International Social Research Nexus (ISRN)
ISSN (Online): 3105-0069

Research Article

Mapping Sanitation and Hygiene Conditions in Bangladesh: Identifying Vulnerable Districts through Regional Delineation

Sanzida Sumaiya Suchana*, **Md. Kawsar Jahan Khan**

Department of Urban & Regional Planning, Rajshahi University of Engineering & Technology, Rajshahi- 6204, Bangladesh.

***Correspondence**
Sanzida Sumaiya Suchana
Email: sanzidasuchana72@gmail.com

Article History
Received: June 15, 2025
Accepted: August 21, 2025
Published: September 1, 2025

Citation
Suchana, S. S., & Khan, M. K. J. (2025). Mapping Sanitation and Hygiene Conditions in Bangladesh: Identifying Vulnerable Districts through Regional Delineation. *International Social Research Nexus (ISRN)*,1(3),1-13.
https://doi.org/10.63539/isrn.2025014

Abstract

In Bangladesh, not everyone yet has the same access to safe water, sanitation, and hygiene. Things have gotten better over the years, for example, more people now get safe drinking water and improved sanitation services. But these improvements haven't reached all areas equally. Some regions are still behind, which causes health problems like diarrhea and breathing infections, which are still major reasons why many children in the country get sick or die. This study focuses on the variation of the sanitation and hygiene situation all over Bangladesh. It focuses on five important indicators, including whether people have hand washing facilities with water and soap, access to better toilets, and whether waste is being properly managed and treated elsewhere. The data came from the Bangladesh Bureau of Statistics and were analyzed using the Composite Weighted Index method. Then SPSS and GIS tools were used for spatial classification into six categories. The analysis shows that Bandarban is the most vulnerable district in terms of sanitation and hygiene status, followed closely by Rangamati. These districts got the lowest overall scores due to limited accessibility, poor sanitation infrastructure. Both are hilly, remote districts with challenging geography that restricts infrastructure development and service delivery. However, many urban and lowland districts benefit from better infrastructure, easier access, which results in higher sanitation and hygiene scores. The variation between vulnerable and better-performing districts highlights the urgent need for region-specific approaches. Targeted efforts in Bandarban. Rangamati and similar districts should support community-led initiatives that fit the local culture and needs.

Keywords

Public Health, Sanitation and Hygiene, Composite Weighted Index Method, Formal Regionalization.

1. Introduction

Sanitation and hygiene play a necessary role in determining the public health status of a nation. Bangladesh, a country with a population exceeding 160 million people, has remained a challenge despite significant strides in infrastructure development over recent decades, with access to adequate sanitation and hygiene facilities still being a concern. While 93% of the population has access to clean drinking water, only 61% have access to improved sanitation facilities (Bangladesh Bureau of Statistics, 2018). The importance of water, sanitation, and hygiene (WASH) cannot be overstated, as it directly affects the health, well-being, and economic productivity of communities. However, major regional inequalities persist in access to WASH, especially in rural and marginalized areas, intensifying vulnerabilities and posing greater health risks, particularly in densely populated slums and areas prone to disasters. The socio-economic divide exacerbates these issues, with ethnic minorities and marginalized communities facing even lower access to sanitation and hygiene services. Ethnic minority groups in rural regions, such as those in the Chittagong Hill Tracts, have a sanitation coverage of only 27% compared to 55% in mainstream Bengali populations (Alam & Sheoti, 2024). The background of sanitation and hygiene in Bangladesh is multifaceted, shaped by various socio-economic, cultural, and geographical factors. While urban centers like Dhaka, Rajshahi, and Chittagong generally have better access to basic sanitation services, rural and coastal districts still face struggles due to poor infrastructure, poverty, and climate-induced disasters such as floods and droughts (M. H. Sarker & Ahmed, 2015). According to the MICS Report, only 36.4% of rural areas in Bangladesh have proper sanitation systems that meet safety standards, while 42.6% have reliable access to clean drinking water (Multiple Indicator Cluster Survey, 2019). These figures highlight the urgent need for targeted interventions to reduce disparities in sanitation and hygiene access. These challenges disproportionately affect vulnerable populations such as the urban poor, ethnic minorities, and people with disabilities, making them more susceptible to waterborne diseases and poor hygiene practices (Nawaz et al., 2024).

The research addresses the inequality in access to sanitation and hygiene facilities among different regions of Bangladesh. While some areas have better infrastructure, a considerable number of areas remain underserved, which is a threat to sanitation-borne diseases. This study aims to assess sanitation and hygiene conditions in all districts, identify the most disadvantaged ones, and give concrete recommendations to alleviate these inequalities. By means of a detailed regional analysis, the report seeks to guide policymakers in making informed, evidence-based policy choices to improve the living conditions of the most vulnerable groups.

The objective of this study is to evaluate the existing sanitation and hygiene conditions in various regions of Bangladesh and identify areas most vulnerable to sanitation-related health risks. It also aims to provide actionable suggestions for service improvement in such high-vulnerability areas. To this end, the study applies spatial and statistical analyses to investigate regional differences, followed by a detailed discussion of key findings and policy-based suggestions to address the identified gaps.

