsenic, iron, manganese and E-coli were tested in the laboratory using collected water samples.

The selection of these values was based on their national and international applicability according to water safety standards.

Apart from the lab testing, standardized water, sanitation and hygiene surveys were conducted to collect data on the respondents reported practice of household sanitary condition and personal hygiene practices including frequency of water tank cleaning, method for storing water, type and location of sanitation facilities availed in their house hold along with the types (if any) of water treatment system used.

This paper does not reflect industrial water and large-scale urban water, as well as commercial establishments. It provides no hint instead regarding the water quality status at point of use in households. The results aim at providing a context-specific picture of the challenges in water safety and to contribute to practical actions which are consistent with Sustainable Development Goal (SDG) 6.

1.4 Organization of the Thesis

This thesis is structured into six chapters:

- Chapter 1: Introduction (5,046 words) Introduces the research study; describes the background of the problem, gives objectives, scopes and presents organizational structure of a thesis.
- Chapter 2: Literature Review: Provides an overview of existing literature and studies related to water quality, sanitation practices, and Sustainable Development Goal 6.
- Chapter 3 - Study Area and Data Collection: Information on the geographical extent of the study, sample distribution, and approach to water and questionnaire data collection.
- Chapter 4: Methodology Describes the analytical techniques such as Laboratory testing and method of data analysis.
- Chapter 5: Results and Discussion: Presents and discusses the findings of both water quality analysis and sanitation data.
- Chapter 6: Conclusions and Recommendations: Road maps the key learnings, limitations as well as recommendations for action ahead and research related to SDG 6.

Chapter 2: Literature Review

2.1 Overview of Global Water and Sanitation Challenges

Clean water and sanitation are basic human rights and an essential act for sustainable development. While substantial progress has been made in recent years, global inequality in access to water supply and sanitation remains a challenge. The WHO/UNICEF Joint Monitoring Programme (2021) estimates that around 2.2 billion people do not have safely managed drinking water services, and over 4.2 billion people do not have safely managed sanitation services. Additionally, approximately 663 million people continue to depend on unimproved sources of water such as unprotected wells and springs (Ramutsindela & Mickler, 2019). Bain et al have published a systematic review (2014) reported that even when supplied with “improved” water sources, 38% of household samples collected from the source were microbiologically unsafe as a result of post-collection contamination, particularly in low and middle-income countries. Shields et al. (2015) have also showed the importance of deterioration in water quality from source to consumption on sustained waterborne disease burden […] in low-income settings.

The challenge of poor water and sanitary facilities is heavier in low- and middle-income countries that are hard pressed to cope with rapidly growing cities and population. Waterborne diseases kill more than 1.5 million people each year as a result of unsafe drinking water, poor sanitation and hygiene (The World Bank, 2022). Children are particularly at risk; exposure to unsafe water and poor sanitation can lead to high rates of child mortality and stunted growth as well as recurrent bouts of malnutrition (UNICEF, 2021).

Water scarcity is a growing danger. According to the United Nations World Water Development Report (2022), some 40 per cent of people already suffer from water scarcity and it estimated that by 2030, global demand could exceed supply for water because demands will outstrip supply by 40%, given current trends. Climate change exacerbates these challenges. Higher temperatures and changing precipitation patterns are projected to increase droughts and limit freshwater supplies, especially in already water-stressed areas of Africa, South Asia, and the Middle East (IPCC Sixth Assessment Report 2021).

The levels of poor water and sanitation is however not even. Diarrhoea (predominantly waterborne, due to poor access to safe drinking water and sanitation, and lack of hygiene) continues to be one of the leading killers of children under 5 years old with an estimated 525 000 deaths per year (Bartram & Cairncross, 2010). Prüss-Ustün et al. (2019) concluded that interventions to introduce WASH facilities were estimated to result in 297,000 deaths averted annually from diarrhea alone.

Safe water and sanitation are in addition challenged by urbanization. Currently about 1 billion people today live in slums, where services are usually informal, unimproved and unreliable (UN-Habitat, 2020). Research by Arias-Granada et al. (2018) demonstrated, ‘piped’ water is available to a wide range of poor households; but service continuity for the amenities and quality of water were poor, and very few had achieved safely managed sanitation.

Informal settlements often acquire water from unregulated vendors and illegal connections, which can be dangerous. Hanchett et al. (2003) observed that the problems such as unsafe water supply, management and accountability weaknesses, and contamination vulnerabilities were common in informal water systems of Bangladesh water aid. Also WaterAid (2020) observed that community-managed water points in slums have maintenance problems, and limitations to access because of overriding cost.

Sanitation remains deeply inadequate globally. Although 74% of the world population have access to basic sanitation facilities, only 45% use safely managed sanitation services (WHO/UNICEF, 2021). Even with some progress, open defecation remains a major concern in South Asia and leads to contamination of drinking water sources river (JMP, 2021).

The health consequences of unclean water and inadequate sanitation are devastating. Wolf et al16 The meta-analysis by Wolf et al. (2018) showed that the decrease in diarrheal incidence due to interventions for water quality at the point of use would be 34% and for sanitation it could be 16%. In addition, good water and sanitation are associated with wider impacts; research reveals that school attendance (especially for girls) increases, along with a decreased health care bill and improved nutrition (Cumming & Cairncross, 2016).

Economic costs are equally staggering. The World Bank (2016) calculated that developing countries lose up to 7% of their annual GDP because of the insufficient water supply and sanitation (from healthcare cost, productivity loss and early death). In Bangladesh, solely poor sanitation was estimated to cost the economy USD 4.2 billion per year, or 6.3% of GDP (Water and Sanitation Program, 2008).

Acknowledging these problems, the Sustainable Development Goal 6 (SDG 6)1 was adopted to "ensure availability and sustainable management of water and sanitation for all" by 2030 (United Nations, 2015). SDG 6 consists of several targets, including those aimed at ensuring universal safe drinking water and sanitation access, improving as much water quality as possible, increasing the efficiency in usage of both supply sources, preserving water ecosystems (along with the acceptance of local communities in water-management decisions).

But reaching SDG 6 remains a Herculean task. According to the UN-Water SDG 6 Progress Update (2021) progress is seriously off-track at a global level, particularly for sanitation. Only 29 percent of wastewater is safely treated, and water scarcity is on the rise in two-thirds of the world's regions. Worse still, those who are marginalized or characterized by poverty in the city (particularly slum-dwellers) are often the least able to take advantage of improvements.

In Bangladesh, despite significant gains in reducing open defecation and increasing tube well coverage, the quality of drinking water is a primary concern. The national surveys by DPHE and UNICEF (2015) found household drinking water samples to be highly contaminated with microbes even from improved sources of water. Additionally, rapid urbanization in places like Dhaka and Gazipur is occurring at a faster pace than infrastructure development, leading to lack of sanitation facilities, over-extraction of ground water, spread of an informal and often unsafe market for water (Arias-Granada et al., 2018).

Overall, the global water and sanitation crisis is a complex problem in need of immediate, collective response. Tackling it requires better infrastructure, human behavior changes about hygiene, governance mechanisms and also investments in water saving and pollution control. Such actions are necessary not only for the realization of SDG 6, but also for human dignity, health security and environmental sustainability.

2.2 Previous Studies on Water Qualities and Sanitation

Safe drinking water and adequate sanitation remain a challenge around the world, especially at the household level in urban slums and peri-urban neighborhoods. Although coverage has substantially improved, quality and safety of drinking water as well as appropriate hygienic practices for safe sanitation remain critical challenges in less developed countries such as Bangladesh.

Globally, Shields et al. (2015) found that contamination increased due to microbial growth during collection from source and consumption at household, indicating the significance of domestic storage and handling. Bain et al. (2014) also reported that 38% of household water samples in low income countries deteriorated in microbial quality post storage. The WHO/UNICEF (2021) Joint Monitoring Programme found that even though there is access to improved sources of water, safe treatment and handling at the point of use remains low, leading to high levels of water related diseases.

A similar pattern emerges from the numerous studies conducted in Bangladesh that confirm risks of contamination at household level. Akter et al. (2016) showed that 67% of rural households in Bangladesh drank water of inferior quality due to his pollution by chemical (arsenic, iron, manganese) and microbiological (E. coli) originampilov et al., 2013. Rahman et al. (2014) also found although source water quality was generally safe, transportation and storage had contaminated drinking water.

Within the urban slums of Dhaka water quality in the Korail and Geneva Camp slums was evaluated by Subrata Chowdhury (2021) who reported that while physical parameters of water samples were generally consistent with national standards, microbiological quality was severely impaired and evidence for E.coli and fecal coliforms was widespread. This was in keeping with trends similarly observed by Hanchett et al. (2003) in WaterAid-supported facilities, which enhanced access but remained predicated on cost and intermittent maintenance that left many families exposed to unsafe waterwater aid.

Arias-Granada et al. (2018) carried out an intensive household survey of Dhaka slums and found that even though 97.1% of the households in slums had access to “improved” source of water, nearly half faced odd taste/smell/colour (TSC) problem in drinking water and sanitation facilities were highly congested with ~ 16 households sharing single latrine. 'In addition, only 2% of slum dwellers were observed to safely treat their sanitation by SDG definition.

WSPs also become relevant to urban poor settlements as in the case of study by Jahan et al. (2015) from Rajshahi where, chemical factors in the majority of sources remained within acceptable limits for quality; seasonal contamination through microorganisms raised very high due to during flood season.

Shaibur et al. (2019) analysed the hand tube well water of suburban Jashore and found that although most chemical parameters were within limits, Mn levels exceeded WHO guidelines in over 50% of samples. This contamination represented a great public health threat, as tube well water is perceived safe and there is lighter measurement of it. Likewise, Muhammad et al.in slums and peri-urban areas of Dhaka also exerted such dynamic analysis to determine the role of demographic variables rather poliovirus infection. Groundwater supplies were found to have elevated salinity and iron levels and household level of treatments (like boiling, filtration) practice was reported as low. The WaterAid evaluation (2003) provides an additional perspective, demonstrating that the presence of community-managed water points and sanitation blocks doesn’t necessarily guarantee safe drinking water at household level, with maintenance and cleaning being key factors in relation to behaviourwater aid.

In a recent study conducted in the Korail slum, Islam et al. (2020) emphasized that poor hygiene practices, such as the use of uncovered storage containers, infrequent handwashing, and irregular cleaning of tanks, contributed to high rates of fecal contamination despite access to "improved" sources.

Sanitation has been found to have a direct impact on household water quality. Ahmed et al. (2017) demonstrated in peri-urban Dhaka that microbial contamination of drinking water was strongly associated with the proximity of latrines to tube wells and household tanks. However, Pickering et al. (2012) in a multi-country study including Bangladesh, confirmed that the safe siting of sanitation facilities and regular cleaning practices significantly reduced E. coli contamination in stored drinking water.

WaterAid Bangladesh's urban interventions (2003) also demonstrated that full cost-recovery models for sanitation facilities often excluded the poorest settlement dwellers and resulted in escalated open defecation and diarrhoeal disease, furthering community-wide unsafe water aid.

The WCCELD analysis (Arias-Granada et al., 2018) of slums in Dhaka suggests that water accessibility is high, but reliability, taste and microbial safety are major concerns. Middlemen and mastans control the informal water market which complicates issues of accountability and affordability, particularly for the most impoverished households.

In the meantime, investigation by Asaduzzaman et al. (2021) on sanitation in Bangladesh slums, it was revealed that common toilets were not regularly cleaned, and this contributed to the spread of bacteria to nearby households. Another research from Sultana et al. (2020) found slum households without a piped drainage were also much more likely to test positive for microbial contamination in their drinking water compared to those that had basic sanitation infrastructure.

A cross-sectional study was conducted by Haque and Shahjahan (2019) in Gazipur described that the majority of households used tube well water for drinking, and about 47% were observed with unsafe E. coli due to irregular cleaning of storage containers and poor management on latrine proximity. While access to infrastructure has improved, numerous studies continue to demonstrate that storage practices, frequency of tank cleaning and sanitation conditions are paramount to ensuring the safety of drinking water.

2.3 Impact of Physical and Chemical Parameters on Drinking Water

The physical and chemical quality of drinking water is influenced by various parameters; all of which have far-reaching effects on human health, ecological equilibrium and sustainable development. National and international studies have found that these indicators deviating from their recommended standards pose significant immediate and long term threats to the health of populations, especially in vulnerable contexts such as slums and peri-urban areas.

2.3.1 Physical Parameters and Health Implications

Turbidity is one of the most measured physical characteristic of water quality. High turbidities do not only lower aesthetic satisfaction, they also protect pathogens from disinfection and support microbial survival (LeChevallier et al., 1981). The WHO (2017) states that a turbidity value of ≤ 1 NTU is necessary for chlorination to be effective. Many Bangladeshi studies, such as Islam et al. (2010), observed household drinking water in storage to commonly exceed WHO recommended turbidity, the elevated levels most prevalent during periods of monsoon when the water in these sources are frequently contaminated with organic and inorganic matter through run-off.

TDS and EC are important measures of salinity, as well as the amount of contamination caused by dissolved ions in water. Rusydi (2018) indicated that high contents of TDS lead to poor taste, possible gastrointestinal irritation and infrastructure corrosion. In Bangladesh, Jahan et al. (2015) reported the TDS level of rajshahi City’s urban slum water sources from 376 to 513 mg/L, most often within acceptable range however occasional spikes were observed during dry season, mostly in street standpipe water.

Solubility and accessibility to the organism of heavy metals, but also of nutrients is influenced by pH. Drinking water should have a pH between 6.5 and 8.5 according to WHO (2017). Variations can result in corrosivity of pipes (at low pH) or scaling (at high pH), indirectly impacting safe tap water. Studies by Shaibur et al. (2019) reported mild acidification of tube well water in Jashore where the pH ranged from 6.2 during monsoon.

DO concentrations are not as readily monitored in drinking water but have significant implications for microbial activity. Low DO content may be indicative of high organic pollution. Research by Ahmed et al. (2017) in peri urban Dhaka observed low DO in household water sources that also had high bacterial load which implied association between organic contamination and microbial growth.

2.3.2 Chemical Parameters and Associated Risks

The most notorious chemical threat to drinking water in Bangladesh is arsenic contamination. Following a widespread finding of arsenic contamination in tube-wells in the 1990s, many studies have reported on its serious health consequences such as skin lesions, cardiovascular disease and cancers (Smith et al., 2000). The WHO (2017) has established the guideline value for arsenic at 0.01 mg/L and while more recent studies, e.g., Jahan et al. (2015), have reported finding levels of arsenic below critical thresholds in slums such as those found in Rajshahi, there are areas like representative of a larger fraction rural and peri-urban zone where isolated exceedances continued to be an issue.

One of the most common elements in Bangladesh's groundwater is iron, which can cause taste and staining problems. While iron is fine as a micronutrient, high concentration consumption (>0.3 mg/L--> in accordance with WHO) can cause stomach cramps and enhance bacterial populations in water lines. In the Korail slum, nearly 40% of household users of STWs consumed iron in excess of acceptable concentrations (Subrata Chowdhury 2021).

Discolouration through the presence of manganese, a less publicised but equally important problem. Long-term exposure to high concentration of Mn (>0.4 mg/L) is linked with neurotoxicity (WHO, 2011). Shaibur et al. (2019) reported that in suburban Jashore, 60% of tested tubewells exceeded the WHO reference level for manganese.

Nitrate polltion, mainly from agricultural runoff and poor sanitation, inter alia is a hazard for methemoglobinemia ("blue baby syndrom") in neonates (Ward et al., 2018). Although nitrate levels in deep aquifers are low in Bangladesh, some studies such as those by Islam et al. (2015) warn that intensive urbanization and inefficient waste management can result in regional nitrate pollution, particularly for the shallow aquifers.

The physical and chemical conditions of the water quality frequently act simultaneously and synergistically to exacerbate health risks. For instance, turbidity of high levels can shield pathogenic microorganisms from UV or chlorination, while water rich in iron and manganese may provide a nutrient source for bacteria growing back in reservoirs (LeChevallier et al., 1981). Likewise, low pH can increase the leaching of heavy metals such as arsenic and lead. Brouwer et al. (2023) argued that, in the absence of simultaneous change in (i) physical-chemical parameters and (ii) household hygiene practices, even an improvement of source water quality would have not resulted to a relevant protection for public health. This highlights the importance of combined WFS improvement and promotion of DW management practices interventions.

2.3.3 Local Context: Bangladesh's Specific Challenges

In Bangladesh temporal variation plays a role in physico-chemical parameters. Studies by Arias-Granada et al., 2018) found that there was an increase in household water contamination during the monsoon and turbidity and TDS levels spiking unpredictably. On the other hand, in the dry season, chemical concentration increased with decreasing groundwater recharge. Additionally, slum/peri-urban areas are exposed to nested risks -Industry pollution and low sanitation infrastructure and high population density work together to further contaminate water (Haque & Shahjahan 2019).