2. Literature Review

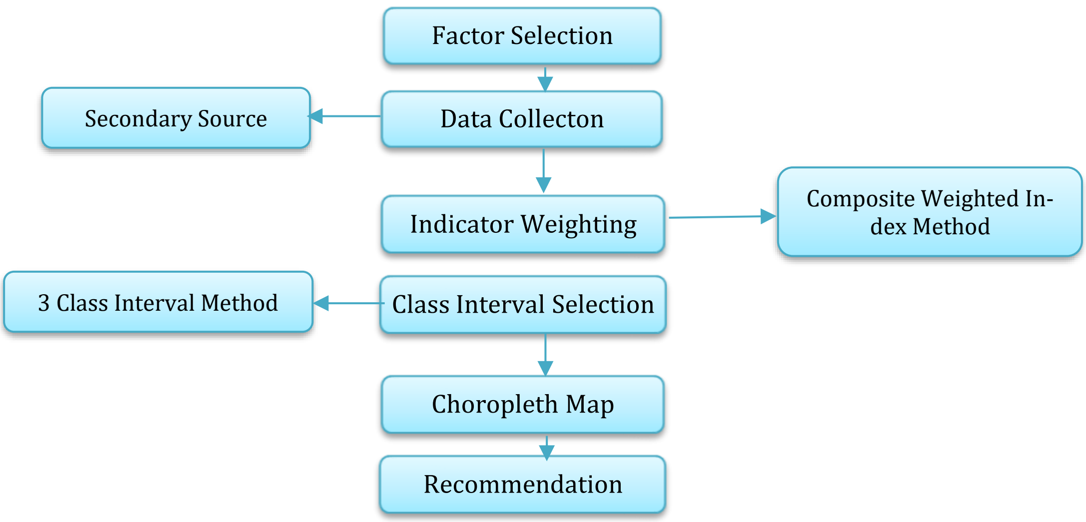
Access to sanitation and hygiene (WASH) facilities is an important public health determinant in Bangladesh. While there has been outstanding achievement in water and sanitation facilities over the past few decades, there remain substantial regional disparities, particularly among marginalized groups such as ethnic minorities, refugees, and urban poor. These inequalities are shaped by a mix of socioeconomic, cultural, and geographical factors, which have been well-documented in various studies. Several studies reveal major regional variations in access to water, sanitation, and hygiene facilities within Bangladesh (Alam & Sheoti, 2024). Ethnic minority groups have relatively lower access to WASH services compared to the majority population. For example, while 98.5% of the Bengali group has access to basic drinking water service, only 60.6% of the ethnic minorities share the same level of access. This trend is also reflected in the provision of improved sanitation and handwashing facilities, where ethnic minorities are well behind the Bengali group. Additionally, the National Hygiene Survey highlights significant variations in water, sanitation, and hygiene practices within four city corporation areas: Rajshahi, Sylhet, Barishal, and Gazipur. While over 94% of the population in these areas is served by upgraded water sources, challenges are faced, notably for the reliability and timeliness of municipal water supply services (Bangladesh Bureau of Statistics, 2018).

The application of Geographic Information Systems (GIS) has become important in mapping, analysis, and monitoring WASH conditions in Bangladesh. GIS helps and enables researchers and policy-makers to identify and address disparities in the coverage of services, and it is critical in responding to differences in regional access to safe water and sanitation (Pradhan et al., 2025). Also, provide an example of using GIS to identify sanitation and hygiene conditions in Khulna City slums, pointing to the need for upgrading urban slum infrastructure. The findings reveal that slum dwellers are disproportionately exposed to poor sanitation, which spreads diseases like diarrhea and respiratory infections. The health consequences of inadequate access to sanitation and hygiene are extensive. In Rohingya refugee camps in southeastern Bangladesh, the lack of proper sanitation and clean water facilities has significantly contributed to the spread of waterborne diseases such as cholera, dysentery, and respiratory infections. Overcrowding additionally contributes to these health issues, demonstrating the vulnerability of refugees with no basic hygiene facilities (Paul et al., 2024). Large-scale WASH interventions, such as the Sanitation, Hygiene Education, and Water Supply in Bangladesh Programme (SHEWA-B), have been evaluated for public health impacts. The SHEWA-B program, which targeted 20 million rural citizens over five years. Despite community health promoters' efforts and hygiene education campaigns, the intervention uncovered negligible changes in health outcomes, specifically childhood diarrheal disease (Aluri et al., 2022).

Recent studies also unveiled the link between WASH problems and climate change. Persons with disabilities face greater challenges in maintaining hygiene in the event of climatic disasters such as cyclones and floods. In districts like Satkhira and Gaibandha, disabled people are forced to bathe in contaminated floodwater or even avoid bathing, leading to a host of diseases, including skin disease (Nawaz et al., 2024). A study of Bangladesh schools, the WASH facilities reveal concerning gaps in drinking water quality and sanitation, with severe health implications for school children. The study found that all water samples from schools in Tongi, a mixed urban and industrial zone, were contaminated with Escherichia coli, indicating a high level of health risks. Furthermore, the presence of manganese and iron in the water at high levels posed additional health threats (Karim et al., 2024). The WASH condition of climate-vulnerable slums of Rajshahi City Corporation using a WASH Poverty Index to compare access to safe water, sanitation, and hygiene. The results refer to the extreme inequalities, with slums like Ashrayan and Char Christian Para having the lowest WASH Poverty Index. These slums have poor sanitation conditions and low access to water, which reflects the need for targeted intervention. Migration exacerbates existing WASH challenges, particularly in densely populated urban slums (Tabassum et al., 2022). Another study deals with the migration of people from the coastal and flood-prone areas of Satkhira and Bagerhat to the urban slums of Khulna City Corporation. These migrants routinely face severe scarcity of water, inadequate sanitation facilities, and lack of proper drainage systems, which heighten health vulnerability among. Additionally, the COVID-19 pandemic has further exacerbated the situation, as shared water and sanitation facilities have heightened the risk of disease transmission, disproportionately affecting women due to the lack of separate sanitation facilities (Khan, 2022).

3. Methodology

Figure 1: Methodological Framework



Source: (Author's Preparation, 2025)

3.1. Factor Selection

Five factors are selected to capture the nature of sanitation vulnerability, based on their relevance and availability in national datasets.

1. Use of safely managed drinking water services: Measures the percentage of the population with access to safe drinking water, which is critical for public health and disease prevention (Bangladesh Bureau of Statistics and UNICEF 2019).
2. Handwashing facility with water and soap: Assesses the availability of handwashing facilities with water and soap, which is vital for preventing disease transmission and maintaining hygiene standards (Bangladesh Bureau of Statistics and UNICEF 2019).
3. Use of improved sanitation facilities: Focuses on the proportion of the population using safe sanitation systems, such as flush toilets or ventilated improved pit latrines, to ensure safe disposal of faecal waste (Bangladesh Bureau of Statistics and UNICEF 2019).

4. Removal of excreta for treatment off-site: Looks at the management and treatment of faecal sludge, especially in areas where waste is removed and safely treated away from the household, to reduce health risks (Bangladesh Bureau of Statistics and UNICEF 2019).
5. Menstrual hygiene management: Examines the availability of appropriate facilities and resources for managing menstrual hygiene, which is integral for health and dignity, particularly for women and girls in vulnerable communities (Bangladesh Bureau of Statistics and UNICEF 2019).

3.2. Data Collection

Factors data for 64 districts were obtained from the Multiple Indicator Cluster Survey (MICS), 2019. Besides secondary sources, government reports, national surveys other concerned organizations were used. The latest and most reliable datasets available were utilized in the research to maintain the accuracy.

3.3. Weight Calculation and Composite Index Construction

To effectively measure the relative weights of each factor, the research employs a Composite Weighted Index technique. The measurement data of each factor were first logarithmically transformed to normalize differences in measurement scales and distributions. The weight for each factor (W_n) was calculated as the ratio of the mean to the standard deviation of the log-transformed data for that factor.

$$W_n = \frac{\text{Mean of } \text{Log}_{10} X_n}{\text{Standard Deviation of } \text{Log}_{10} X_n} \text{ .... (i)}$$

Here,

n= 1, 2, 3, 4, 5.
X_n= Individual Factor Data;
W_n = Weight of Individual Factor

Table 1 presents the calculated weights for each selected factor based on the normalized log-transformed data, highlighting their relative contribution to the composite vulnerability index.

Table 1: Composite Weight Calculation for Selected Factors

Factor	Safely managed drinking water	Handwashing Facility	Improved sanitation facilities	Removal of excreta off-site	Menstrual hygiene management
W_n	W_1	W_2	W_3	W_4	W_5
Value	8.588906184	16.62380628	24.10951717	-0.487044709	60.44856227

Source: (Author's Preparation, 2025)

The composite weighted index for each district was then computed by aggregating the weighted log-transformed factors (Glasson 1984).

$$\text{Composite Weight, W} = \frac{\sum_{n=1}^{5} W * \text{Log}_{10} X_n}{\sum_{n=1}^{5} W_n} \text{ .... (2)}$$

3.4. Selection of Class Interval

Three different methods were employed to calculate the class interval, assuming a preference for five classes.

i. Equal Interval Method

In the equal class interval method, the class interval has been determined by following (3)

$$Class\ interval = \frac{\text{Highest value} - \text{Lowest value}}{\text{Class Number}} \text{ .... (3)}$$ (Gupta 2020)

From the equation;

Highest value = 2.842579182
Lowest value = 2.542024915

Preferred class number = 6
And, Class interval = 0.0501

ii. Mean Standard Deviation Method

The mean and standard deviation of the composite score is determined utilizing the mean standard deviation method. The principle of this method is to calculate,

Mean ±1 Standard Deviation
Mean ±2 Standard Deviation
Mean ±3 Standard Deviation

iii. Arithmetic Method

This method is performed using the following equation (4)

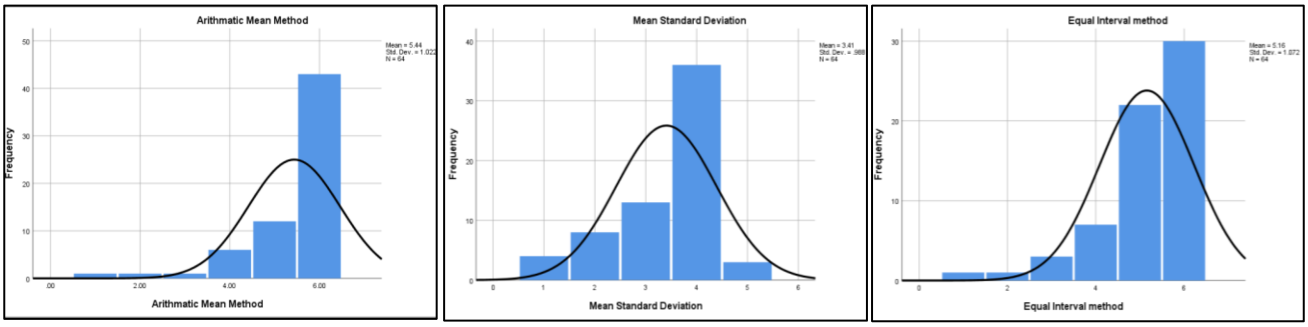
A+X+2X+…………..+NX=B ……………… (4) (Gupta 2020)

Here,

A= Lowest Value
B= Highest Value
N= Number of Class= 6
And, X= (B-A)/21 = 0.014312

The principle is to calculate the lowest cut points of each class. The cut points are then included in SPSS software to generate frequency, mean, median, mode, skewness, kurtosis, and finally a histogram. Figure 2 shows a histogram of Normal Distribution in the Equal Class Interval Method, the Arithmetic Method, and the Mean Standard Deviation Method, respectively.