The present data reveals that the household drinking water of urban industrial areas like Gazipur is at particular risk for both physical and chemical deterioration, more so where poor household sanitation prevails. Nevertheless, few comprehensive household-level studies have been conducted to relate physical, chemical and bacteriological parameters with the storage and handling of water; for that matter, literature is scanty concerning this issue.

2.4 Bacteriological Contamination and Health Risks

Bacteriological contamination continues to pose the most imminent and essential threat to safety of drinking water in household settings, especially in developing countries. Whereas toxins may cause chronic health effects, such chemical agents typically are not encountered as acute exposures leading to serious and often life-threatening illnesses within days of exposure.

Microbial waterborne diseases contribute significantly to morbidity and mortality on a global scale. As reported by the WHO (2020), diarrhoeal diseases brought about by unsafe drinking water, poor sanitation and hygiene result in approximately 485,000 deaths each year, with children under five years age suffering most from this type of illnesses. Wolf et al. (2018) demonstrated that better microbial water quality per se would lead to a decrease of about 34% in the incidence of diarrheal diseases.

Bacteriological indicators, including coliform groups and E. coli, are often used as indicators of fecal pollution. WHO (2017) holds E. coli to not being present in any 100 mL drinking water sample. His detection signals that there is potential contamination of human or animal feces (and an associated higher risk of pathogenic organisms- virus, protozoa, bacteria).

Bacteriological contamination is widespread in urban slums and informal settlements. Studies by Arias-Granada et al. (2018) among slum areas of Dhaka, revealed that although 97% of the households reported having access to improved sources of water suspected microbial quality was absent, and high percentage ever felt with taste smell and turbidity problem. Similarly, Subrata Chowdhury (2021) found high levels of E. coli in Korail slum households even with “improved” tube wells.

Water-borne pathogens are most often introduced during dirty handling practices of water storage vessels (Ahmed et al., 2017); Closeness in distance between sanitation areas and water sources without hygienic barriers (Pickering et al., 2012) and cross-contamination while transporting and using the water within family compounds (Shaheed et al., 2014).

The risk of biological contamination increases particularly during monsoons, when the flooding and waterlogging provide favourable conditions for leaching of faecal matter into sources of drinking water. Jahan et al. (2015), recorded significantly increased counts of microbes from hand tube wells during the rainy season in Rajshahi slums.

Research in peri-urban Bangladesh also indicates the importance of household practices in reducing bacterial contamination [8]. Shaibur et al. (2019) found that containers with lids and cleaning tanks frequently were significantly associated with a lower detection rate of E. coli. By contrast, infrequent cleaning, use of open bucket storage and absence of point-of-use treatment (boiling or filtered) were associated with dramatically higher microbial risks.

Bacteriological contamination is also influenced by the practice of handwashing. Prüss-Ustün et al. (2019) also highlighted the fact that hand hygiene alone could decrease diarrhea prevalence by

40%. However, Arias-Granada et al. (2018) observed that soap and water facilities for handwashing were not consistently available near sanitation in Dhaka slums, increasing the hazards at the household level.

National surveys in Bangladesh conducted by the Department of Public Health Engineering (DPHE) and UNICEF (UNICEF, 2015) have found that more than 80 % of improved water sources were contaminated with E. coli at the point of consumption, demonstrating a disparity between infrastructure availability and drinking water quality.

The cumulative evidence underscores that:

- Infrastructure isn’t enough without addressing Water Hygiene and Sanitation.
- Water and hygiene interventions need to be combined in order to deliver substantive reductions in microbial contamination;
- Bacteriological water quality is strongly determined by seasonal influences (e.g. monsoon rains) and household behaviours (e.g. tank cleaning, handwashing).

Given this context, the current study specifically addresses bacteriological indicators; that is E. coli contamination of household drinking water in Gazipur city and elsewhere. It aims to understand the association between microbial presence and sanitation facility use, water storage practices, tank cleaning frequency and hand hygiene practices recorded during household surveys that provide comprehensive data needed to achieve Sustainable Development Goal 6.

2.5 Importance of Hygiene and Sanitation Practices

Hygiene and sanitation have made the foundation in ensuring safe drinking water within the premises and reduce prevalence of waterborne diseases. Enhancement of water infrastructure is important, but evidence has consistently demonstrated that drinking-water quality deteriorates dramatically between the source and point of consumption in the absence of proper hygiene conditions and an appropriate environment for sanitation (WHO/UNICEF, 2021).

Worldwide, poor hygiene plays a significant role in the spread of diarrheal illnesses. Frequent handwashing alone attended to prevent 1 out of every 3 episodes of diarrhea and almost 1 out of 5

(18%) respiratory tract infections, was a conclusion by WHO (2019). In a large umbrella review, Freeman et al. (2014) found that handwashing with soap may reduce the incidence of diarrhea by up to 40%. Nevertheless, the availability of basic handwashing facilities is still disparate and around 3 billion people do not have soap and water at home (JMP, 2021).

The presence and type of toilet facilities also can effect water safety. Open defecation, substandard pit latrines and unsewered flush toilets often contaminate groundwater supplies - particularly in densely populated or flood-prone regions. Pickering et al. (2012a) observed that provision of sanitation facilities within 30 metres from the periphery of household water sources, and their usage, increased E. coli numbers in rural context directly.

In Bangladesh, there is wide diversity in sanitation practices between urban, peri-urban and rural areas. Water Aid (2003) investigated latrine access in Dhaka's slums and found that although the condi- tion of latrines had improved, maintenance was lacking; which led to unhygienic conditions of use and subsequently contributed as a definable source for contamination of water aid with faecally associated pathogenic agents. Arias-Granada et al. (2018) observed that safe managed sanitation waste was not accessible for 98% residents dwelling in Dhaka's slum, while they mostly used shared facilities which were also not cleaned frequently as well overrun following rain season .

Jahan et al.loggedInstitution[9] reported 12.37% prevalence of diabetics among the urban poor population residing in slum settlements in Rajshahi city. (2015) noted that pit latrines were often sited in dangerously close vicinity to domestic tube wells. The lack of suitable suctions or drains enabled faeces to leach into groundwater in waterlogged conditions. In the Gazipur, households without proper drainage facilities had higher prevalence of waterborne disease, reporting same findings as Haque & Shahjahan (2019).

The cleaning of water tanks – a neglected but important practicen95 Cleaning artificial reservoirs and water storage affected the bacteriological contamination. Ahmed et al. (2017) reported that household's water storage tanks cleaned less than once a year were more than twice likely to have E. coli in stored water compared to those that cleaned tanks monthly. In Jashore, Shaibur et al.

(2019) found that poor hygienic water handling (dipping hands or dirty utentils into storage containers) caused fast microbial re-growth even in cases where source water was safe.

Handwashing-associated behaviors also impact the risk of household contamination. According to the Bangladesh MICS (2019) access to soap and water is reported by 82% of respondents but only 56% report always washing hands after using the toilet. Prüss-Ustün et al. (2019) highlighted the fact that simple hygiene education programs can have a large impact on compliance and disease prevalence.

The linkage between hygiene education and water and sanitation facilities is increasingly seen as an essential component for the lasting effects on health. In a study in rural Bangladesh on community WASH initiatives, Huda et al. (2012), who discovered that interventions to improve hygiene -based behavior change (i.e. hand washing demonstrations, how-to use a toilet, and water storage) were associated with lower prevalence of diarrheal cases than infrastructure alone.

Although the importance of hygiene and sanitation is evident, behavior change continues to be one of the greatest challenges for sustainability. Social normative influences, time and affordability constraints, load of work and gender roles are all involved in determining if hygiene practices will be adhered to. For instance, Brouwer et al. (2023) found that while the women in Dhaka slums had ultimate responsibilities for managing household water and sanitation, they did not have decision making authority or financial resources to act upon it.

In conclusion, hygiene and sanitation with special reference to handwashing, periodic water tank cleaning and the availability of suitably placed and maintained sanitation facilities are critical factors in determining drinking water safety at household level. Infrastructure may supply the base, but lasting impacts on public health can only be obtained when sanitation behaviors and hygiene are incorporated into water security interventions. The current study acknowledges this linkage and aims to evaluate the effect of behavioral practices of households in Gazipur on bacteriological water quality and overall drinking quality and provides action-oriented knowledge for SDG 6-focused interventions.

2.6 Research Gap and Justification

Although a large amount of global and national research has been carried out on water quality, sanitation and hygiene practices, there are still major gaps in knowledge, particularly at the nexus between these fields of inquiry in rapidly urbanizing environments such as Gazipur. Many previous studies have focused either on water source quality or on sanitation infrastructure, but relatively few have investigated the combined influence of household water storage, hygiene behaviors, sanitation practices, and tank cleaning frequency on drinking water quality.

On an international scale, research carried out by Bain et al. (2014) and Shields et al. (2015) highlighted how post-collection contamination is one of the key contributions to household water safety, but it has also rarely been specifically linked directly to hygiene practices or infrastructure siting at the micro-scale. In the same vein, the WHO/UNICEF Joint Monitoring Programme (2021) lacks details of local behavioural drivers behind waterborne risk as it deals with compiled data.

In Bangladesh, significant research has been carried out in the form of studies conducted within slums, such as those by WaterAid (2003), Arias-Granada et al. (2018), and Jahan et al. (2015)), often with high microbial risk associated with poor sanitation, lack of water infrastructure and so on. But it is primarily focused on congested metropolitan cities such as Dhaka and Rajshahi, and little emphasis has been placed on semi-urban industrialized areas like Gazipur where urbanization and environmental pollution are increasing.

Furthermore, few studies focus less on chemical (e.g., arsenic, iron) and microbial (e.g., E. coli) parameters separately rather than considering them in conjunction while also analyzing behavioural habits (e.g., frequency of hand washing/toilet use, household awareness about water source quality/steps that households take to clean storage tanks), which are essential to understand how contaminants reach the populace.

Furthermore, although Water Safety Plans (WSPs) and (institutional monitoring frameworks) exist the household-level studies may not cover water-related behaviours and perceptions in depth making them less valuable for developing targeted interventions. The scant few studies that utilize behavioural data (e.g., Ahmed et al., 2017; Huda et al., 2012) are either regional in scope, or no longer current.

For Gazipur, considering that it plays an important role as a rapidly growing industrial centre there is very little locally produced field-based information on the quality of drinking water at HH level along with sanitation infrastructure hygiene practice and public awareness. The contribution of the frequency of household tank cleaning to E coli contamination has not been sufficiently addressed.

In this paper, we fill these gaps by doing the following:

- Testing of 100 households water samples from all eight unions of Gazipur.
- Testing for 14 water quality parameters: physical, chemical and bacteriological.
- Distributing an in-depth WASH questionnaire to the study household with questions on sanitation facility, hygiene practice, water source usage, tank cleaning frequency, awareness.
- Comparison of findings with national (ECR, 2023) and international (WHO, 2022) benchmarks.

By linking water quality testing to household level sanitation and hygiene behaviours in an integrated package, this study adds new perspectives, local level evidence for pragmatic, community-driven responses that are consistent with SDG.

Chapter Three: Study Area

3.1 General Overview

A well-defined study area provides the necessary spatial and contextual foundation for effective environmental research. The selection of a location that is representative of diverse environmental, demographic, and socio-economic characteristics ensures meaningful and generalizable findings. This study was conducted in the Gazipur district of Bangladesh, a region experiencing rapid urban expansion, intensive industrialization, and growing population density—factors that collectively place significant pressure on water and sanitation infrastructure.

Gazipur is considered a crucial contributor to the national economy due to its concentration of manufacturing industries. However, these same industries, along with an expanding residential population, have led to heightened concerns over environmental sustainability, particularly in relation to water pollution, poor waste management, and limited access to safe sanitation.

3.2 Geographic and Administrative Context

A clearly defined area for study is a prerequisite to any successful environmental analysis. Sampling in an area with a variety of environmental, socioeconomic and demographic scenarios guarantees the results are valid and applicable to other areas. The present study was conducted in Gazipur, a district of Bangladesh characterised by fast-urbanisation coupled with intense industrialisation and increased population density all culminating to exert overwhelming pressure on water and sanitation infrastructure.

The presence of industries makes Gazipur an important part of national economy. Yet at the same time these industries, and a rapidly increasing residential population, have raised new concerns around environmental sustainability – including water pollution, inadequate waste treatment and restricted access to safe sanitation.

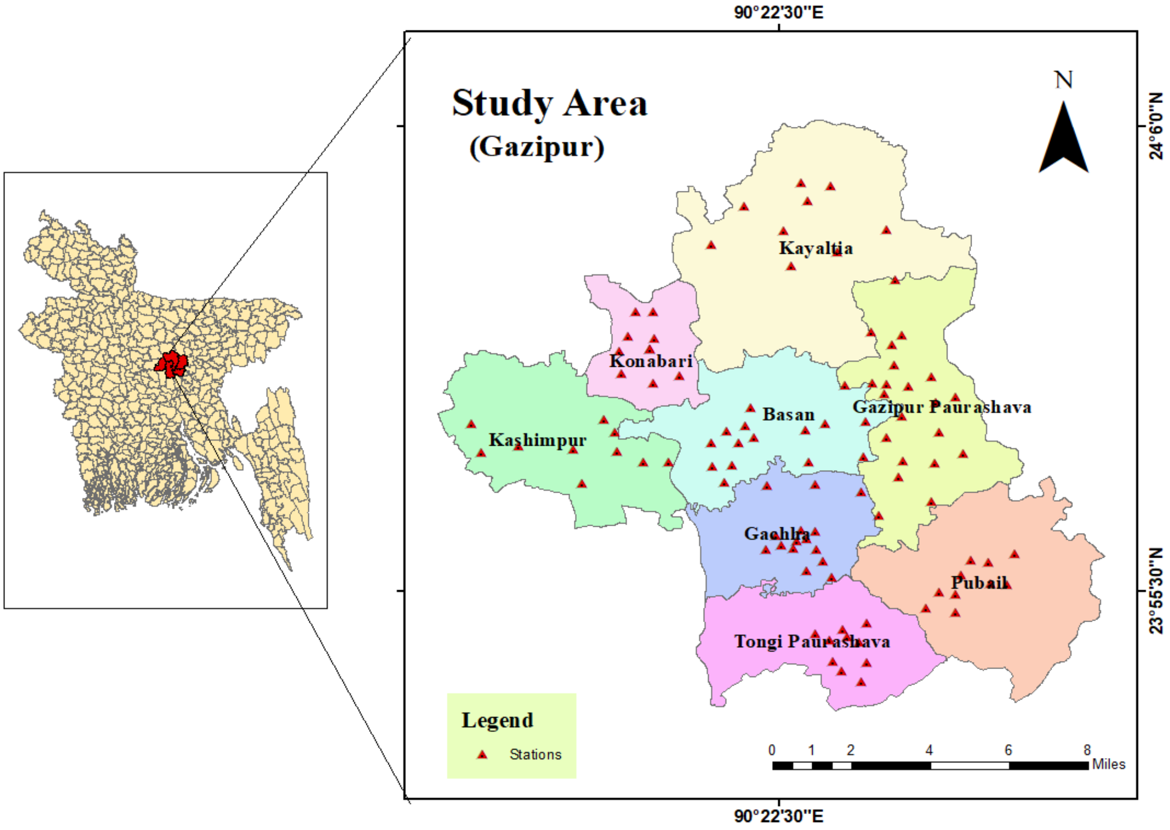

Figure 1: Study Area (8 Unions Across Gazipur)

3.3 Environmental and Water-Related Challenges

Gazipur's environmental scenery includes a monsoon climate, heavy rains in the south west monsoon, from June to September. Seasonal flooding is widespread and frequently leads to water-logged conditions, drainage problems and pollution of surface as well as shallow groundwater sources. Groundwater from boreholes through tube wells is still the principal household drinking water source, however its quality increasingly fluctuates.

The area with its fast paced industrialization in sectors like textiles, drug and dyeing has brought about a wide range of problems connected to discharge of untreated effluent and handling of solid waste. These challenges raise the likelihood of waterborne diseases, especially for households not connected to piped water supplies and dependent on shared or informal water sources.

Besides, the swelling population is exerting pressure on the already existing sanitation facilities. Sanitation facilities are under used or poorly maintained in much of the area, especially peri-urban areas and low-income settlements, leading to even larger public health risks. High levels of open defecation along with inadequate toilet siting and unclean water storage practices support sustained endemic waterborne diseases.

In this intersectional context, the district of Gazipur represents a significant location to explore linkages between household water quality, sanitation, hygiene behaviours and environmental stressors which are all key foci in the pursuit of Sustainable Development Goal 6 (SDG 6).

Chapter Four: Methodology

4.1 Field Investigation

For this study purposive and stratified sampling method were used to select the households that will be studied in Gazipur District. Selection of the study area The site was selected because Gazipur has rapid industrialization, urbanization and socio-economics diversity leading to different water quality and sanitation conditions. The eight unions comprising the sample, Gazipur, Pubail, Gacha, Bason, Konabari, Kashimpur,Tongi and Kayaltia were chosen to represent a wide range of geographic zones and community characteristics in the district.

Design of the field investigation An important goal of our design of the field investigation was to sample differences in water quality and sanitation practices that result from different socio-economic strata. Consequently, sampling was deliberately mixed to include low income as well as middle and upper-middle income families. This approach was taken to capture the true situation in Gazipur, including variation and similarities between economic strata regarding access to safe drinking water sources and sanitation facilities.

Before commencing fieldwork, the study team met with local officials and community leaders to describe research objectives and data collection procedures, as well as ethical protections in place. Ethical issues were very important, and we made sure that all participants knew the exact aim of our study as well as guaranteed confidentiality and anonymity of responses from the onset before consent was granted. Families could chose to not participate at any stage without consequences.

During the field investigation, which took place during two different seasonal periods in order to capture any possible weather-dependent variation of water quality:

- The dry season, from December through January and February.
- The wet season, between June and August.

A 100 household water samples were collected in each season – a total of 200. Standardized methods were used for all procedures during the home visits. Researchers visited the homes themselves to look at water sources, storage containers and restroom facilities. Observations included:

- Type and status of water storage tanks.
- Frequency of water tank cleaning.
- Proximity of latrines to water points.
- General hygiene practices
- Surrounding water conditions that may affect the safety of the water, such as open sewers, industrial practices or garbage dumps.

Field teams also used structured questionnaires to acquire in-depth knowledge from household members on their water use, sanitation facilities and behavior (hygiene practices) as well as perceptions regarding the safety of the available water. Furthermore, the coordinates of all sample sites were collected with GPS instruments. This spatial data gathering was important for allowing subsequent GIS based mapping and spatial analysis that could be useful in identifying the possible areas of water contamination hotspots and spatial patterns in water quality within the district.

Detailed notes and, with consent, photographs are made during the fieldwork to record physical state of the samples and assist in understanding laboratory analyses. The use of intensive field based observations along with structured questionnaires and geospatial data/bathymetry helped to develop a well-rounded view of the factors that affect overall household water quality and sanitation habits in Gazipur District. This community-based approach was necessary to derive the baseline data needed in order to measure progress towards meeting SDG 6 in the study region.

4.2 Questionnaire Development

The question from the questionnaire was an important instrument to document primary data on household practices, perceptions and socio-economic factors influencing water quality, sanitation and hygiene (WASH) of Gazipur District. Its construction was driven by the requirement for a tool to provide an in-depth analysis of the structure and management of drinking water safety barriers, which include behavioral and contextual factors influencing HWT at household level, not just the physical and chemical quality of drinking water. This was done in order to position the study within the overall scope of Sustainable Development Goal 6 (SDG 6), which includes not only water quality (Target 6.1) but also sanitation and hygiene issues (Target 6.2).

The questionnaire was developed following a scoping of the literature, covering earlier published research on WASH conditions in urban and peri-urban Bangladesh, reports by World Health Organization (WHO), and monitoring framework indicators under SDG 6. consulted experts on-environmental-engineering and public health to review the content in order to make it relevant to local situation in Gazipur.

The questionnaire was pre-tested among a few households in the area not included in the main study for ease of understanding and cultural relevance. The information obtained from this pilot test prompted changes in question phrasing, ordering of questions on the form, and the inclusion of special instructions to reduce any confusion among respondents and to enhance data quality.

The pre-final questionnaire in its complete complexity consisted of five major sections corresponding to a variety of areas:

1. Demographic and Socio-Economic Information
    - Classification of households into income groups (Upper and Middle income, or Lower income)
    - General household information and location details

2. Drinking Water (Target 6.1)
    - Primary sources of drinking water
    - Water treatment practices at the household level
    - Perceptions of water quality based on physical indicators such as turbidity, color, odor, and taste
    - Satisfaction with water quality and quantity
    - Daily water consumption rates
3. Water for Other Domestic Uses
    - Sources of water used for cooking, washing, and cleaning
    - Incidence of waterborne diseases within the household
    - Estimated daily domestic water consumption
4. Sanitation and Hygiene (Target 6.2)
    - Type and condition of sanitation facilities used
    - Connection of toilets to sewage systems or septic tanks
    - Cleanliness and availability of water for toilet facilities
    - Presence and accessibility of handwashing stations
    - Monthly expenditure on hygiene products
    - Frequency of handwashing, particularly before meals and after toilet use
5. Public Awareness and Perception
    - Awareness of government or NGO-led water safety and sanitation campaigns
    - Perceptions regarding changes in water availability and quality over the past five years
    - Suggestions for improving water and sanitation services in the area

- Rating of local government performance in managing water supply and sanitation infrastructure

The completed questionnaire contained a set of both closed ended questions aimed at quantitative analysis, as well as open-ended questions to elicit qualitative community perspectives and recommendations for intervention development, which would give context for interpreting laboratory findings and inform on behavioral and infrastructural elements influencing water safety. The questionnaire was administered by extensively trained enumerators to reduce interviewers' bias and to ensure consistency across the interviews; face to face interviews with heads-of-households were carried out during visits to households which made it easy for enumerators/research team to ask questions in detail, receive concise answers and also check what respondents wrote. The integration with laboratory-based measures of faecal contamination, and spatial mapping allowed for a more complete picture of how water quality, sanitation practices and socio-economic status inter-relate in Gazipur District, supporting the study's role as an assessment tool to find out where the gaps are and advise on specific actions aligned with SDG 6.

4.3 Sample Collection & Preservation

The water samples were field-preserved and collected with great care, to ensure validity of the laboratory analysis. As this study was conducted to assess the drinking water quality at household level in Gazipur district, the sampling scheme was composed so as to reflect the fluctuations of water quality with respect to different seasons and safeguard sample stability during collection and transportation. A total of 200 water samples were collected from domestic sources in eight unions of Gazipur District (50 each season), half in each climatic period; dry season was December and January, rainy season included June–July. This temporal stratification was necessary in order to establish possible variations in water quality that might occur as a result of the pattern of rainfall and site flooding during monsoon recharge events.

Two different types of water samples were collected from each household for detailed laboratory investigation. In the first stage, involving microbiological analysis, samples were taken in sterilized (autoclaved at 121°C for 3 h) 1L glass bottles. The bottles were cooled to around 55 °C and transported to the field in order not to invoke thermal stress on the bottles during handling. The other sample for physical and chemical analyses was stored in 500 mL clean plastic bottles that have been deeply rinsed with distilled water to avoid possible contamination from the substances remaining within them. The water samples were directly composite from the household drinking water sources, which might be tube wells, piped water supply or stored water tanks as per the household's accessed infrastructure.

All samples were sealed, well-marked and labeled with distinct identification codes to achieve traceability and preserved in cold insulated cool boxes at low temperatures to minimize biological activity and chemical out of control during transit. The samples were transported from the collection site to Environmental Engineering Laboratory, Islamic University of Technology (IUT), on the same day of sample collection whenever elapsed time was a limitation factor keeping holding times as short as possible in order to avoid compromises in sample integrity. Nevertheless, when laboratory testing was not performed on the day of collection, samples were refrigerated in the laboratory to ensure their stability and prevent degradations in sensitive parameters. Laboratory analysis was always started as soon as feasible after retrieval from storage, especially for microbiological indicators like E. coli.

We adhered to the conventional protocol (WHO, 2022; ECR, 2023) during the sampling and preservation. Field workers were trained extensively on techniques for proper sampling, sterilizing techniques and safety to ensure the validity of data. This strict methodology guaranteed the water quality results were comparable with real domestic situations and it was confidently employable in further analytical assessments.

4.4 Sample Testing

Instrumentations and chemicals used for water quality testing in this study are summarized below:

Table 1: Summary of instrumentations and chemicals used for water quality

Quality Parameters	Instruments Used	Chemicals Required (if any)
pH	pH Meter	-
Turbidity	Spectrophotometer	-
Color	Spectrophotometer	-
Total Dissolved Solids (TDS)	TDS Meter	-
Electrical Conductivity (EC)	EC Meter	-
Dissolved Oxygen (DO)	EC Meter	-
Nitrate Content	Spectrophotometer	Reagents specific for Nitrate testing
Iron (Fe) Content	Spectrophotometer	Hydrochloric Acid, Potassium Permanganate, Potassium Thiocyanate
Manganese Content	Spectrophotometer	Appropriate reagents for Manganese testing
Arsenic (As) Content	HACH Arsenic Test Kit	Reagent #1, Reagent #2
Chloride Content	Titration	Silver Nitrate, Potassium Chromate
Salinity	EC Meter	-
Color and Odor	Spectrophotometer	-
Escherichia coli (E. coli)	MPN Method Setup	Endo Broth, Bacto Agar, Rosolic Acid, Sodium Hydroxide

4.5 Data Analysis

The data analysis level of this study is referred to as the process of refining and interpreting field data. Following the framework described in previous chapters, the chapter is structured under a number of steps to systematically assess drinking water physical, chemical and microbiological quality and sanitation practices. The stages include:

- Statistical analysis, where the basic characteristics of the dataset are summarized.
- Water Quality Indices, using the Integrated Water Quality Index (IWQI) approach to synthesis multiple parameters into a single score.
- Hypothesis testing, including Wilcoxon signed-rank tests and chi-square tests to examine differences between seasons and associations with categorical variables.
- Pearson correlation matrix, to explore linear relationships among parameters.
- Sanitation analysis, where questionnaire responses and observational data are assessed to understand hygiene practices.

This section introduces the statistical analysis stage, setting the foundation for the more advanced techniques described later.

4.5.1 Statistical analysis

Statistical analysis is the process of collecting, summarising and interpreting large quantities of data in order to identify trends and draw meaningful conclusions. In this study the water-quality and sanitation dataset comprises measurements of fourteen physico-chemical and microbiological parameters collected from 200 households across eight unions in Gazipur District during both the dry and wet seasons, together with responses to a structured WASH questionnaire. Because the raw data include numerical measurements (e.g., pH, total dissolved solids, nitrate concentration) and categorical variables (e.g., type of sanitation facility, income group), the first step of the analysis involved calculating descriptive statistics to characterize each parameter.

Mean

The mean was used to summarize each numeric parameter. The mean, or arithmetic average, is obtained by summing all observations and dividing by the number of values ucd.ie. Overall mean values were calculated for each water-quality parameter and separate seasonal means were derived to highlight differences between the dry and wet seasons. The mean provides an easily interpretable summary of water quality but can be sensitive to extreme values.

Median

To complement the mean, the median was also computed. The median is the middle value of a dataset that has been ordered in terms of magnitude from lowest to highest(middle meaning for a odd number of data values there will be an exact equal number both higher and lower than the middle, and for even numbers there will be exactly 1/2 as many less than the "middle", and also 1/2 greater) if theres two middles,the mean between these are taken ucd. ie. Computing medians is a way to characterise the "typical" water-quality status that is not too sensitive to extreme high or low values or non-normal distributions, so it is a robust measure of centr al tendency.

Minimum Value

Comparison with the minimum value for each parameter can be used to determine the lower effective threshold of water quality. The minimum is the smallest observation for a set of data. ucd. i.e. the lowest value for each parameter was reported for the full dataset and by season to highlight those households experiencing very low pH, dissolved oxygen or other parameters and raise awareness of possible risks associated with these lowest observed values.

Maximum Value

The largest observation in the dataset is referred to as Maximum value ucd. ie., determining the maximum for each parameter and season) highlighted most extreme water-quality conditions experienced during sampling (e.g., peak turbidity, salinity or E. coli counts). These maxima helped to identify outlier sites, and households most severely at risk for exposure.

Standard Deviation

The standard deviation was determined to measure the variability of each characteristic. The standard deviation is obtained from the variance and indicates how spread out is the data around the average ucd. ie A high standard deviation suggests that water quality varies a lot across households, and a low standard deviation means consistently. Standard deviation differences between various parameters and seasons were used to determine if there is an increasing variation during the wet, as well as to investigate water-quality situations that remain constant in households (Yu et al.)

Descriptive Statistics

Descriptive statistics were generated with simple spreadsheet functions and statistical software. Quantitative variables (as turbidity, electrical conductivity or iron) were summarised by their means, medians, minima, maxima and standard deviations; qualitative variables (like presence of ESBL-producing E. coli) were summarised by frequencies and percentages. Tables and figures were used to display data when appropriate, to demonstrate seasonal trends and between-union differences. This preliminary analysis allowed the subsequent application of Integrated Water Quality Index, non-parametric tests and multivariate techniques and it guaranteed that the data were correctly understood before more complex analyses.

4.5.2 Integrated Water Quality Index (IWQI)

The IWQI developed as an aggregated index, providing a way of summarizing several water-quality parameters into one single value and facilitating comparison among seasons and sites. It is based on physico-chemical characterization and standard drinking-water guidelines, which results in a short categorization about the overall water quality.

This section outlines how the IWQI was applied to household samples in Gazipur District.

Step 01: Selecting the parameters

12 key water-quality parameters were selected for inclusion: pH, dissolved oxygen (DO), total dissolved solids (TDS), Total Solids (TS), Electric Conductivity(EC), color, turbidity, iron (Fe), arsenic (As) ,manganese (Mn), chlorine (Cl-) and Nitrate(NO3-). These parameters were chosen because they represent common drinking-water contaminants in urban and peri-urban Bangladesh and because both desirable limits (DL) and permissible limits (PL) for each are defined in the Bangladesh Drinking Water Standards (BDWS 2005). The desirable limit reflects the optimum concentration for drinking water, while the permissible limit indicates the highest concentration that does not pose an immediate risk.

Step 02: Desirable Limit (DL) and permitted limit as per Bangladesh Drinking Water Standards

The permissible range for each parameter was determined by subtracting the desirable limit from the permissible limit (Range = PL – DL) (Mukate et al., 2019).

The equation is denoted as below:

Range = Permissible Limit (PL) – Desirable Limit (DL) (2.2.1)

The calculated values of the range of selected parameters along with DL, PL are represented in Table 1.

These ranges provide the scaling needed to compare parameters with different units and acceptable intervals.

Table 2:Calculated values of range

Parameters	DL	PL	Range (PL-DL)
pH	6.5	8.5	2
DO	0	6	6
TDS	0	1000	1000
TS	0	1000	1000
EC	0	400	400
Color	0	15	15
Turbidity	0	5	5
Fe	0.1	0.3	0.2
As	0	0.05	0.05
Mn	0	0.1	0.1
Cl-	0	250	250
NO3-	0	50	50

All the table composed values are expressed in mg/L except color in Pt-Co, turbidity in NTU and electric conductivity in µs/cm

Step-03: Formation of Modified Permissible limit (MPL)

A Modified Permissible Limit (MPL) was calculated for each parameter to allow for minor exceedances above the permissible limit. The MPL is derived by subtracting 15 % of the range from the permissible limit (MPL = PL – 0.15 × Range). (Mukate et al., 2019)

Modified Permissible Limit (MPL) = Permissible Limit (15%Range) (2.2.2)

Table 3: Values of MPL

Parameters	PL	Modified PL (MPL) (15% deficit to original)
pH	8.5	8.2
DO	6	5.1
TDS	1000	850
TS	1000	850
EC	400	340
Color	15	12.75
Turbidity	5	4.25
Fe	0.3	0.27
As	0.05	0.0425
Mn	0.1	0.085
Cl-	250	212.5
NO3-	50	42.5

Step 04: Calculation of Sub-Indices (SI)

A sub index (SI) is calculated for each parameter based on the monitored concentration. The value of the sub-index reflects how far a given measurement deviates from the desirable range.

Three cases are considered which are illustrated below:

1) If the concentration of the parameter lies between the desirable limit (DL) and the modified permissible limit (MPL), the water quality is deemed excellent and the sub-index is set to zero.

2) If the concentration falls below the desirable limit, the sub-index is computed using SI = (DL – C_i)/Range, where C_i is the monitored value.

3) If the concentration exceeds the modified permissible limit, the sub-index is calculated as SI = (C_i – MPL)/Range.

These expressions ensure that the sub-index increases in proportion to the deviation from the acceptable range and remains zero when water quality complies with standards.