Figure 2: Histogram of Equal Class Interval, Standard Deviation Method, and Arithmetic Method



Source: (Author's Preparation, 2025)

The selection of the equal class interval method was guided by the skewness value, with preference given to values close to zero. A near-zero skewness value means that the data is normally distributed. Among the three methods that were experimented with, the mean standard deviation method had a skewness of 0.988, which was closest to zero. Therefore, this approach is ideal for generating choropleth maps.

Table 2: Comparison of Class Interval Methods Based on Skewness and Kurtosis

Method	Equal Class Interval	Mean Standard Deviation	Arithmetic
Skewness	1.072	0.988	-2.361
Kurtosis	-1.677	-1.007	.299

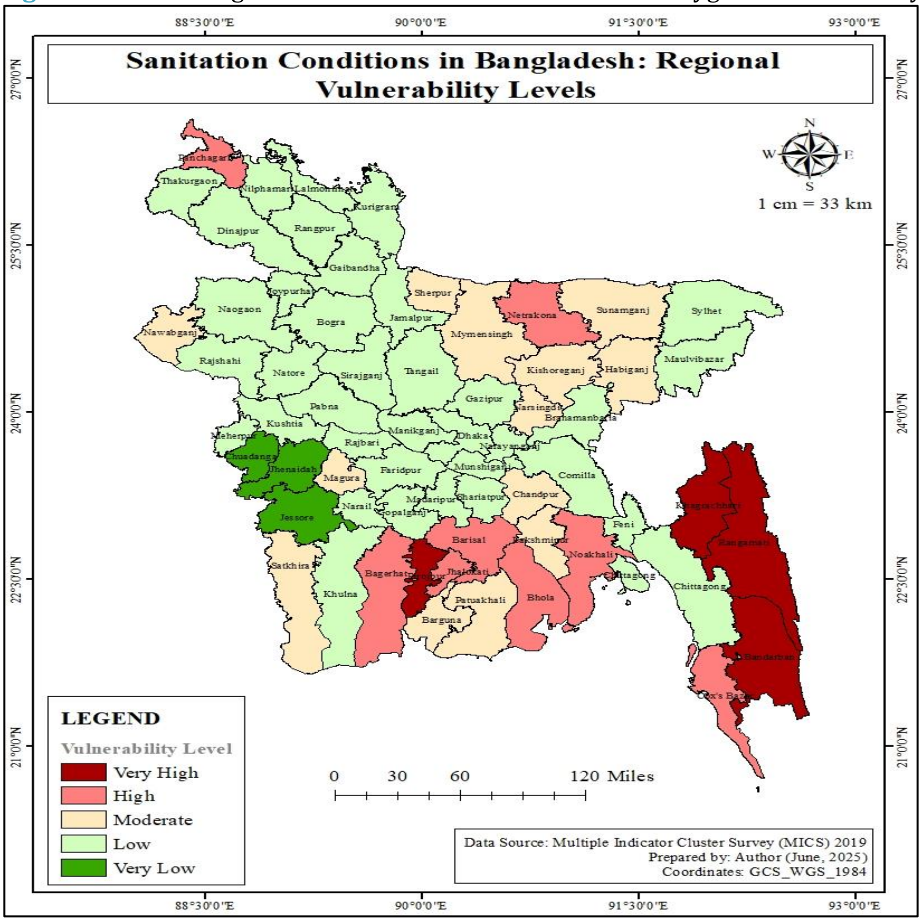
Source: (Author's Preparation, 2025)

4. Results and Discussion

4.1. Regional Delineation of Sanitation Vulnerability

The spatial distribution of sanitation vulnerability across districts is illustrated in the choropleth map below. The map categorizes districts into vulnerability levels: very low, low, moderate, high, and very high, based on a composite weighted index derived from five key indicators: use of safely managed drinking water services, handwashing facility with water and soap, use of improved sanitation facilities, removal of excreta for treatment off-site, and menstrual hygiene management.

Figure 3: Delineating the Districts Based on Sanitation and Hygiene Vulnerability



Source: (Author's Preparation, 2025)

As depicted in the map, distinct regional clusters emerge, particularly highlighting southwestern districts with notably high levels of vulnerability. Conversely, eastern and southeastern districts mostly fall into the lower vulnerability categories.

4.2. Classification Summary from the Map

In addition to the spatial visualization, districts were categorized into vulnerability classes using the mean standard deviation method, ensuring consistent range widths for each category. **Table 3** shows how many districts fall under each vulnerability category according to the map. This helps us understand how many areas are at high risk and where they are located. Major cities such as Dhaka, Chittagong, and Rangpur fall into the moderate category. These cities have a mix of stress factors, like urban challenges and socio-economic issues, which contribute to violence levels.