Mathematical formulations of the three cases are illustrated below by a figure and then by successive equations:

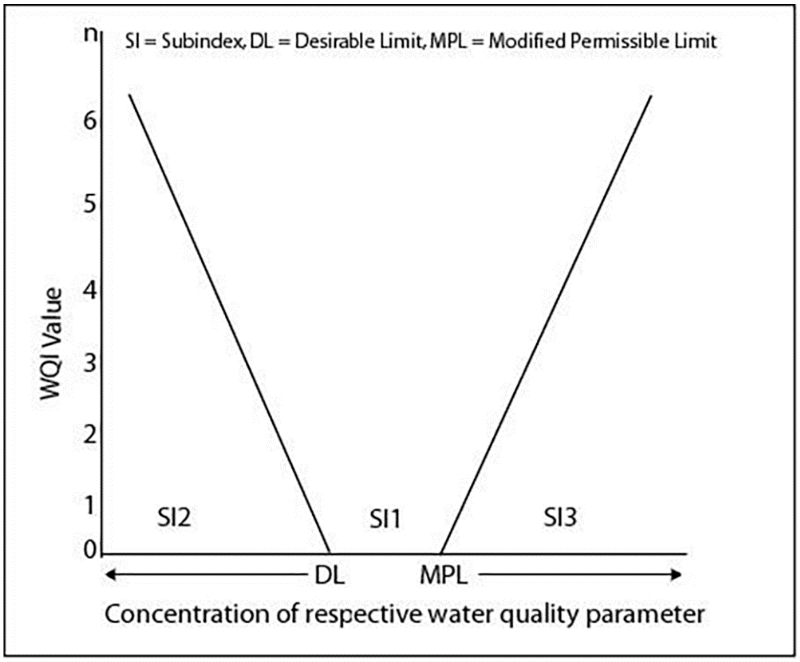

Figure 2:IWQI values vs water quality parameters

For the first case, if the monitored value of ith parameter,

Vi is between DL and MPL i.e., DL ≤ Vi ≥ MPL then, SI1 = 0 (2.2.3)

For the second case, when Vi ≤ DL

$SI2 = (DL - Vi)/DL$, (2.2.4)

For the third case, when, Vi ≥ MPL

$SI3 = (Vi - MPL)/ PL$ (2.2.5)

Where, SI = Sub-Index Value

Vi = Monitored value of ith parameter

Step 05: Determination of IWQI:

Ultimate result which is final Integrated water quality index of ith sample can be calculated by summing up all sun indices value acquired from Eq. 2.2.3 to 2.2.5.

Therefore,

$IWQIi = \sum SIij\ n\ j=1$

Where $SIij$ = Sub-index of jth parameter of ith sample

After passing through all these steps, the final water quality can be evaluated by the IWQI values according to the table below:

Table 4: Rating of water quality in terms of IWQI values

IWQI Value	Rating of Water Quality	Explanation
<1	Excellent	Excellent for Drinking
1-2	Good	Good for Drinking
2-3	Marginal	Acceptable for Domestic
3-5	Poor	Not Suitable for Drinking
>5	Unsuitable	Unsuitable for Drinking

4.5.3. Hypothesis Testing

As a part of hypothesis testing, Wilcoxon Signed Rank Test and Chi Square Test were done to get a prompt idea of the water quality and a deep analysis between them.

The hypothesis testing is done for the following conditions:

- Whether water-quality conditions vary between seasons for the same households.
- Whether sanitation and other categorical outcomes are aligned with contamination outcomes.

Tests were two tailed with a 5% significance level ($\alpha = 0.05$), and results are reported with the test statistic, degrees of freedom (where applicable), p-value, and an effect-size measure to support practical interpretation.

The two tests are described in detail below:

4.5.3.1. Wilcoxon Signed Rank Test:

The Wilcoxon signed rank test is a non-parametric procedure for the prompt analysis of statistical significance. The Wilcoxon signed rank test was used for paired observations from the same households both in dry and wet seasons. By this Wilcoxon signed rank test, we will assess the seasonal shifts in continuous parameters (example, turbidity, TDS, EC, iron, manganese, nitrate, and *E. coli* counts where treated as continuous or ranked). For each parameter, the household differences (wet − dry) were ranked by the absolute values and by providing signs to the ranks and by final summation, the test statistic was achieved.

The procedure for the Wilcoxon signed rank test is illustrated below step by step:

Step-01: Paired differences computation

The difference of data of dry and wet season need to be computed for the next functionality procedures:

Difference, di=weti−dryi

Here, weti = wet season sample value

dryi = dry season sample value

Step 02:Zero Removal

When the difference is found zero, drop di=0 and new N need to be taken

Step 03: Absolute differences Ranking

Rank di from smallest to largest

Step 04: Attach signs to ranks

Attach positive if di>0; negative if di<0

Step 05: Sum signed ranks:

Go through the following computation:

W+ (sum of positive ranks) and

W−(Sum of negative ranks)

Step-06: Compute test statistic

W=min (W+.W-)

Step 07: Obtain p value

The p value need to be obtained with exact (small N) or normal approximation with continuity correction (Large N)

Step 08: Effect size reporting:

The effect of the particular data whether it falls in small, medium or large ranges need to be computed by the following way:

r=$\frac{|Z|}{\sqrt{N}}$

where, (small =0.1, medium =0.3, large =0.5).

Step-09: Significance declaration

Provide a declaration of significance ($p < \alpha$) and indicate whether wet > dry or wet < dry using median (or HL) difference.

4.5.3.2. Chi Square Test:

The Pearson Chi square test of independence was performed to have an observation of the categorical variables. These categorical variables can be of between income groups like (lower income group vs upper or middle income groups), sanitation facility characteristics (example, improved vs. unimproved sanitation facilities and clean vs. unclean conditions), tank-cleaning frequency categories, and contamination status (example, *E. coli* present vs. *E. coli* absent; turbidity above vs. turbidity within the standard).

The procedure for the Pearson Chi square test ($\chi2$) is illustrated below step by step:

Step 01: Identification of variables and defining the hypothesis

The two categorical variables need to be identified and a hypothetical relationship of them need to be established.

H0: Variables are independent (no association).

H1: Variables are related.

Step 02: Formation of contingency table

To form the contingency table, it is required to create an (r × c) table of observed counts Oij . Also it is required to note row totals, column totals, and grand total N

Step 03: Scrutinizing assumptions

Firstly, the independent observations need to be checked where each households appear once. The expected counts guideline demonstrates a vision where at least 80% ≥ 5, and none < 1.

Step 04: Computation of expected counts

The expected counts according to the guideline need to be computed by the following formula:

$Eij = [(\text{row total})_i \times (\text{column total})_j]/N$

Step 05: Calculate Chi-Square test-statistic

The Chi square test statistic need to be computed by the following formula:

$$\chi 2 = \sum_{i=1}^{r} \sum_{j=1}^{c} \frac{(Oij - Eij)2}{Eij}$$

Yates continuity corrections may be reported by table with moderate counts.

$$\chi Y^2 = \sum \frac{(|Oij - Eij| - 0.5)2}{Eij}$$

Step 06: Compute degrees of freedom

By the summation of rows and columns, the degrees of freedom need to be computed.

$df=(r-1)(c-1)$

Step-07: p-value computation

The $\chi 2$ need to be compared to the chi-square distribution with df. For two sided analysis, significance need to be declared at $\alpha=0.05$ (two-sided)

Step 08: Determination of effect size for associating strength

Using Cramer’s formula by Cramer’s V we get:

$V = \sqrt{\frac{\chi 2}{k(N-1)}}$ where $k=\min(r,c)$

(small =0.1, medium =0.3, large =0.5).

Step 09: Computing standardized residuals

The standardized residuals need to be computed by the following formula:

Rij = (Oij−Eij) / Eij

Step 10: Interpretation of significance

p<α need to be described. If significant results come, then directional pattern need to be described. If it is insignificant, insufficient evidence of association need to be concluded and include χ2, df, p, **V.**

4.5.4.Pearson Correlation Coefficient

The Pearson correlation matrix delivers a linear relationship between two variables. Continuous variables can face a smooth Pearson Correlation matrix. This correlation technique among the variables was developed by Karl Pearson This correlation supports pattern finding among the variables and delivers a prompt relationship among the variables

The correlation value is dictated by r.

If two variables x and y are taken then and both variables contain n pair of values, then the Pearson Correlation can be computed by the following equation:

$$r = \frac{\sum_{i=1}^{n}(x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i-\bar{x})^2 \sum_{i=1}^{n}(y_i-\bar{y})^2}}.$$

Here, r value ranges from -1 to +1.

Where, -1= Negative Correlation, 0 = No Correlation, +1= Positive Correlation

4.5.5. Sanitation Analysis

The sanitation analysis of households were performed based on the standardized questionnaire that has been set up for the survey. The on-site records by the questionnaire created a suitable medium to assess the sanitation system in households. By using statistical features and mediums, responses from the questionnaire were analyzed. This analysis lead to the identification of the trends, patterns and dissimilarities in the facilities which helped thereby to take decision regarding whether the existing facilities aligns with SDG 6.1 and SDG 6.2 or misalign.

The on-site observations were used to supplement the survey findings and thereby identify dissimilarities which later on provided additional insights to take a prompt decision. The survey regarding sanitation assessed the water usage amounts and bills, boiling the water or not , handwashing after defecating, cleanliness of the toilet and a varied things which later helped to check the very alignment with SDG 6.

To exemplify, the number of households surveyed contain toilets and water tanks, the cleanliness of those were assessed and thereby the determination and possibilities of microbial contamination could be assessed from there. Again, if the survey responses dictated lack of hand washing facilities and drinking water facilities, the absence or inadequacy of those facilities were assessed.

Chapter five: Result and Discussion

5.1 Statistical Analysis

Water samples were collected from household storage tanks across eight unions of Gazipur in two distinct seasons. The dry season survey was conducted from December to the end of February, while the wet season survey spanned from mid-June to the end of August. For each season, 100 samples were analysed for key physicochemical and microbiological parameters. The following sections summarise the maximum, minimum, mean and estimated standard deviation for each parameter, and compare the observations with regulatory limits from the Bangladesh Environmental Conservation Rules (ECR 2023) and WHO 2022 guidelines.

5.1.1 Dry Season Analysis

In the dry season (December–February), forty-three household water samples were evaluated across multiple unions in Gazipur. The pH values were slightly acidic to neutral, ranging from 6.1 to 7.26 with a mean of 6.74 ± 0.21; all samples fell within the WHO and ECR recommended interval of 6.5–8.5. Colour readings were highly variable (0–150 PtCo) with an average of 9.73 ± 19.39 PtCo; about 13 % of samples mostly from Basan exceeded the 15-PtCo aesthetic guideline, indicating localised organic or iron contamination. Total dissolved solids (TDS) ranged from 59.1 to 426 mg/L (157.12 ± 61.90 mg/L) and never approached the 500-mg/L secondary standard, suggesting moderate mineralisation. Turbidity was generally low (0.23–7.53 NTU; 0.89 ± 0.97 NTU); only 1 % of samples chiefly in Tongi exceeded the 5-NTU threshold. Dissolved oxygen (DO) showed greater dispersion (1.96–8.29 mg/L; 6.42 ± 1.06 mg/L), and alarmingly 73 % of samples fell below the 6-mg/L minimum, particularly in Kashimpur, implying stagnant storage and high biological oxygen demand. Nitrate concentrations were minimal (0.1–1.1 mg/L; 0.35 ± 0.17 mg/L) and far below the health limits of 45–50 mg/L, while arsenic was undetectable across all samples. Salinity averaged 132.52 ± 0.81, and total solids (TS) spanned 63.1–426 mg/L (160.94 ± 62.15 mg/L); neither parameter has a household standard, but the wide range reflects differing sources and degrees of evaporation.

Major ions and metals exhibited mixed patterns. Chloride concentrations were modest (4–96.1 mg/L; 19.46 ± 18.78 mg/L) and well below the 250-mg/L guideline, while electrical conductivity ranged widely from 112.5 to 868 µS/cm (325.58 ± 127.35 µS/cm); about 26 % of samples especially in Gacha exceeded the 400-µS/cm benchmark, signaling elevated mineral content. Iron levels averaged 0.06 ± 0.08 mg/L (0.01–0.39 mg/L); only 3 % of samples slightly surpassed the 0.3-mg/L limit, mostly in Gazipur. In contrast, manganese concentrations were often high (0.049–0.65 mg/L; 0.19 ± 0.11 mg/L); over 76 % of samples exceeded the 0.1-mg/L guideline, particularly in Konabari, pointing to geogenic influence or prolonged stagnation. Microbiological quality remained the most serious concern: E. coli counts varied from 0 to 500 CFU/100 mL, with a mean of 95.49 ± 135.87 CFU/100 mL; fully 86 % of samples—chiefly from Gacha failed the zero-tolerance standard. The combination of low DO and high bacterial loads underscores the need for routine tank cleaning and disinfection ahead of the dry season to protect household health.

-

Table 5: Percentage of samples exceeding the standards in dry season

Parameter	Unit	Maximum	Average	Minimum	ECR 2023	WHO 2022	% Exceeding	Union with highest exceedance	Standard Deviation
pH	N/A	7,26	6,74	6,1	6.5-8.5	6.5-8.5	0	-	0,21

Color	Pt-Co	150	9,73	0	15	15	13	Basan	19,39
TDS	mg/L	426	157,12	59,1	1000	-	0	-	61,90
Turbidity	NTU	7,53	0,89	0,23	5	5	1	Tongi	0,97
DO	mg/L	8,29	6,42	1,96	6	-	73	Kashimpur	1,06
Nitrate	mg/L	1,1	0,35	0,1	45	50	0	-	0,17
Arsenic	mg/L	0	0	0	0	0.01	0	-	0,00
Salinity	µS/cm	430	132,52	7	-	-	-	-	0,81
TS	mg/L	63,1	160,94	426	-	-	-	-	62,15
Chloride	mg/L	96,1	19,46	4	250	250	0	-	18,78
Ecoli	CFU/100mL	500	95,49	0	0	0	86	Gacha	135,87
Iron	mg/L	0,39	0,06	0,01	0.1-0.3	0.3	3	Gazipur	0,08
Manganese	mg/L	0,65	0,19	0,049	0.1	0.1	76	Konabari	0,11

EC	µS/cm	868	325,58	112,5	-	400	26	Gacha	127,35

5.1.2 Wet Season Analysis

During the wet season (June to August), the water quality of household storage tanks exhibited greater variability, reflecting the influence of monsoon rainfall. The pH ranged from 5.86 to 7.81 (mean 6.94 ± 0.48), with about 15 % of samples falling below the recommended 6.5–8.5 band. Colour values were highly dispersed, averaging 13.87 ± 23.40 PtCo with a maximum of 128 PtCo; 27 % of samples mostly from Basan exceeded the 15-PtCo aesthetic guideline. Despite heavy runoff, total dissolved solids (TDS) remained moderate (52.5–427.2 mg/L; mean 147.3 ± 60.92 mg/L) and well below the 500-mg/L secondary standard. Turbidity increased compared with the dry season, ranging from 0.3 to 13.6 NTU (mean 1.25 ± 2.11 NTU); about 6 % of samples particularly in Pubail and Tongi exceeded the 5-NTU limit, indicating the infiltration of suspended sediments during rainfall events. Dissolved oxygen (DO) improved slightly, averaging 6.52 ± 0.69 mg/L, yet 19 % of samples (notably in Kashimpur) still fell below the 6-mg/L threshold, signaling residual stagnation.

Nutrient levels remained low: nitrate concentrations spanned 0.1–1.2 mg/L (mean 0.30 ± 0.19 mg/L), far below the 45–50 mg/L health limits, and arsenic was undetectable in all samples. Salinity was modest (0.05–3.2 ppt; mean 0.58 ± 0.60 ppt) and total solids (TS) ranged widely from 52.5 to 435.2 mg/L (mean 154.46 ± 61.73 mg/L); no drinking-water standards apply to these measures, but the high variability suggests differing sources and intermittent dilution. Chloride levels remained low (2.01–57.06 mg/L; mean 12.21 ± 11.68 mg/L), well below the 250-mg/L guideline. Electrical conductivity, a proxy for dissolved mineral content, showed a broad spread (109.5–827 µS/cm; mean 320.2 ± 148.62 µS/cm); 16 % of samples, mainly from Gacha, exceeded the 400-µS/cm benchmark, indicating pockets of high mineralization.

Microbiological and metal contaminants remained the principal health concerns. E. coli counts during the wet season ranged from 0 to 690 CFU/100 mL (mean 78 ± 135.55 CFU/100 mL); fully 90 % of samples violated the zero-tolerance standard, with the highest contamination again in Gacha. Iron levels (0.10–0.93 mg/L; mean 0.13 ± 0.19 mg/L) exceeded the 0.3-mg/L limit in about

10 % of samples, concentrated in Pubail. Manganese concentrations varied between 0.01 and 0.93 mg/L (mean 0.05 ± 0.15 mg/L); 78 % of samples, particularly in Konabari, surpassed the 0.1-mg/L guideline. Taken together, these results show that while the monsoon dilutes some physico-chemical parameters, it also introduces turbidity and maintains high levels of microbial and metal contamination, underscoring the need for improved storage conditions and regular disinfection throughout the rainy season.

Table 6: Percntage of samples exceeding the standards in wet season

Parameter	**Unit**	**Maximum**	**Average**	**Minimum**	**ECR 2023**	**WHO 2022**	**% Exceeding**	**Union with highest exceedance**	**Standard Deviation**
pH	N/A	7,81	6,94	5,86	6.5-8.5	6.5-8.5	15	-	0,48
Color	Pt-Co	128	13,87	0	15	15	27	Basan	23,40
TDS	mg/L	427,2	147,3	52,5	1000	-	0	-	60,92
Turbidity	NTU	13,6	1,25	0,3	5	5	6	PUBAIL,TONGI	2,11
DO	mg/L	8,01	6,52	0,3	6	6	19	KASHINPUR	0,69
Nitrate	mg/L	1,2	0,3	0,1	45	50	0	-	0,19
Arsenic	mg/L	0	0	0	0.05	0.01	0	-	0,00

Salinity	µS/cm	3,2	0,58	0,05	-	-	0	-	0,60
TS	mg/L	52,5	154,46	435,2	-	-	10	-	61,73
Chloride	mg/L	57,06	12,21	2,01	250	250	0	-	11,68
Ecoli	CFU/100 mL	690	78	0	0	0	90	Gacha	135,55
Iron	mg/L	0,93	0,13	0,01	0.1-0.3	0.3	10	PUBAIL	0,19
Manganese	mg/L	0,93	0,05	0,01	0.1	0.1	78	Konabari	0,15
EC	µS/cm	827	320,2	109,5	-	400	16	Gacha	148,62

Overall, the wet season brought modest dilution of dissolved minerals yet only slight improvement in microbial safety. Average pH remained near neutral in both periods (6.74 ± 0.21 dry vs. 6.94 ± 0.48 wet), but colour and turbidity rose during the rains: mean colour doubled (9.73 to 13.87 PtCo) and the proportion of samples exceeding the 15 PtCo guideline climbed from 13 % to 27 %, while turbidity increased from 0.89 to 1.25 NTU with exceedances rising from 1 % to 6 %. Total dissolved solids stayed moderate in both seasons, but chloride and electrical conductivity fell slightly in the wet season, suggesting dilution of salts; conversely, iron levels increased (0.06 to 0.13 mg/L) and the proportion of iron-exceeding samples rose from 3 % to 10 %. Dissolved oxygen improved markedly mean DO rose to 6.52 mg/L and the share of tanks failing the 6-mg/L threshold plunged from 73 % to 19 % reflecting better mixing, yet E. coli contamination remained high (86 % exceedance in the dry season vs. 90 % in the wet). Manganese remained persistently elevated in both seasons, exceeding the 0.1-mg/L limit in roughly three-quarters of samples. Taken together, these results indicate that the monsoon modestly dilutes mineral constituents and enhances oxygenation but does little to reduce microbial and heavy-metal contamination, underscoring the need for year-round interventions such as regular tank cleaning, point-of-use disinfection and source protection.

5.2 Integrated Water Quality Index (IWQI)

The Integrated Water Quality Index (IWQI) is used to turn many water tests into **o**ne simple cla**ss** for each household Excellent, Good, Marginal, Poor**,** or Unsuitable. First, each measured value is compared with health guideline**s** to make small sub-scores. Then those sub-scores are combined and weighted to give one overall number, which is placed into a class by fixed cut offs. In this way, the reason for any low class can still be **see**n (for example, high turbidity, manganese, or E. coli), and clearer seasonal and location based comparisons are made possible.

In the dry season, the IWQI distribution is skewed toward safer classes: Excellent (36%) and Good (31%) together account for 67% of household tanks, indicating broadly acceptable quality across most unions. A further 18% fall into the Marginal class, while Poor (11%) and Unsuitable (4%) represent the minority that require urgent attention. This profile is consistent with the parameter statistics for the dry months generally lower turbidity, moderate TDS/EC, and fewer metal exceedances yet it also reflects persistent local vulnerabilities (e.g., infrequent tank cleaning, poor lids/overflow seals, and sites with elevated Mn or intermittent E. coli). Overall, the dry season presents comparatively favorable conditions, but about one in seven tanks remains below acceptable thresholds and should be prioritized for remedial action.

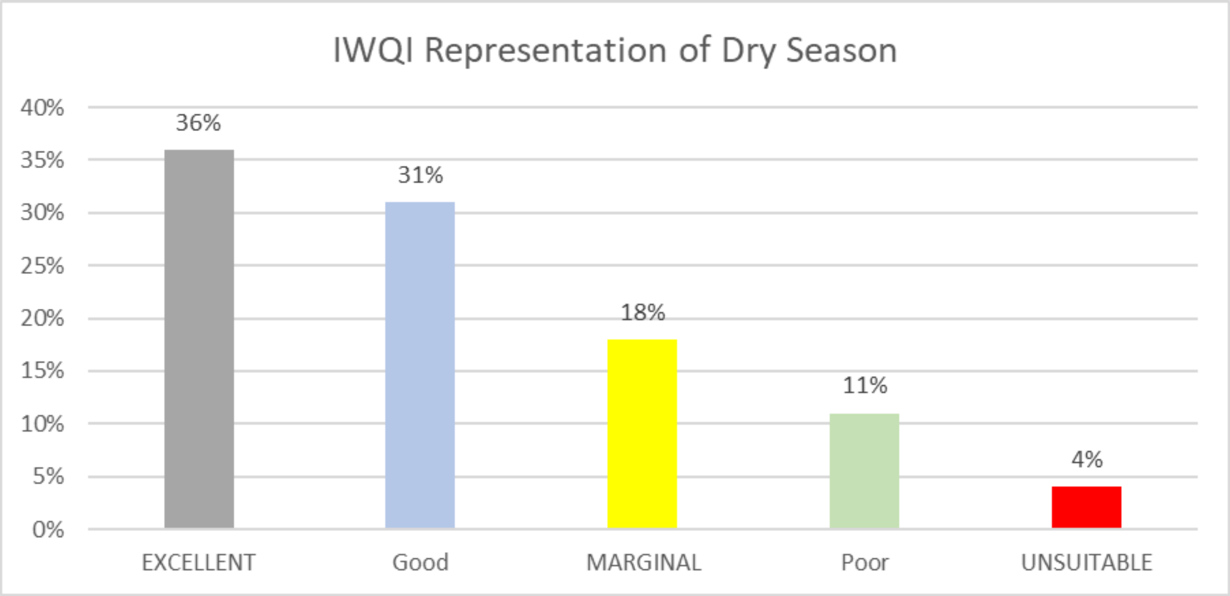

Figure 3: Bar chart of IWQI Representation of Dry Season

In the wet (rainy) season, the IWQI profile shifts toward lower classes: Excellent 30% and Good 19% together fall to 49% of households, while the lower categories expand to Marginal 24%, Poor 17%, and Unsuitable 10%. This redistribution reflects monsoon pressures on household storage roof/surface runoff introducing particulates, resuspension of tank sediments, and persistent E. coli contamination despite some dilution of salts. Many tanks that were Good in the dry months slide to Marginal or Poor in the rains, especially where lids and downpipes are unsealed, first-flush diversion is absent, or cleaning frequency is low. Overall, the rainy season leaves one in four households in Marginal and nearly one in three in Poor/Unsuitable, underscoring the need for pre-monsoon cleaning, secure covers and inlets, first-flush devices, and simple chlorination/residual checks during the season.

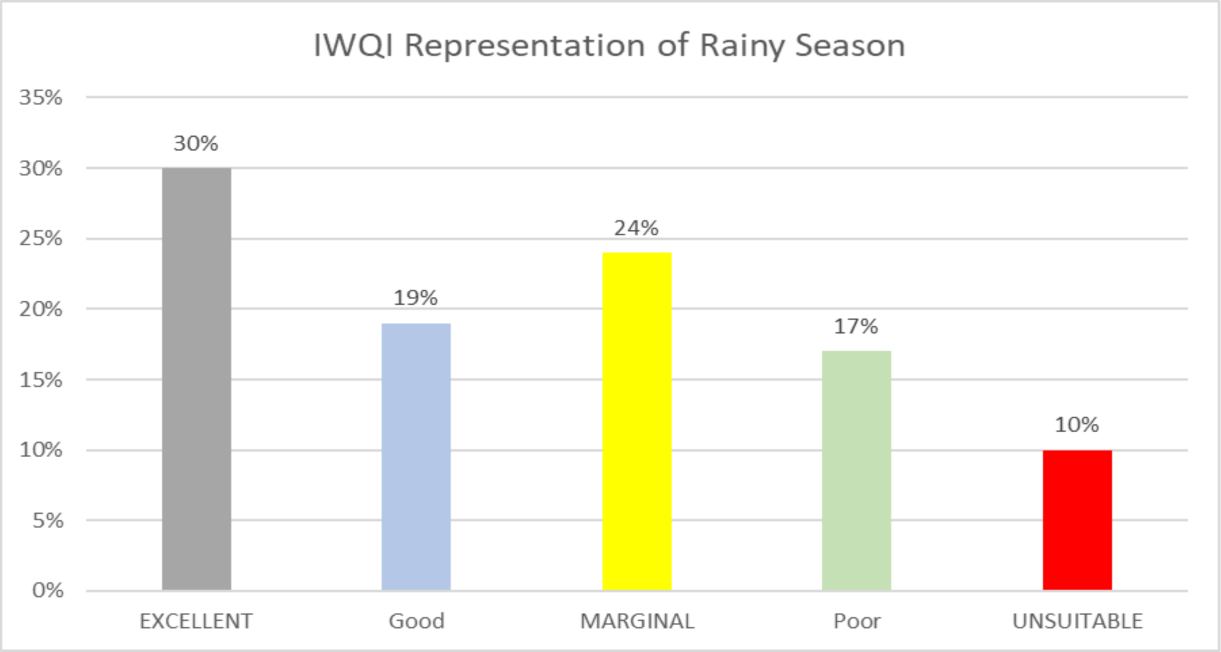

Figure 4: Bar chart of IWQI Representation of Rainy Season

Across seasons, the IWQI clearly degrades with the onset of the monsoon. In the **d**ry season, Excellent+Good = 67%, Marginal = 18%, and Poor+Unsuitable = 15%; in the wet season, Excellent+Good falls to 49%, Marginal rises to 24%, and Poor+Unsuitable nearly doubles to 27%. This downward shift is consistent with parameter-level patterns: rains dilute salts (slightly lowering EC/Cl) but increase turbidity, resuspend tank sediments, and sustain E. coli and Mn problems pushing many households down one or two IWQI classes. Notably, dissolved oxygen improves in the wet months due to mixing, yet the gain is outweighed by microbial and metal risks, especially where tanks lack tight lids/first-flush or are cleaned infrequently. In practical terms, pre-monsoon cleaning + sealed inlets/lids + first flush diversion and in season chlorination/residual checks are the most direct actions to shift households back toward Excellent/Good during the rainy period.

5.3 Hypothesis Testing

5.3.1 Wilcoxon Signed Rank Tests

The paired (dry season vs. wet season) observations for each household were analysed with the Wilcoxon signed rank test because the seasonal differences were not assumed to follow a normal distribution. The test evaluates whether the median paired difference is zero. For each parameter, the dry season and wet season medians, the Wilcoxon statistic, *p* value, and effect size (*r*) were compiled (table provided). Results are summarized below by statistical significance and direction of change.

Among the paired parameters, clear seasonal shifts were detected by the Wilcoxon signed-rank test. The strongest change was seen for salinity, which fell sharply from a median of 1.45 in the dry season to 0.22 in the wet ($p < 0.0001$; $r = 0.87$, large), consistent with monsoon driven dilution of stored water. Chloride showed the same pattern, decreasing from 12.26 to 8.06 mg/L ($p = 0.0001$; $r = 0.40$, medium), and the bulk ionic measures TDS and TS also declined (TDS: 139.2 mg/L from 152.4mg/l, $p = 0.0256$; $r = 0.22$, small; TS: 144.85 mg/L from 156.3mg/L, $p = 0.0300$; $r = 0.25$, small). Together, these results indicate that dissolved and total solids were systematically lower in the rains, pointing to a robust dilution effect across households. In contrast, pH shifted upward, from 6.77 to 7.12 ($p = 0.0002$; $r = 0.38$, medium), suggesting slightly more neutral conditions in the wet season.

For metals, iron (Fe) increased from 0.03 to 0.05 mg/L ($p < 0.0001$; $r = 0.82$, large), a sizeable seasonal effect that is consistent with greater mobilisation from plumbing or tank sediments during monsoon inflows and fluctuating redox. Manganese (Mn) presented a large effect as well ($p < 0.0001$; $r = 0.67$), even though the medians were close (0.19 mg/L from 0.2mg/L), indicating a systematic paired shift that is not captured by medians alone many households moved in the same direction by small amounts. Nitrate behaved similarly (medians both 0.30 mg/L, $p < 0.0001$; $r = 0.74$, large), implying consistent but very small household specific changes around a low baseline rather than a large practical shift. Overall, the significant results depict a dual seasonal signal: strong dilution of salts/solids and a rise in pH during the monsoon, coupled with greater Fe mobilisation (and subtle, consistent movements in Mn and nitrate), all of which help explain the wet-season downgrades seen in the IWQI for a subset of households.

However, no statistically reliable seasonal shift was detected for several parameters. Colour showed a medium effect size ($r = 0.34$) but did not reach significance ($p = 0.1130$), suggesting that increases in some households were offset by decreases in others, as would be expected when episodic runoff events are uneven across sites. Dissolved oxygen (DO) exhibited a negligible effect ($r = 0.06$; $p = 0.5580$), indicating that any aeration or stagnation changes between seasons were small relative to within-household variability. E. coli likewise showed no systematic paired change (r = 0.15; p = 0.8790); contamination appears to be driven by intermittent ingress and hygiene practices rather than a uniform seasonal shift detectable by the Wilcoxon test. Electric conductivity (EC) presented a small effect (r = 0.18; p = 0.1060) and thus no significant change after pairing, consistent with counteracting process dilution during rains versus mineral inputs from plumbing or source mixing. Finally, turbidity displayed a negligible effect (r = 0.09; p = 0.3740), implying that short-lived spikes during storms were not consistent enough across households to move the paired median. Overall, these non-significant results indicate high household-level heterogeneity and episodic influences, rather than a single, season-wide directional shift for these parameters.

Table 7: Summary of Wilcoxon Signed Rank Test Analysis

Parameter	**Median (Dry)**	**Median (Wet)**	**Wilcoxon Statistic**	**p value**	**Significant**	**Effect Size (r)**	**Effect Label**
Chloride	12,26	8,06	1359,5	0,0001	Yes	0,401	Medium
Color	4	6.	1539,5	0,1130	No	0,34	Medium
DO	6,49	6,55	2354,5	0,5580	No	0,06	Negligible
E.coli	30,5	22,5	2100	0,8790	No	0,146	Small
Electric Conductivity	294,5	317,5	2012,5	0,1060	No	0,176	Small
Iron	0,03	0,05	138	0,0000	Yes	0,819	Large
Manganese	0,2	0,19	571,5	0,0000	Yes	0,672	Large

Nitrate	0,3	0,3	384,5	0,0000	Yes	0,74	Large
Salanity	1,45	0,22	655	0,0000	Yes	0,87	Large
TDS	152,4	139,2	1876	0,0256	Yes	0,223	Small
TS	156,3	144,85	1836,5	0,0300	Yes	0,25	Small
Turbidity	0,595	0,59	2058,5	0,3740	No	0,09	Negligible
pH	6,77	7,12	1409	0,0002	Yes	0,38	Medium

Overall, dilution in the wet season is strongly supported for salinity, chloride, TDS, and TS, while pH tends to rise. Iron shows a large, significant increase during the rains, consistent with mobilisation from pipework or tank sediments. Manganese exhibits a large effect despite nearly unchanged medians, indicating systematic paired shifts that the median alone masks. Microbial indicators (E. coli) and DO did not show significant paired changes, implying that wet-season contamination patterns are driven more by episodic ingress and storage conditions than by a uniform seasonal shift detectable by the Wilcoxon test.

5.3.2 Chi Square Test

A 2×2 chi-square test of independence was applied separately for each season. Cleaning frequency was dichotomized as equal or less than2 cleanings/year vs more than 2 cleanings/year, and E. coli status was coded as Absent vs Present. For each season, a contingency table was constructed and the Pearson chi-square statistic was calculated ($\alpha = 0.05$; df = 1). Where any expected cell count was <5, results were checked with Yates' continuity correction and Fisher's exact test for sensitivity. Effect size was reported as Cramér's V with qualitative labels (small/medium/large).

In the dry season, a strong association was detected ($\chi^2 = 31.0$, $p = 2.5\times10^{-8}$, V = 0.56, large). In households cleaning ≤2 times/year, all tanks were E. coli present (0 Absent, 68 Present). Among households cleaning >2 times/year, 44% were E. coli absent (14 Absent, 18 Present). Interpreted practically, moving from ≤2 to >2 cleanings per year was associated with an absolute 43–44 percentage point reduction in E. coli positivity in the dry season.

In the wet season, a significant, though smaller, association was also observed ($\chi^2 = 7.0$, $p = 0.006$, V = 0.27, small). With ≤2 cleanings/year, 95.6% of tanks were E. coli present (3 Absent, 65 Present); with >2 cleanings/year, 75% were present (8 Absent, 24 Present). Thus, more frequent cleaning was associated with an absolute 21 percentage point reduction in wet season E. coli positivity beneficial but attenuated compared with the dry season, likely because monsoon ingress introduces additional contamination pathways.