Table 3: Formal Regionalization with Best-Class Interval

Class Range	Categories	Count	Percent	Districts
<= 2.632784	Very High	4	4.7%	Bandarban, Rangamati, Pirojpur, Khagrachhari
2.632785 - 2.696642	High	8	12.5%	Netrokona, Barishal, Bhola, Coxsbazar, Jhalakathi, Bagerhat, Noakhali, Panchagarh
2.696643 - 2.760498	Moderately	13	39.1%	Barguna, Chapainawabganj, Kishoreganj, Lakshmipur, Mymensingh, Narsingdi, Satkhira, Sherpur, Sunamganj, Chandpur, Habiganj, Magura, Patuakhali

2.760499-2.824356	Low	36	34.4%	Brahmanbaria, Chattogram, Faridpur, Feni, Gopalganj, Jamalpur, Khulna, Nilphamari, Rajbari, Bogura, Cumilla, Dhaka, Dinajpur, Gaibandha, Gazipur, Joypurhat, Kurigram, Kushtia, Lalmonirhat, Madaripur, Manikganj, Meherpur, Moulvibazar, Munshiganj, Naogaon, Narail, Narayanganj, Natore, Pabna, Rajshahi, Rangpur, Shariatpur, Sirajganj, Sylhet, Tangail, Thakurgaon
2.824357 - 2.888214	Very Low	3	9.4%	Chuadanga, Jashore, Jhenaidah

Source: (Author's Preparation, 2025)

These regions exhibit consistently high scores across multiple indicators, especially in attitude justifying violence and low perceived safety. And the most affected districts categorized as Very High Vulnerability Exposure, about 9.4%, are Barguna, Bagerhat, Khulna, and others.

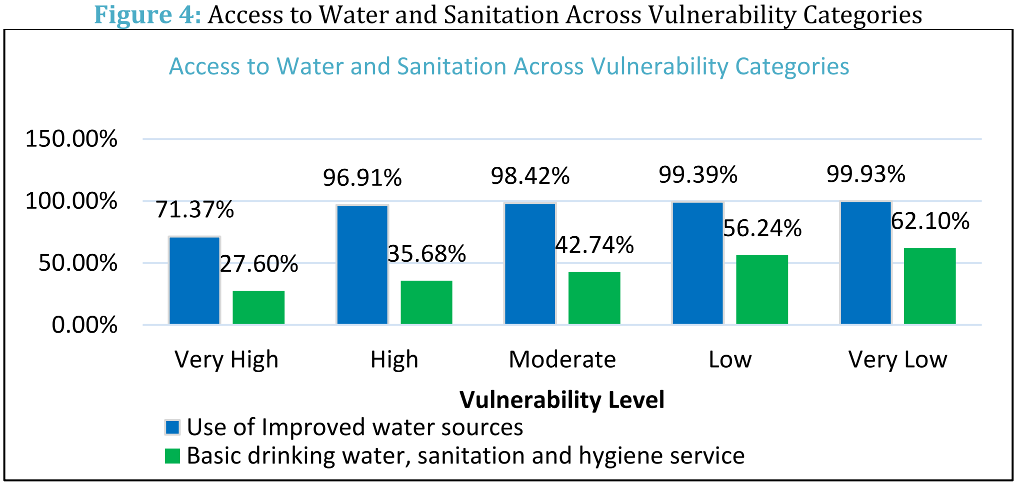
4.2. Improved Drinking Water and Sanitation Services Across Bangladesh

The data highlights significant disparities across these categories, which are further illustrated by the corresponding averages of two key indicators: Access to Improved Water Sources and Basic Drinking Water, Sanitation, and Hygiene Services.

Districts within the Very High Vulnerability category, including Bandarban, Rangamati, Pirojpur, and Khagrachari, exhibit particularly low access to both drinking water and sanitation services, with 71.37% access to drinking water and 27.60% sanitation services. This indicates a severe lack of infrastructure and services, which greatly exacerbates the vulnerability of these regions. On the other hand, high-vulnerable districts such as Netrokona, Barishal, Bhola, and Cox's Bazar show slightly improved conditions, with around 96.91% of people getting safe access to sanitation and about 35.7% having access to improved drinking water. However, these areas still face significant challenges that contribute to their vulnerability.

Although access to improved water sources is fairly widespread, access to basic sanitation and hygiene services remains alarmingly low in many parts of the country. In most districts, less than half of the population has proper sanitation facilities, pointing to a serious gap in infrastructure. While progress has been made in providing safe drinking water, poor sanitation continues to threaten public health, especially in districts marked as highly or very highly vulnerable. These findings show a pressing need for targeted action to improve sanitation systems, which could greatly reduce health risks and strengthen resilience in the worst-affected areas.

Figure 4: Access to Water and Sanitation Across Vulnerability Categories



Source: (Author's Preparation, 2025)

4.3. Impact of Flood and Drought on Sanitation and Water Access

Frequent floods and droughts, especially in highly vulnerable districts, make sanitation problems worse and limit access to clean drinking water. These climate-related events put pressure on already weak infrastructure, often disrupting basic services. As a result, people face greater health risks and are forced to adopt unsafe sanitation practices.

4.3.1. Impact of Flooding

Floods in coastal and low-lying districts like Pirojpur, Khulna, and Bagerhat often lead to severe water contamination. Overflowing sewage, damaged sanitation systems, and polluted freshwater sources are common during these events. For instance, during the 2014 floods, Khulna and Pirojpur faced major outbreaks of waterborne diseases like cholera and dysentery due to contaminated water (Pantho Rahaman, 2015). In such areas, toilets and latrines often become inaccessible or unusable because of flood damage or submersion. As a result, many people are forced to resort to open defecation, which increases the spread of disease and worsens public health conditions. Besides the health risks, floods also damage infrastructure, making it harder to maintain good hygiene in affected areas. The shortage of clean drinking water and poor waste management increase the vulnerability of communities, especially in places like Khulna and Bagerhat, where sanitation systems were already weak before the floods (Pantho Rahaman 2015).