Table 8: Summary of Chi- Square Test Analysis

Season	<=2 Cleanings per Year		>2 Cleanings per Year		Chi-square	p value	Degrees of freedom	Cramer V	Effect category
	Absent	Present	Absent	Present					
Dry	0	68	14	18	31	2.5×10^{-8}	1	0,56	Large
Wet	3	65	8	24	7	0,006	1	0,27	Small

Overall interpretation. Across both seasons, more than two cleanings per year was consistently associated with lower E. coli contamination, with a large effect in the dry season and a small-to-moderate effect in the wet season. The results support pre-monsoon and mid-monsoon cleaning schedules, plus complementary measures in the rains (sealed lids/inlets, first-flush devices, and residual disinfectant checks) to sustain microbiological safety.

5.4 Pearson Correlation

Linear associations among the monitored variables were explored with Pearson's correlation and displayed as season specific heatmaps for dry and wet season. Coefficients (r) close to +1 indicate strong positive association, values near –1 indicate strong negative association, and values around 0 suggest little or no linear relation. Interpretation focuses on patterns that are consistent across many households and that align with process understanding (dilution, mixing, metal mobilisation, and microbial ingress).

5.4.1 Dry Season Patterns

The clearest positive links were observed between TDS and EC (strong; r≈0.75), reflecting the expected electrical response to dissolved ions. Colour and turbidity also rose together (moderate–strong; r= 0.6), indicating that visually darker water tended to carry more suspended material. DO showed inverse relations with color and turbidity (r around −0.3 to −0.4), consistent with oxygen being lower where particulates and organic matter were higher. Correlations with metals were generally modest in the dry months; Fe/Mn related weakly to EC/TDS, and E. coli displayed only weak, near-zero links with most physico-chemical variables, suggesting that microbial contamination was driven more by tank hygiene and ingress pathways than by the bulk chemistry.

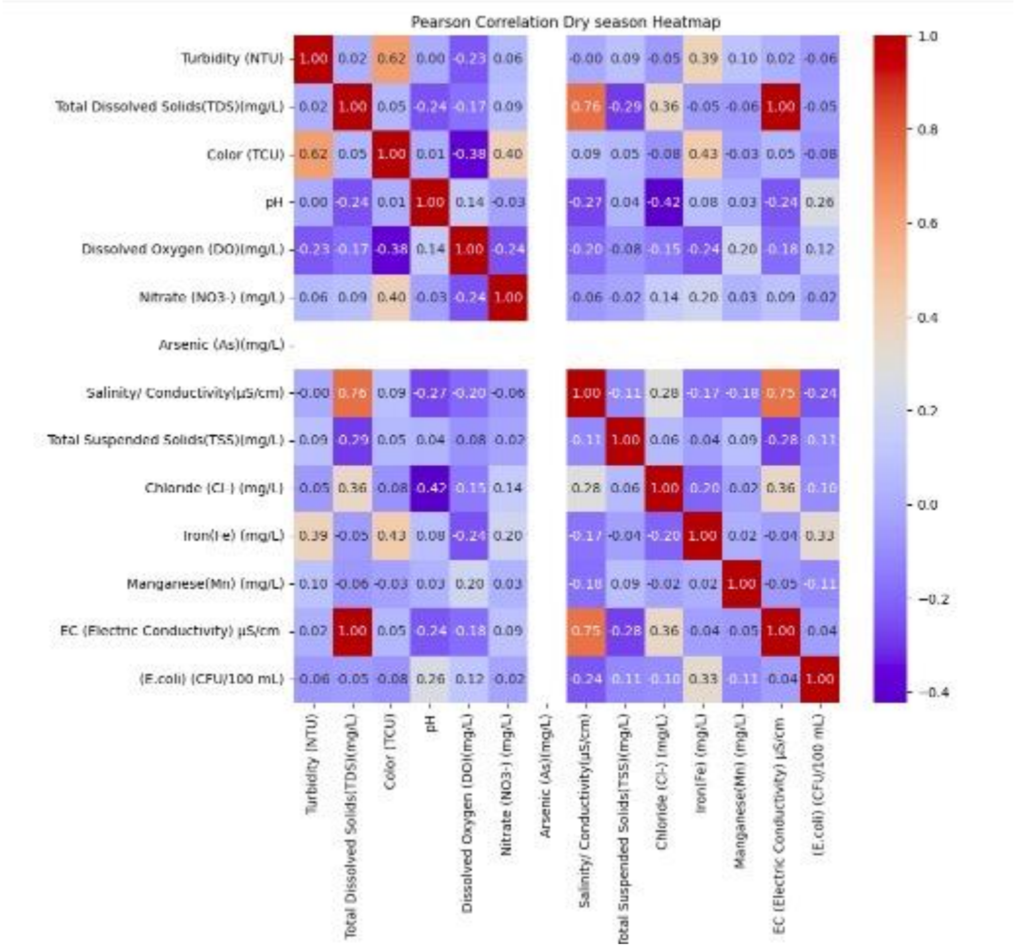

Figure 5: Pearson Correlation Heatmap of Dry Season

5.4.2 Wet season patterns

Monsoon conditions tightened several relationships. The TDS–EC correlation became very strong (r=0.95), and EC also tracked salinity more closely, reflecting dilution/mixing of ionic constituents. The colour turbidity link strengthened (r= 0.8+), consistent with runoff driven particulates and stained humics entering storage. DO retained negative associations with turbidity/colour, again indicating oxygen drawdown where particle and organic loads were higher. Metals showed slightly clearer positive ties with EC/TDS than in the dry season (e.g., Fe and Mn with EC/TDS at low moderate r), compatible with wet season mobilisation from plumbing and sediments. E. coli correlations remained weak, reinforcing that microbial spikes were episodic and structural (covers, downpipes, first-flush), rather than chemically controlled.

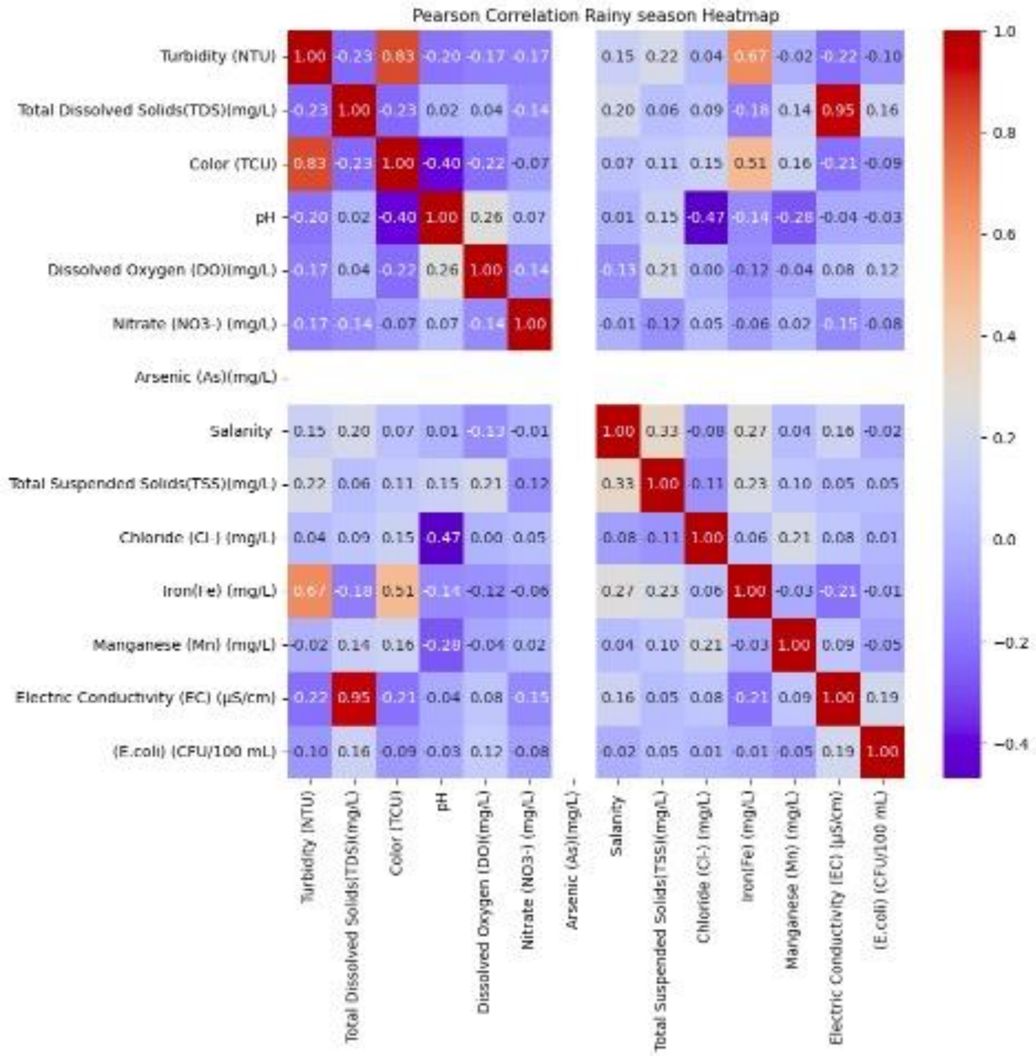

Figure 6: Pearson Correlation Heatmap of Wet Season

Across seasons, EC can be treated as a reliable proxy for ionic strength (via TDS/salinity), while color and turbidity jointly indicate particle/organic loads that depress DO. Because E. coli does not co vary strongly with these bulk measures, microbial risk should be managed directly (cleaning/disinfection and sealed inlets) rather than inferred from chemistry alone. The stronger wet-season correlations (EC, TDS and color, turbidity) suggest that monsoon processes act coherently across households, which helps explain the seasonal IWQI downgrades observed for a subset of sites.

5.5 Questionnaire and sanitation assessment

For the sanitation and primarily water quality assessment, some questionnaires were built and divided into four sections. And these sections are categorized:

1. Drinking water
2. Water source and storage practices
3. Sanitation
4. Hygiene

5.5.1 Drinking water

From the household questionnaire responses, 57% reported that their drinking water appeared clear, while 43% noted loss of clarity. This split suggests that visual turbidity is not universal but remains a concern for a sizeable minority, likely linked to seasonal resuspension in storage tanks and roof runoff entry during the rains. The finding is consistent with laboratory turbidity results that showed mostly acceptable values with episodic spikes in certain unions. Similarly regarding color, 73% described the water as colorless, and 27% observed discoloration. The minority reporting color aligns with locations where iron/manganese and turbidity were elevated, which can impart yellow brown tints or staining. These reports reinforce the need for routine tank cleaning and, where relevant, simple polishing filters for households repeatedly affected.

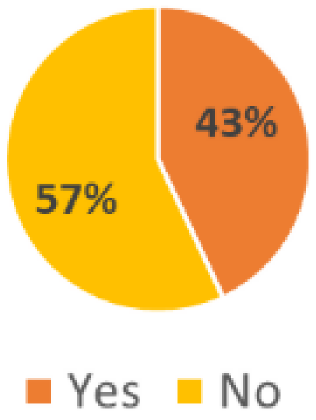

Figure 8: Pie chart of clarity of water

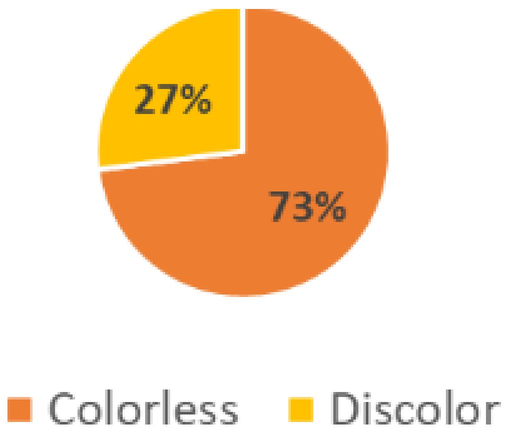

Figure 7: Pie chart of Color of water

In contrast Only 12% of respondents reported any odour, whereas 88% reported no smell. The low frequency of odour complaints is compatible with moderate organic load and sulphide levels in the dataset. Where odour was noted, it is likely tied to stagnant storage, biofilm growth, or metal-related reactions, pointing to the importance of regular tank flushing and secure covers. Perceptions of taste were favourable: 91% rated the water good, with 9% rating it bad. The generally positive taste reports match the measured ranges for salinity, chloride, and TDS, which were mostly moderate. The small fraction noting unpleasant taste may reflect localised issues such as elevated iron/manganese or residual disinfectant imbalance, warranting site specific checks.

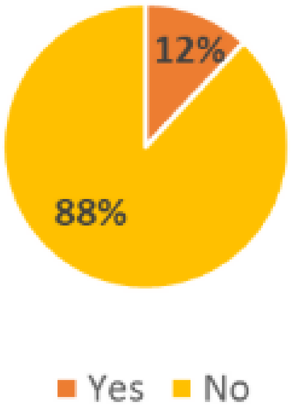

Figure 10: Pie Chart of Odor of water

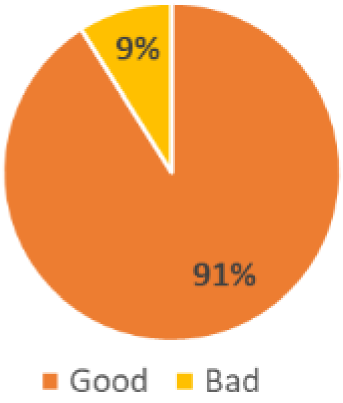

Figure 9: Pie Chart of Taste of water

Taken together, the household perceptions point to generally acceptable drinking-water aesthetics with a clear minority of concern. Most respondents described their water as clear (57%) and colorless (73%), and a large majority reported no odor (88%) and good taste (91%); accordingly, 82% were satisfied with the visual quality overall. At the same time, the 43% noting loss of clarity and the 27% reporting discoloration indicate localized and likely seasonal issues, consistent with rain-time sediment entry, re-suspension in storage, and occasional metal (Fe/Mn) staining. These perceptions align with the laboratory findings: bulk chemistry was typically moderate, but a subset of tanks showed aesthetic problems that can be addressed through better tank covers and downpipe seals, pre monsoon cleaning with midseason flushing and simple point of use polishing where issues recur.

5.5.2 Water source and storage practices

Service supply was found to be groundwater dominant, with submersible pumps accounting for 88% of household sources and piped water for 12%**.** Union-wise pump settings indicated abstraction from intermediate aquifers, with average depths of 200 ft in Kyalzta and 300–350 ft in Gacha, Pubail, Basan and Konabari, increasing to 400 ft in Gazipur, Kashimpur and Tongi**.** This distribution suggests that most households draw from layers buffered against short-term rainfall variability, while still shallow enough for iron and manganese to appear locally consistent with the laboratory results and community reports of occasional discoloration.

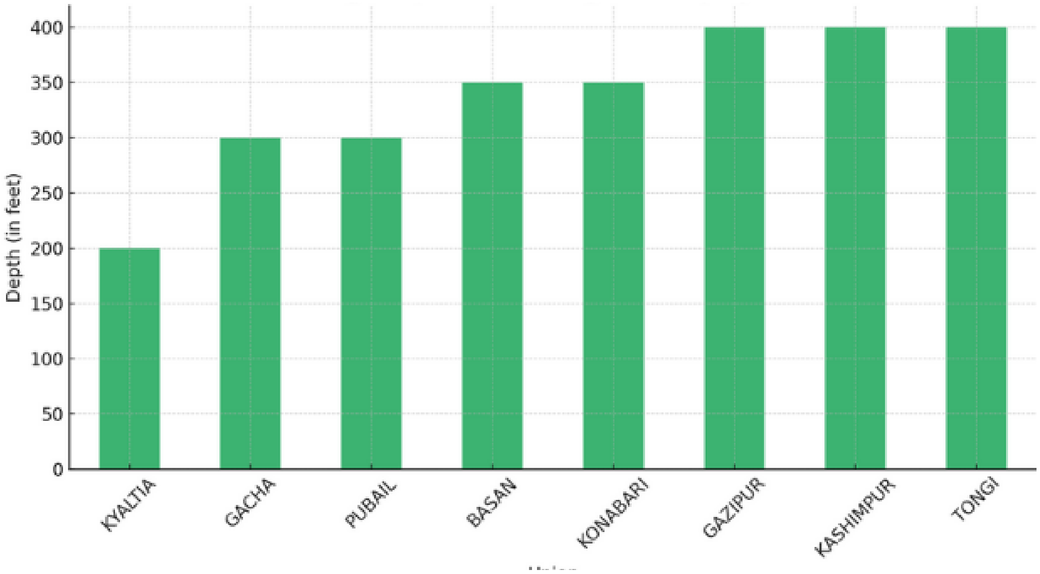

Figure 11: Average depth of submersible pump unionwise of Gazipur

Daily demand patterns imply routine reliance on storage. Reported use averaged 8–9 L/person/day for drinking and 45–50 L/person/day for domestic purposes, so household and rooftop tanks were typically used to bridge supply gaps. Where storage was practiced, water turnover was observed to be the key determinant of quality: tanks left stagnant showed more aesthetic complaints during the rains. Field responses on operation and maintenance indicated that 62% of households cleaned their tanks at least once per year, whereas 38% never cleaned. This practice profile aligns with the statistical finding that more frequent cleaning was associated with lower E. coli occurrence, underscoring storage hygiene as a practical control point.