4.3.2. Impact of Drought

On the other hand, droughts cause severe water shortages that impact both drinking water availability and sanitation. During droughts, water sources like rivers, reservoirs, and groundwater drop significantly, leaving communities with not enough water for daily needs, including basic hygiene (M. H. Sarker & Ahmed, 2015). For example, the 2015-2016 drought in Pirojpur and Barisal left many rural areas struggling to access clean water and maintain proper sanitation. Without enough water for flushing toilets, cleaning, and handwashing, hygiene practices suffer greatly in these already vulnerable districts (M. H. Sarker & Ahmed, 2015). Moreover, droughts can lead to dehydration, malnutrition, and waterborne diseases because people often have to use unsafe water sources. This worsens public health problems. Water shortages caused by drought don't just reduce access to drinking water; they also limit sanitation services, increasing health risks related to poor sanitation and making these communities even more vulnerable (The Guardian, 2024). In Rangpur and Kurigram, droughts have caused serious water shortages that affect sanitation and increase hygiene-related diseases. These areas have faced moderate to severe droughts, with much less rain during the monsoon season, about 13% less than usual. This has disrupted water supplies, making it hard for people to keep up good sanitation and hygiene (Mamun et al., 2020). Additionally, the Teesta River, which is an important water source for the area, has seen reduced flow because of water being taken upstream by India. This situation has worsened the scarcity of water, affecting farming activities and limiting water available for household needs, placing more pressure on sanitation services in Rangpur and Kurigram (Islam, 2025).

4.4. Faecal Sludge Management in High and Very High Vulnerability Zones

4.4.1. Bandarban

According to the SFD Lite Report for Bandarban Municipality, only 12% of excreta is safely managed, while a significant 88% is unsafely managed. This includes faecal sludge that is not contained, not emptied, or not delivered to treatment facilities (CWIS-FSM Support Cell DPHE, 2021a). It has limited infrastructure for faecal sludge treatment. Still have Dependence on manual emptying methods. Lack of awareness and technical expertise in FSM (WaterAid, 2023). The Chattogram Hill Tracts Inclusive and Resilient Urban Water Supply and Sanitation Project aims to improve FSM services in Bandarban Town, focusing on fecal sludge management and solid waste management (Asian Development Bank, 2022).

4.4.2. Rangamati

The SFD Lite Report for Rangamati Municipality indicates that only 13% of excreta is safely managed, with 87% being unsafely managed. This includes untreated wastewater 5%, faecal sludge not contained 69%, faecal sludge not emptied 13%, and supernatant not delivered to treatment 1%. The municipality lacks a dedicated sewerage system, and many toilets and septic tanks are directly connected to open drains or storm sewers, contributing to the unsafe disposal of wastewater and sludge (CWIS-FSM Support Cell DPHE, 2021b). Besides, there are inadequate faecal sludge treatment facilities. High reliance on manual emptying methods. Limited institutional capacity and resources (Department of Public Health Engineering, 2014). The Rangamati Municipality is exploring public-private partnerships to implement a mechanized faecal sludge collection system, including the use of vacutugs for more efficient collection and transportation of faecal sludge. In addition, collaboration with local NGOs and community-based organizations is being pursued to improve public awareness and engage residents in proper sanitation practices and waste disposal (Singh et al., 2021).

4.4.3. Pirojpur

In Pirojpur Pourashava, a survey found that 100% of households have access to toilets, but 21.66% use unhygienic toilets. The majority rely on pit latrines, with limited access to faecal sludge collection services. Lack of municipal faecal sludge collection services. High cost of manual cleaning services. Limited awareness and willingness to pay for improved services. The Sanitation Plan for Pirojpur Pourashava recommends introducing drying beds at the landfill site for primary treatment of faecal sludge and co-composting of dried faecal sludge (Asian development bank 2014).

4.4.4. Khagrachhari

The SFD Lite Report for Khagrachhari Municipality highlights that a significant portion of faecal sludge is not safely managed, with many areas lacking proper treatment facilities. Absence of faecal sludge treatment plants. High dependence on manual emptying methods. Limited institutional capacity and resources (UPM Umwelt-Projekt-Management GmbH, 2020). The Department of Public Health Engineering (DPHE) is working on implementing solid waste and faecal sludge management systems in 53 district-level municipalities, including Khagrachhari.

4.4.5. Netrokona

A recent initiative under the Third Urban Management and Infrastructure Improvement (Sector) Project (UGIIP-Three) led to the inauguration of a sanitary landfill and renovation of the faecal sludge treatment plant in Netrokona Municipality (Rubel, 2024). A key challenge in Netrokona Municipality is moving from manual to mechanized faecal sludge management systems. The current dependency on manual methods is inefficient and poses health risks, thus making the shift to mechanized systems like vacutugs is crucial. Also, keeping the new facilities like the sanitary landfill and the upgraded faecal sludge treatment plant (FSTP) working well needs regular upkeep, skilled workers, and enough funding. The renovation of the faecal sludge treatment plant aims to improve the capacity and efficiency of faecal sludge management in Netrokona (Datta et al., 2017).

4.4.6. Bhola

In Bhola Sadar, most septic tanks and pit latrines are still cleaned by hand using basic tools like buckets, ropes, and bamboo poles. Although about 70% of lined tanks and 85% of unlined pits are emptied regularly, a large number of households dispose of the waste into nearby water bodies such as lakes, canals, or rivers, which leads to serious environmental pollution. While emptying is common, only 40-50% of the emptied sludge is properly transported to a safe location, covered with soil to prevent contamination. Bhola Sadar lacks a faecal sludge treatment facility. About 70% of the emptied sludge is disposed of in newly dug pits covered with soil, but this method is unsafe in areas with high groundwater tables, as it poses a risk of contamination (UPM Umwelt-Projekt-Management GmbH, 2020).

4.5. Sanitation Infrastructure in Vulnerable Districts

In Bandarban, the absence of a dedicated sewerage system forces many households to rely on pit latrines, septic tanks, or open defecation. Many toilets are connected to open drains or storm sewers, leading to the direct discharge of wastewater into the environment, further polluting local water sources. Pirojpur primarily uses borehole systems for drinking water, and the separation between sanitation facilities and water sources is often insufficient. Contamination of groundwater remains a concern, especially when wastewater is discharged into the open environment (Abdullah Al Zubaer 2025). The sanitation system in Jhalakathi is primarily based on pit latrines and septic tanks, with limited access to modern sewage systems. Most households rely on manual methods for desludging, which are not only unhygienic but also pose significant health risks to workers. Additionally, untreated sludge is often dumped into open drains or water bodies (Department of Public Health Engineering 2023). In Bhola, 22% of households use lined tanks, while the majority, 62%, depend on unlined pits for waste containment. A further 15% use damaged or abandoned systems, and about 1% of the population practices open defecation (UPM Umwelt-Projekt-Management GmbH, 2020).

4.6. Water Pollution and Ecosystem Damage in Vulnerable Zones

The Sundarbans, located near Khulna and part of high vulnerability zones, faces severe threats from water pollution due to industrial activities. Pollution from untreated industrial waste and oil spills disrupts the ecosystem, affecting both freshwater and marine species. For example, the 2014 oil spill in the Shela River damaged over 350 km^2 of mangrove forests and impacted the biodiversity of the area, including endangered species like the Irrawaddy dolphin. The ecosystem, which relies on clean water sources, continues to face risks from such pollution events, affecting both the environment and the livelihoods of local communities dependent on fishing and agriculture for sustenance (The Guardian 2014).

Moreover, in regions like Cox's Bazar, where tourism and local populations are concentrated, improper waste management contributes to water contamination. Many households in these areas rely on unsafe methods of faecal sludge disposal, which lead to the contamination of both freshwater sources and marine ecosystems. These polluted water bodies often lead to the spread of diseases such as diarrhea, impacting community health and local economies (Islam et al. 2024).

Many of the toilets in Bhola Sadar are connected to open drains or storm sewers, causing the direct discharge of untreated wastewater into the environment. This increases the risk of water contamination and exacerbates public health issues in the area (UPM Umwelt-Projekt-Management GmbH, 2020). To mitigate these issues, urgent actions are needed to strengthen sanitation infrastructure, improve waste management systems, and enforce environmental regulations that limit industrial discharge into water bodies. Additionally, community education on safe waste disposal and government intervention are essential for safeguarding the environment and public health.

4.7. Problems Faced in Subsidy Programs

Subsidy programs aimed at improving sanitation access have faced several challenges, especially when designed under tight operational constraints. Some of the key issues include:

4.7.1. Limited Time Windows

Sometimes, short deadlines to use vouchers mean fewer low-income families can participate because they struggle to quickly gather money or the necessary paperwork. For example, WaterAid's program in Timor-Leste gave families only one month to redeem vouchers. This short period was challenging for many vulnerable households, resulting in fewer families benefiting from the program (WaterAid 2017).

4.7.2. Travel and Financial Barriers

Households in remote areas often need to travel long distances to use vouchers or get rebates. This takes up their valuable time, which could otherwise be spent earning money. Additionally, many low-income families find it hard to quickly collect enough money to pay their portion of the product's cost. Because of this, they frequently miss out on getting subsidies (WaterAid 2017).

4.7.3. Ineffective Subsidy Amounts

In some areas, the subsidy amount has not been enough to fully support households, especially poorer families. For example, in rural Tanzania, only 36% of households redeemed vouchers for latrine platforms when the subsidy was just 15%. This indicates that providing a higher subsidy could encourage more families to invest in better sanitation products (Peletz et al. 2017).

4.7.4. Social and Administrative Challenges

Some households may not get the benefits because they don't know about the program, can't manage the money in time, or face problems with the paperwork. This happens more often when programs do not consider the real-life social problems poor families face, like not knowing the right people, not having transport to reach the offices, or not having enough time because of work or family duties (Kohlitz et al. 2022).

5. Recommendations

5.1. Scale Up Rainwater Harvesting and Decentralized Wastewater Treatment

In coastal areas like Bhola Sadar and other high-risk zones, collecting rainwater has become one of the most suitable and long-lasting ways to get safe water. These regions receive about 2,900 mm of rain each year, with over 70% falling during the monsoon. This shows there is a big chance to use this natural resource. By using a method called Multi-Criteria Decision Analysis (MCDA), experts have found that rainwater harvesting is the best option to deal with water shortages in these areas. Expanding rainwater harvesting systems will help communities rely less on groundwater and offer a safer, more climate-friendly, and long-term water source. Implementing community-level RWH in schools, clinics, and households, alongside decentralized treatment of greywater and blackwater, will both improve public health outcomes and bolster climate resilience in these vulnerable districts. It will also ensure access to safe drinking water and reduce the harmful effects of taking too much groundwater, especially in areas where the water level is already low (Fahim & Islam, 2024).