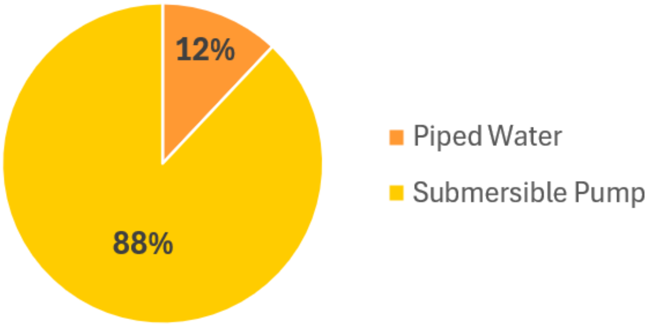

Figure 12: Pie Chart of Main Sources of water

Overall, a system that relies on submersible pumped groundwater with household storage was documented. Water safety in this configuration is best preserved by covered tanks, secure downpipe connections, and scheduled cleaning before the monsoon with one mid-season flush, so that stored volumes are turned over quickly and microbial regrowth is limited.

5.5.3 Hygiene

Hygiene conditions were assessed through self-reported practices and recent illness history. Access to hand-washing stations with soap was reported by 57% of households, while 43% reported no designated station. General awareness of safe hygiene practices was found to be limited; only 5% reported being aware of recommended behaviours, and 95% reported low or no awareness. These findings indicate that everyday risk-reduction behaviours (handwashing after toilet use, before food preparation, and safe storage/serving) are not being applied consistently across the study area.

Table 9: Reported water related illnesses (last 6 months)

Disease	Percentage (%)
Diarrhoea	41
Skin disease	38
Typhoid	12
Cholera	3
Hepatitis	3
Dysentery	3

Recent health experience was also recorded to understand possible outcomes of hygiene gaps. Within the previous six months, 35% of respondents reported that at least one household member had been affected by a water-borne disease, while 65% reported no recent illness. Among reported illnesses, diarrhoea (41%) and skin disease (38%) were most common, followed by typhoid (12%), and smaller shares of cholera (3%), hepatitis (3%), and dysentery (3%). The pattern is consistent with faecal exposure pathways, where inadequate hand hygiene and contact with unclean water or drains are typical drivers.

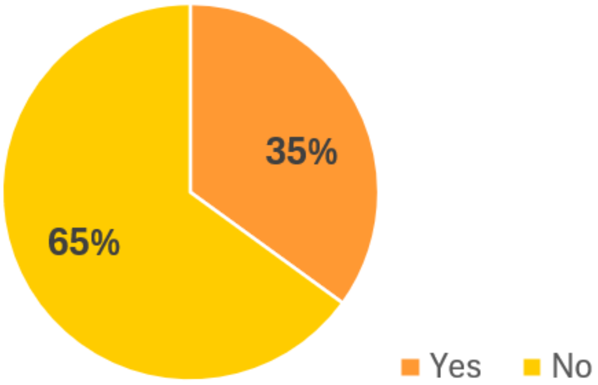

Figure 13: Pie Chart of Affected by water borne diseases in last six months

The likely mechanisms underlying these outcomes were interpreted from the survey prompts given alongside each disease category. Diarrhoea was most often linked by respondents to high *E. coli* in drinking water; skin diseases were linked to contact with unclean water or poor drainage; typhoid was linked to consumption of faecal contaminated water; and cholera, hepatitis, and dysentery were linked to severe contamination, viral ingestion, and faecal pollution respectively. When viewed together with the laboratory findings that detected *E. coli* in a large share of samples, the illness profile appears consistent with the environmental risks identified in water testing.

Overall, hygiene conditions in the study area can be characterised as mixed: hand-washing access exists for just over half of households, awareness is low, and a substantial minority reported recent water-related illness. The results suggest that meaningful health gains could be achieved through simple behaviour-focused actions (ensuring a functional hand-washing station with soap at critical points, routine cleaning of taps and containers, and safe handling of stored water), combined with attention to drainage to minimise skin exposure to contaminated water.

5.5.4 Sanitation

Sanitation facilities across the surveyed households were found to be predominantly pit latrines (79%), with flush toilets reported by 21%. Although 90% of facilities were reported as connected to a septic tank or sewer, stormwater and greywater were mostly conveyed by open drains (70%), indicating that on-plot containment often coexists with surface discharge around homes.

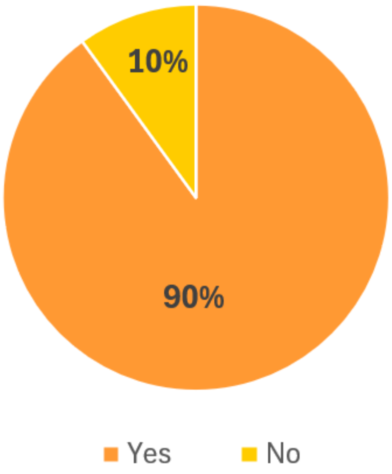

Figure 14: Pie Chart Connection of sanitation facility to sewage or septic system

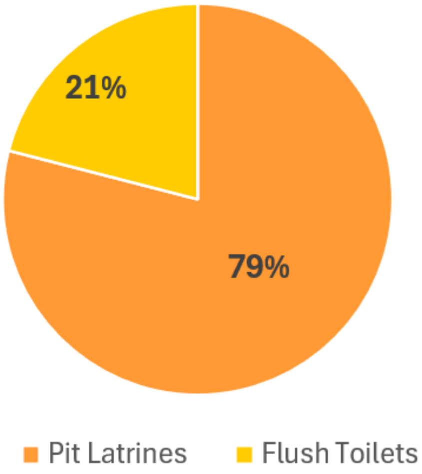

Figure 15: :Pie Chart of Types of Toilets

Routine upkeep appeared uneven. Tank cleaning was reported by 62% of households at least once per year, while 38% reported never cleaning, which implies a gradual loss of containment efficiency and a higher likelihood of overflow or seepage during the wet season.

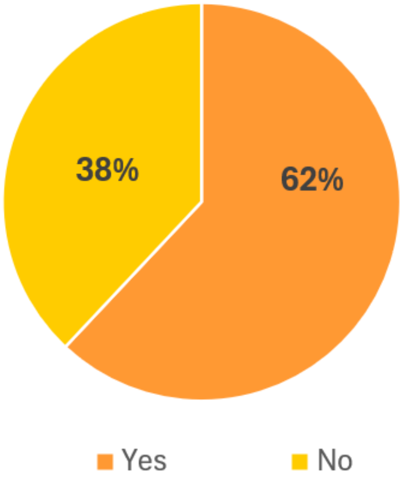

Figure 15: Pie Chart of Tank Cleaning at least once per year

Affordability barriers were indicated by the reported cleaning costs. For higher-income households, desludging/cleaning typically cost 500–600 BDT, whereas lower-income households reported 150–200 BDT, usually associated with ad-hoc manual emptying or partial cleaning. Such differences suggest that safe, mechanical emptying is not equally accessible and that some households may defer maintenance because of cost. Water availability for sanitation activities was generally adequate; 89% reported sufficient water and 11% reported shortages, which helps to explain why facilities are functional but does not guarantee hygienic conditions around the plot.

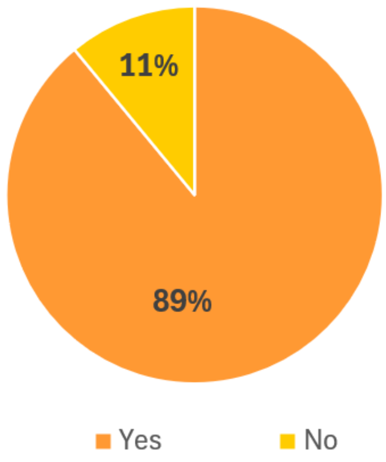

Figure 16: Pie Chart of Sufficient water availability for sanitation use

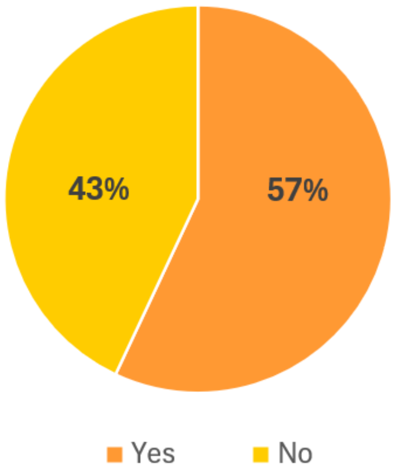

Figure 17: Pie Chart of Access to Hand Washing

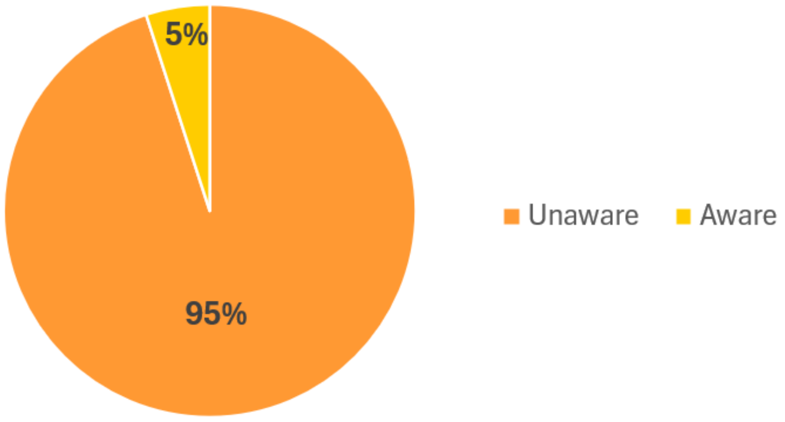

Figure 18: Pie Chart of public awareness

Behavioural and awareness indicators point to important gaps. Only 5% of respondents considered themselves aware of recommended sanitation and hygiene practices, while 95% reported low awareness. Consistent with this, access to a hand-washing station with soap was reported by 57%, leaving 43% without a dedicated station at or near the toilet. These shortfalls, together with open drainage, create pathways for faecal contamination in the immediate environment and align with the illness pattern noted in the hygiene section (high reports of diarrhoea and skin disease). Overall, sanitation coverage exists in form, but regular maintenance, safe emptying, and behaviour change remain the critical levers for reducing exposure.

5.6 Limitations

Interpretation of the results should proceed with care because several design and data constraints were present. Sampling was conducted at the household point of use across the eight unions and then repeated in the wet season to obtain paired observations. This frame delivers a season-resolved snapshot but not a census. Fine scale heterogeneity within unions, as well as rare contamination events, may therefore have been underrepresented. Because the campaign was scheduled in two seasonal windows rather than monitored continuously, short lived excursions after heavy rainfall, pipe repairs, tanker refills, or tank-cleaning events could have been missed; consequently, causal attributions for the observed seasonal differences are necessarily tentative.

Analytical coverage focused on a conventional suite of physicochemical and microbiological parameters that are most relevant to household safety screening. However, virological hazards (e.g., norovirus, hepatitis A), protozoan pathogens (e.g., Giardia, Cryptosporidium), disinfection by-products, pesticides, and many industrial organics were not included, and no isotopic or source-tracking tracers were used. Where these unmeasured hazards are present, overall risk would be underestimated. Standard laboratory constraints holding time, sample transport, instrument precision, and method detection limits apply. Several variables showed values at or below detection (e.g., arsenic) or at structural zeros; these “censored” observations reduce power and can bias non-parametric tests toward the null if ties are common.

The seasonal hypothesis testing relied on the Wilcoxon signed-rank test, which assumes that the distribution of within household differences is symmetrically centered under the null. In practice, many water quality variables are right-skewed, and several were discretized (reporting to one or two decimals) or exhibited ties due to detection limits. Under such conditions, p values can be conservative and effect sizes sensitive to a small number of large shifts. Likewise, the chi square analysis relating E. coli presence to tank-cleaning frequency dichotomized both exposure and outcome for tractability (≤ 2 vs. >2 cleanings; absent/present). Dichotomization sacrifices information (e.g., the difference between three and twelve cleanings is treated equally) and, when any cell count is very small or zero as occurred in the dry-season table χ^2 statistics can be inflated; Yates’ continuity correction or Fisher’s exact test would be more conservative checks. Pearson correlation heatmaps were used to explore linear co-variation among parameters. Because many variables are non-normal and bounded, linear correlations may under or over-state association strength; monotonic but non-linear relations are better captured by Spearman’s ρ. In addition, shared physical drivers (ionic strength, dilution) induce collinearity (e.g., EC, TDS, chloride), making partial correlations or multivariate models preferable for causal interpretation.

Construction of the Integrated Water Quality Index (IWQI) followed a weighting and threshold scheme appropriate for communication with non-specialist readers. The index usefully compresses multidimensional measurements into classes; however, different parameter combinations can map to the same class, and health risk is not uniform across parameters (for example, a moderate iron exceedance is not equivalent to E. coli presence). No formal sensitivity analysis was performed to show how IWQI classes change under alternative weights or cut offs, so classification stability could not be quantified. Benchmark comparisons relied on WHO (2022) and ECR (2023) limits; for some parameters (e.g., EC, colour for certain uses) guidance values were absent or context-dependent, which restricted exceedance reporting and complicates international comparability.

Survey based variables self-reported tank cleaning frequency, water use volumes, type of sanitation, hand-washing access, and recent illness are subject to recall error and social-desirability bias. Shared or communal facilities may have been misclassified as household facilities. Environmental and socio-economic covariates that plausibly confound water quality (industrial discharges, septic leakage, drain connectivity, population density, income, and education) were not measured at sufficient resolution; as a result, observed associations between practices and quality should be viewed as indicative rather than causal. Spatial processes were not modelled explicitly (e.g., through kriging or network-aware analyses), so potential hotspots linked to hydrology, pipe age, or land use could not be resolved beyond descriptive mapping.

Finally, external validity is bounded. The study area is a fast-urbanizing district where mixed sources (submersible pumps, intermittent piped supplies, and household storage) coexist. Extrapolation to rural aquifers, continuously chlorinated utilities, or flood-prone chars should be made cautiously. Overall, the evidence assembled here is best interpreted as a conservative, paired, season-specific profile of household water quality and sanitation practices that can guide local intervention design while motivating future work with higher temporal resolution, expanded analyte panels (including pathogens and organic contaminants), explicit spatial modelling, and sensitivity analyses for index construction and statistical inference.

Chapter six: Conclusions and Recommendations

This chapter brings together the evidence generated on drinking water quality, sanitation practices, and hygiene conditions across the study area. Key analytical results are synthesized spanning seasonal statistics, IWQI classes, Wilcoxon and χ^2 tests, Pearson correlations, and questionnaire findings to judge the present safety of household supplies and the likely drivers of risk. The practical relevance of the study is underscored by describing how these findings can help advise interventions for schools and communities, enhance surveillance activities and inform local policy-makers. Quick comments on future improvements (e.g., increased spatial range, follow-up cohorts) are reported. Last, actionable recommendations are provided regarding point-of-use treatment, infrastructure maintenance, sanitation education and waste/drainage systems so that the findings from the study can be translated into tangible gains.

6.1 Conclusion

This study was conducted to describe the quality of drinking water, sanitation status at household level in eight unions of Gazipur using multi-method cross-sectional survey. Physico-chemical (PC) and bacteriological (BA) quality were monitored during dry and wet seasons in parallel, an Integrated Water Quality Index (IWQI) was constructed for the general suitability status, seasonal fluctuations were assessed using Wilcoxon signed-rank test, tank cleaning frequency to E. coli occurrence relationship was checked by χ^2 while inter-parameter dependencies explored by Pearson correlation. Practices regarding sources, storage, hygiene and sanitation were documented using a structured questionnaire. Taken together, these threads present a consistent story of seasonal water quality, its probable drivers, and the public health implications in this heavy-industrialized region.

Over the 2 seasons, microbiological risk was the overwhelming public-health issue. E. coli was present in nearly all household samples, above the WHO threshold of 0 CFUs/100 mL in 100% of sites in both seasons, suggesting sustained faecal contamination at the point-of-use. A few chemical values also had frequent exceedances: manganese was in excess of national/WHO standards in approximately 75% of samples, iron in about a third. Dissolved oxygen was regularly over 4–6 mg/L (extra during the wet season) which is not in itself harmful but indicative of aeration/measurement dynamics as opposed to potability. Low pH and turbidity, chloride and nitrate exceedances were relatively rare (and localized) (e.g., Tongi had highest level of turbidity which often exceeds the global guideline).

The synthesis of IWQI highlighted such patterns and illustrated the seasonal degradation. During the dry season, Excellent and Good comprised 36% and 31% of households respectively with Poor/Unsuitable accounting for just 15%. During the wet season, the distribution was broader and skewed toward a lower class; Excellent decreased to 30% and Good dropped to 19%, whereas Poor/Unsuitable increased to 27%. So while a large portion of households were typical of adequate overall quality, a definite monsoonal penalty was found with more sites transitioning into uncomfortable and inadequate when rainfall, runoff and water pipe disturbances are at their highest.

It was possible, through statistical testing, to identify what parameters led to that seasonal shift.Wilcoxon results showed significant dry-to-wet changes for chloride (decrease), nitrate (increase), salinity (decrease), TDS and total solids (decrease), manganese and iron (increase), and pH (increase), with effect sizes ranging from small to large. Colour, dissolved oxygen, *E. coli*, electrical conductivity and turbidity did not change significantly at $\alpha = 0.05$, underscoring that microbial risk is persistent rather than strictly seasonal. The χ^2 analysis linked behaviour to risk: households cleaning tanks more than twice per year were significantly less likely to have *E. coli*-positive results, with a large association in the dry season (Cramér's V=0.56) and a smaller but still significant association in the wet (V≈0.27). Correlation analysis revealed strong clusters among salinity, chloride, EC, TDS/TS and between iron and manganese, consistent with hydrogeochemical co-occurrence and industrial/pipe-scale influences, while correlations with E. coli were weak implicating sanitary breaks and storage hygiene rather than background chemistry.

Taken together, the evidence indicates that Gazipur's household drinking water is affected by two intertwined challenges: (i) chronic faecal contamination at or after collection, reflected in ubiquitous *E. coli* regardless of season; and (ii) location-specific chemical burdens especially Mn and Fe with seasonal modulation from monsoon dynamics. Infrastructure and practice matter: more frequent tank cleaning and better storage hygiene were associated with lower microbial positivity; unions with higher EC or metal exceedances aligned with known industrial footprints. These findings provide a clear basis for targeted interventions in subsequent recommendations: point-of-use disinfection and safe storage to address the dominant microbial risk; prioritised mitigation for iron/manganese hotspots; and behaviour-focused programs (tank cleaning, handwashing access) that are feasible at household and community level while broader network upgrades are planned.

6.2 Recommendations

Grounded in the season wise laboratory results, the IWQI classes, the Wilcoxon and chi-square tests, and the questionnaire findings, the following actions are recommended. They are grouped so that institutions and local authorities in Gazipur can translate them directly into plans, budgets, and routine practice.

A. Safeguard and treat drinking water

- Disinfect every household/school supply at point of use. Given the universal E. coli exceedance, a continuous residual disinfectant (e.g., chlorination by doser/inline cartridge) or daily point-of-use methods (boiling, chlorine tablets, UV, or gravity filters with disinfection) should be required. Target: free chlorine 0.2–0.5 mg/L at taps; zero thermotolerant coliforms.
- Add iron/manganese removal where needed. Aeration–settling–sand/greensand filters (or pressure filters with MnO_2 media) should be installed on sources showing persistent Fe/Mn above standards. Backwash logs must be maintained.
- Install cartridge or rapid sand filters ahead of chlorination for high turbidity sites to improve chlorine efficacy and taste/odor.
- Protect sources. Raise and seal wellheads, grout annular spaces, and create 10 m sanitary radii free of drains, pits, and washing areas. Repair cracked platforms and ensure positive drainage away from wells.

B. Improve storage and distribution hygiene

- Tank hygiene SOP. Based on the chi-square findings, cleaning frequency should be ≥ 2 times/year at minimum; monthly inspection plus quarterly cleaning where sediment forms quickly. Provide a printed SOP covering drain, isolate, scrub, disinfect, rinse and refill.
- Closed, first flush, and overflow controls. Fit lockable lids, screened vents/overflows, non -return valves, and first flush diverters on rain or piped inflows. Replace flexible hoses with food-grade pipes and eliminate dead-ends.
- Residual tracking. Daily logbooks for free chlorine and turbidity at sentinel taps; corrective actions when residual < 0.2 mg/L or turbidity > 5 NTU.

C. Sanitation and drainage

- Separation and containment. Maintain ≥ 10 m horizontal separation and, where feasible, higher wellhead elevation than latrines/septic tanks. Seal leaking pits; retrofit septic tanks with baffled chambers and watertight lids.

- Regular desludging. Establish a rostered service (every 2–3 years) with safe transport to licensed treatment/disposal points.
- Drainage upgrades. Convert open drains to covered drains around water points; ensure outfalls do not backflow during monsoon.

D. Hygiene behavior change

- Hand-washing access and nudges. Because 57% reported access, place soap-and-water stations at toilets/canteens/entry points; use visual cues and student monitors. Track soap consumption per 100 pupils per week.
- Risk communication. Short, repeated sessions on safe water handling, container hygiene, and diarrhoea prevention for students, caretakers, and food vendors. Use posters that match the local language and reading level.

E. Routine monitoring and reporting

- Tiered testing plan.
    - Daily/weekly: chlorine residual, turbidity, pH at taps.
    - Monthly: E. coli (presence/absence) using field kits for all sites.
    - Quarterly: full physicochemical panel (Fe, Mn, EC, TDS/TS/TSS, nitrate, color).
- Data transparency. Post simple "water safety dashboards" at each institution (traffic-light colors), and upload to a shared spreadsheet for union level supervision.
- Incident response. Written protocols for boil water advisories, shock chlorination, and alternative supply during failures or floods.

F. Seasonal preparedness (dry vs. wet)

- Monsoon playbook. Before rains: raise/repair platforms, clear drains, stock chlorine, and increase bacterial testing frequency to weekly; after floods: shock-chlorinate tanks and flush distribution.
- Dry-season taste/EC management. Where salinity/EC rises in the dry season, blend sources, use demand management (staggered pumping), or pilot low-pressure RO only for drinking points rather than whole campuses.

G. Governance, capacity, and financing

- Assign a Water Sanitation Focal Person in each institution, trained and certified annually in testing, chlorination, and record-keeping.
- Small O&M fund. Ring-fence a modest monthly budget for chemicals, spare parts, and laboratory fees, link disbursement to submission of monitoring logs.
- Vendor/service contracts. Framework agreements for scheduled tank cleaning, desludging, and media replacement to ensure consistency and traceability.

H. Research and follow-up

- Hotspot mapping. Use your IWQI classes and correlation clusters to target unions with repeated non-compliance for intensified investigation (e.g., hydrogeology, industrial discharge pathways).
- Intervention trials. Pilot two or three disinfection/filtration packages and compare E. coli removal, costs, and user acceptance over 6–12 months.
- Longitudinal assessment. Repeat the full survey and IWQI in the same households across seasons next year to quantify trends and intervention impact.

If these measures are adopted with clear responsibilities, simple logs, and seasonal checklists, the study’s key risks like microbial contamination, storage related recontamination, and localized chemical exceedances can be reduced quickly, with measurable improvements in safety, taste, and user confidence.

References

Ahmed, M., Rahman, M., & Hossain, S. (2019). Assessment of water storage hygiene in Dhaka households. *Journal of Environmental Health Studies, 27*(3), 45–52.

Khan, N., & Jahan, T. (2020). *E. coli* contamination in stored household drinking water: A case from peri-urban Bangladesh. *Water Quality Research Journal, 35*(1), 22–29.

Haque, R., Akter, S., & Islam, M. (2021). Drinking water testing behavior among Bangladeshi households: A survey analysis. *Journal of Public Health and Hygiene, 12*(4), 310–316.

World Health Organization. (2017). *Guidelines for drinking-water quality* (4th ed.). WHO Press.

Department of Public Health Engineering (DPHE), & Bangladesh Bureau of Statistics (BBS). (2019). *National sanitation survey report*. Government of Bangladesh.

Rahman, S., & Sultana, R. (2020). Water tank cleaning behavior and contamination risks in peri-urban households. *South Asia Water Journal, 18*(2), 78–85.

Islam, M. S., Haque, A., & Khan, R. (2018). Microbial risks in groundwater: Assumptions vs. evidence. *International Journal of Water Research, 24*(3), 105–112.

Hossain, M., Hasan, M. R., & Alam, M. (2019). Industrial impacts on household water quality in Gazipur industrial zones. *Environmental Pollution Bulletin, 29*(1), 60–67.

Akter, N., & Mahmud, K. (2021). Frequency of water tank cleaning and its impact on *E. coli* levels in household storage. *Hygiene and Water Safety Journal, 11*(1), 33–41.

UNICEF. (2020). *Water, sanitation and hygiene (WASH) behavior in rural Bangladesh*. United Nations Children's Fund.

Sarkar, S., Rahman, A., & Ahmed, K. (2016). Microbial contamination in drinking water of restaurants in Sylhet City. *Journal of Food Safety and Health, 20*(2), 97–102.

Alam, M. S., Rahman, M., & Islam, M. A. (2005). Unsafe iron and microbial contamination in Sylhet restaurant water sources. *Journal of Environmental Safety, 12*(3), 181–188.

Nkere, C. K., Ibe, N. I., & Iroegbu, C. U. (2010). *E. coli* levels in water of restaurants and street vendors in Nsukka town, Nigeria. *Journal of Health, Population and Nutrition, 28*(5), 456–462.

Shariar, M. R., & Himel, S. M. (2021). Unsafe water and poor sanitation in schools of Gazipur: A cross-sectional study. *Bangladesh Journal of Environmental Health, 16*(2), 122–128.

Moniruzzaman, M., Ahmed, S., & Rahman, M. (2011). Prevalence of *E. coli* and *Shigella* spp. in roadside restaurants of Savar and Gazipur. *Journal of Microbial Safety, 10*(1), 35–42.

Shields, K. F., Bain, R. E., Cronk, R., Wright, J. A., Bartram, J., & Nelson, K. L. (2015). Water quality changes between source and point-of-consumption in Kenya. *Environmental Science & Technology, 49*(6), 3841–3849.

Bain, R. E., Cronk, R., Wright, J., Yang, H., Slaymaker, T., & Bartram, J. (2014). Global assessment of exposure to fecal contamination through drinking water: A systematic review. *PLoS Medicine, 11*(5), e1001644.

Pickering, A. J., Davis, J., Walters, S. P., Horak, H. M., Keymer, D. P., Mushi, D., & Boehm, A. B. (2012). Microbial contamination and proximity of sanitation to water sources in rural Tanzania. *Environmental Science & Technology, 46*(11), 5452–5460.

Paramank, M., Islam, M. T., & Huda, Q. (2011). Outbreaks of waterborne diseases in the Korail slum due to sanitation failures. *Bangladesh Urban Health Bulletin, 18*(2), 55–62.

Arias-Granada, Y., Haque, S., Joseph, G., & McKenzie, D. (2018). *Water and sanitation access and affordability in slum households of Dhaka* (World Bank Policy Research Working Paper No. 8652). World Bank.

Brouwer, R., van den Berg, C., & Linderhof, V. (2023). Willingness to pay for water services among Dhaka slum residents. *Journal of Water and Health Economics, 31*(1), 101–113.

Jahan, H., Rahman, M., & Karim, R. (2015). Monsoonal contamination in tubewell water in Rajshahi slums. *Bangladesh Journal of Environmental Research, 22*(1), 66–72.

Shaibur, M. R., Uddin, M. E., & Rahman, S. (2019). Trace metals and microbial pollution in Jashore slum tubewells. *South Asian Water Review, 15*(3), 145–153.

WaterAid. (2003). *Environmental contamination from poor sanitation maintenance in slum areas* (Research report). WaterAid.

Prüss-Ustün, A., Wolf, J., Bartram, J., Clasen, T., Cumming, O., Freeman, M. C., … Cairncross, S. (2019). Burden of disease from inadequate water, sanitation and hygiene for selected adverse health outcomes. *The Lancet Global Health, 7*(5), e681–e693.

Bartram, J., & Cairncross, S. (2010). Hygiene, sanitation, and water: Forgotten foundations of health. *PLoS Medicine, 7*(11), e1000367.

Appendix

Appendix A: Values of IWQI for dry season

DRY SEASON IWQI		
Union Name	**IWQI (SI)**	**Remarks based on IWQI**
Gacha	0,292	Excellent
	0,112	Excellent
	0,020	Excellent
	0,194	Excellent
	1,320	Good
	0,615	Excellent
	0,150	Excellent
	1,825	Good
	1,588	Good
	1,937	Good
	2,520	Marginal
	1,866	Good
Basan	0,483	Excellent
	3,020	Poor
	0,913	Excellent
	0,108	Excellent
	0,451	Excellent
	0,935	Excellent
	0,616	Excellent
	0,842	Excellent
	0,217	Excellent
	9,503	Unsuitable
Konabari	3,572	Poor
	2,538	Marginal
	4,377	Poor
	1,223	Good
	6,781	Unsuitable
	2,203	Marginal
	2,970	Marginal
	2,075	Marginal
	0,558	Excellent
Gazipur	0,323	Excellent

	0,738	Excellent
	1,745	Good
	1,005	Good
	0,705	Excellent
	0,520	Excellent
	2,010	Marginal
	1,507	Good
	1,172	Good
	2,033	Marginal
	0,794	Excellent
	0,577	Excellent
	0,062	Excellent
	1,335	Good
	1,943	Good
	0,790	Excellent
	1,865	Good
	0,287	Excellent
	2,493	Marginal
	1,810	Good
	1,496	Good
	2,461	Marginal
	1,636	Good
	1,728	Good
	0,734	Excellent
	3,587	Poor
	2,705	Marginal
	1,403	Good
	0,990	Excellent
Tongi	3,223	Poor
	4,356	Poor
	6,267	Unsuitable
	4,478	Poor
	3,312	Poor
	3,725	Poor
	1,662	Good
	1,756	Good
	7,840	Unsuitable
	3,053	Poor
Pubail	1,477	Good

	0,937	Excellent
	2,123	Marginal
	0,482	Excellent
	2,867	Marginal
	0,385	Excellent
	3,052	Poor
	1,027	Good
	1,173	Good
	1,368	Good
Kashimpur	2,040	Marginal
	2,420	Marginal
	2,555	Marginal
	1,767	Good
	0,765	Excellent
	1,440	Good
	2,128	Marginal
	1,795	Good
	2,068	Marginal
	0,682	Excellent
Kyaltia	0,540	Excellent
	0,445	Excellent
	0,315	Excellent
	1,417	Good
	2,473	Marginal
	1,780	Good
	0,980	Excellent
	0,402	Excellent
	1,205	Good
	1,877	Good

Appendix B: Values of IWQI for wet season

WET SEASON IWQI		
Union Name	**IWQI (SI)**	**Remarks based on IWQI**
Gacha	0,550	Excellent
	0,480	Excellent
	0,128	Excellent
	0,357	Excellent
	0,283	Excellent
	1,250	Good
	0,447	Excellent
	2,173	Marginal
	0,417	Excellent
	0,563	Excellent
	1,103	Good
	0,423	Excellent
Basan	1,821	Good
	2,003	Marginal
	0,287	Excellent
	0,293	Excellent
	0,538	Excellent
	1,173	Good
	0,622	Excellent
	0,870	Excellent
	0,302	Excellent
	0,740	Excellent
Konabari	4,902	Poor
	3,133	Poor
	5,275	Unsuitable
	0,357	Excellent
	9,791	Unsuitable
	2,667	Marginal
	5,194	Unsuitable
	2,303	Marginal
	0,732	Excellent
Gazipur	0,562	Excellent
	1,017	Good

	1,572	Good
	1,528	Good
	0,937	Excellent
	0,390	Excellent
	2,065	Marginal
	2,262	Marginal
	1,642	Good
	0,901	Excellent
	0,535	Excellent
	0,805	Excellent
	8,563	Unsuitable
	1,513	Good
	2,017	Marginal
	0,973	Excellent
	2,288	Marginal
	0,613	Excellent
	2,505	Marginal
	2,102	Marginal
	1,155	Good
	3,071	Poor
	1,308	Good
	1,647	Good
	0,380	Excellent
	4,138	Poor
	2,635	Marginal
	1,912	Good
	0,945	Excellent
Tongi	2,388	Marginal
	8,167	Unsuitable
	1,913	Good
	2,270	Marginal
	4,278	Poor
	4,783	Poor
	2,603	Marginal
	3,028	Poor
	4,201	Poor
	4,503	Poor
Pubail	3,549	Poor
	8,614	Unsuitable

	12,197	Unsuitable
	11,383	Unsuitable
	7,000	Unsuitable
	2,552	Marginal
	6,805	Unsuitable
	4,597	Poor
	2,787	Marginal
	1,317	Good
Kashimpur	2,215	Marginal
	2,832	Marginal
	4,138	Poor
	4,652	Poor
	3,165	Poor
	1,920	Good
	2,978	Marginal
	3,388	Poor
	4,500	Poor
	1,157	Good
Kyaltia	0,656	Excellent
	0,485	Excellent
	2,614	Marginal
	2,623	Marginal
	2,422	Marginal
	2,907	Marginal
	1,533	Good
	2,047	Marginal
	1,362	Good
	3,399	Poor