5.2. Expand Sanitation Infrastructure in Vulnerable Zones

To address the ongoing sanitation challenges in vulnerable zones like Bandarban, Pirojpur, and Khagrachhari, develop and expand sewerage systems in urban and peri-urban areas where possible, while prioritizing faecal sludge treatment plants in rural regions. This will reduce the reliance on manual desludging and ensure that faecal sludge is treated and disposed of safely. These measures are projected to cut open-defecation–related stunting and parasitic infections by 25–30 % and halve FSM worker exposures.

5.3. Transition to Mechanized Faecal Sludge Management

Encourage the transition from manual to mechanized faecal sludge management, particularly in vulnerable districts, to ensure safer collection, transportation, and treatment of faecal sludge. Ensure safe disposal of faecal sludge by promoting regulated disposal methods, such as wastewater treatment plants and septic tank cleaning services (FSM 2017).

5.4. Improve the Subsidy Program

To enhance the effectiveness of subsidy programs for sanitation, several key measures should be implemented. First, the time limit for using vouchers should be made longer so that poor families, especially those in remote areas with travel or money problems, have enough time to get the support they need (WaterAid 2017). Second, the process of applying for and using the vouchers should be made simpler, so people don't face too many steps or delays (Kohlitz et al. 2022). Third, the amount of money given as a subsidy should be increased to make toilets and other sanitation products more affordable for low-income families. Research shows that when subsidies are higher, more people can install sanitation systems (Peletz et al. 2017). Lastly, awareness programs should be held in communities to explain how the support system works and who can get it, so everyone is informed and can make use of the help.

6. Conclusions

This study has analyzed the sanitation and hygiene conditions across Bangladesh, with a focus on identifying vulnerable districts through regional delineation. The findings indicate significant regional variation in access to improved sanitation and hygiene services, particularly between urban and rural areas. Though various efforts have been made to enhance WASH (Water, Sanitation, and Hygiene) facilities, certain districts, especially in the southwestern and coastal regions, continue to face severe challenges like inadequate infrastructure, poverty, and climate-induced disasters such as floods and droughts. These factors exacerbate the vulnerability of marginalized populations, including ethnic minorities, women, and people with disabilities. The research highlighted the need for targeted interventions to reduce the gap in sanitation service delivery. Specifically, regions with high vulnerability to sanitation-related health risks require urgent improvements in sanitation infrastructure, including the establishment of faecal sludge management systems, expansion of sewage networks, and enhanced public awareness. Additionally, the implementation of rainwater harvesting in coastal regions and the mechanization of faecal sludge management could significantly improve the sustainability and safety of sanitation practices. The current sanitation systems in the most vulnerable districts are insufficient to meet the needs of their populations. Therefore, comprehensive and sustained efforts from both governmental and non-governmental sectors are necessary to address these disparities. Furthermore, the study emphasizes the importance of policy reforms, financial investments, and the active participation of local communities to create a more equitable and resilient sanitation infrastructure in Bangladesh. These actions are crucial not only to reduce health risks but also to enhance the overall quality of life and economic productivity of the affected regions.

6.1. Policy–Practice Integration & Public Health Implications

To address the evaluator's recommendation for stronger linkage between analysis and actionable outcomes, we outline two priority intervention pathways along with their expected health gains. Mandate RWH systems and on-site grey-/black-water treatment in high-risk coastal districts (e.g., Bhola Sadar), financed through blended grants and micro-loans. Reliable harvested rainwater can cut monsoon-season diarrhea disease by ≈40 percent and alleviate groundwater overuse and salinization. Scale up urban sewer networks and rural FSTPs; license and regulate vacuum-tanker operators; simplify and enhance voucher-based subsidies; and roll out mechanized FSM training. These measures are projected to reduce open-defecation–related childhood stunting and parasitic infections by 25–30 percent and halve occupational pathogen exposures among FSM workers

6.2. Future Research Directions

There is a need for cohort studies that follow communities before and after WASH interventions to quantify long-term health, economic, and migration outcomes. Future work should explore alternative weighting methods (e.g., participatory AHP or machine-learning–derived weights) to test the sensitivity and robustness of the Choropleth outputs. Qualitative investigations into local perceptions of water and sanitation services can uncover social barriers and drivers that quantitative models may overlook.

6.3. Limitations

The analysis relies primarily on the 2019 MICS and BBS datasets, which may not capture more recent improvements or disruptions (COVID-19 impacts). Reporting errors and varying survey coverage at the district level could also introduce bias. The study calculated indicator weights as the ratio of the mean to the standard deviation of log-transformed data. This approach assumes equal reliability across factors and does not account for stakeholder priorities or alternative weighting schemes. Without sensitivity testing (AHP or analytic-hierarchy methods), our Composite Weighted Index may under- or over-represent certain vulnerabilities.

Declarations

Author Contributions

Sanzida Sumaiya Suchana was primarily responsible for conceptualizing the study, designing the methodology, collecting and analyzing data, generating maps, interpreting the results, and drafting the manuscript. Md. Kawsar Jahan Khan contributed to the literature review, supervised the research process, validated the analytical framework, critically reviewed the manuscript, and helped refine the policy recommendations. Both authors read and approved the final version of the manuscript.

Funding

The authors declare that no funds, grants, or other support were received during the preparation of this manuscript.

Acknowledgments

We would like to express our sincere gratitude to the faculty members of the Department of Urban & Regional Planning, Rajshahi University of Engineering & Technology, for their academic guidance. In particular, we extend heartfelt thanks to Anutosh Das and Sumita Roy, whose mentorship and instruction throughout the learning process have significantly enriched our understanding and indirectly contributed to the development of this journal paper.

Conflict of Interest

The authors declare no conflict of interest.

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