

Research Article

Drinking Water Quality Assessment in Groundwater-Fed Supply Systems: A Case Study of Female Residential Halls at Khulna University, Bangladesh

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Abstract

Securing safe drinking water remains a pressing public health challenge in Bangladesh, where groundwater quality is increasingly undermined by a combination of natural factors and human-induced activities. This study examined the drinking water quality of two female residential halls such as Bangamata Begum Fazilatunnessa Mujib (BBFM) Hall and Aparajita Hall (AP) at Khulna University over a six-month period. An integrated approach was applied, combining physico-chemical and microbial analyses with multivariate and risk assessment methods such as Pearson's correlation, Water Quality Index (WQI), Principal Component Analysis (PCA), Pollution Index of Groundwater (PIG), Quantitative Microbial Risk Assessment (QMRA) and Chemical Health Risk Assessment. Physical analyses indicated neutral to slightly alkaline water, with moderate electrical conductivity (EC) and total dissolved solids (TDS) reflecting natural geogenic influences. Chemical evaluation revealed a sodium-chloride-bicarbonate-dominated profile, while nitrate, phosphate, and sulfate remained within safe limits, though salinity indicators highlight potential long-term risks. Microbiological assessment detected total coliform (TC), fecal coliform (FC) and *Escherichia coli* (*E. coli*) above World Health Organization (WHO) thresholds, indicating fecal contamination and immediate public health concerns. PCA and correlation analyses identified salinity, carbonate buffering, and phosphorus enrichment as key hydrochemical drivers, whereas the WQI ranged from 42.66 to 51.71, classifying most samples (except BBFM 4) as good. The PIG values (<1.0) indicated insignificant pollution. QMRA estimated annual infection probabilities of 12% to 44%, far above the WHO benchmark ($\leq 10^{-4}$), underscoring cumulative exposure risks. Chemical health risk assessment confirmed no significant non-carcinogenic threat from nitrate or sodium intake. These results indicate that although the water is largely safe from a chemical standpoint, it carries considerable microbial health risks. Based on these findings, a comprehensive management approach is advised, incorporating immediate actions, short to mid-term interventions, and long-term infrastructural improvements, alongside the implementation of a Water Safety Plan (WSP) to ensure safe and sustainable drinking water in university residential facilities.

Keywords

Drinking Water Quality, Microbial Contamination, Water Quality Index (WQI), Pollution Index of Groundwater (PIG), Quantitative Microbial Risk Assessment (QMRA), Khulna University

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1. Introduction

Access to safe drinking water is a fundamental human need and a cornerstone of public health [1, 2]. Yet, billions of people across the globe continue to struggle to secure clean and reliable water sources [3]. Both groundwater and surface water remain indispensable for domestic, agricultural, and industrial purposes, but their availability is increasingly strained by climate variability, geogenic processes, and human activities [4, 5]. Among these sources, groundwater constitutes a critical lifeline, providing drinking and domestic water to nearly one-third of the world's population [6, 7]. However, global water security is under severe threat. Recent global evaluations indicate that water scarcity impacts a significantly greater proportion of the global population than previously assessed. About 4.0 billion people, or two-thirds of the world's population, face severe water scarcity for at least one month each year [8]. Besides about 2.3 billion people now live in countries where water is scarce [9, 10]. Alarming, 21 of the world's 37 largest aquifers have already crossed sustainability thresholds and projections suggest that by 2025, absolute water scarcity will extend across entire regions [11, 12]. This trajectory underlines the urgency of safe water management as one of the defining challenges of the twenty-first century [13, 14].

In developing nations like Bangladesh, the water crisis is particularly acute [15]. As one of the most densely populated countries in the world, Bangladesh faces a dual burden of scarcity and contamination [16, 17]. Natural geochemical processes are affected by rapid urbanization, industrial growth, and intensive farming and livestock due to a lack of quality water [18, 19]. This duality leaves millions vulnerable to microbial pathogens and chemical contaminants [20]. The global statistics are staggering: nearly 1.8 billion people consume fecally contaminated water, leading to almost 2 million diarrheal deaths annually [21]. Unsafe water is implicated in approximately 80% of infections in developing countries, accounting for one-third of all deaths, and remains one of the leading causes of disease outbreaks [22]. Bangladesh presents a unique case where groundwater and surface water are tightly interwoven within seasonal hydrological cycles [7, 23]. However, unsustainable irrigation practices have disrupted this balance, depleting groundwater while simultaneously drying up surface water bodies [24, 25]. In coastal regions such as Khulna, aquifers face additional stress from marine intrusion, leading to rising salinity and altered geochemical properties [20]. Although rainwater harvesting has been proposed as an alternative, its seasonal limitations and infrastructural challenges have restricted its feasibility at scale [26].

Within urban Bangladesh, groundwater remains the dominant drinking water source [27]. In Khulna, the country's third-largest city, the municipal water system meets only about 20% of demand, leaving the majority reliant on private and institutional tube wells [28, 29]. Water safety remains a

critical concern, as research consistently reveals systemic inadequacies: while elevated bicarbonates, nitrates, and salts typically stem from natural or agricultural inputs, microbial contaminants such as coliforms and *Escherichia coli* point to deficiencies in sanitation, storage, and distribution practices [30, 31]. These overlapping risks emphasize the importance of integrated water quality assessments.

To capture such complexity, researchers increasingly employ composite indices and advanced analytical tools. The Water Quality Index (WQI) and the Pollution Index of Groundwater (PIG) provide composite measures of chemical safety, while multivariate approaches such as Principal Component Analysis (PCA) help disentangle natural from anthropogenic drivers of contamination. Similarly, Quantitative Microbial Risk Assessment (QMRA) links microbial indicators with probabilistic health outcomes, offering a risk-based perspective on water safety [32, 33]. In South Asia, PCA has been particularly effective in distinguishing geogenic from human-induced contamination [34], while QMRA is gaining recognition globally as a benchmark for microbial risk evaluation [35]. In Bangladesh, research has largely focused on municipal water supplies, rural households, or urban slums, while institutional settings such as university residential halls remain underexplored. This oversight is significant as residential halls accommodate large populations of young adults who share common water sources, can escalate into widespread illness. Such outbreaks not only endanger student health but also disrupt academic performance and institutional functioning. Despite this progress, critical knowledge gaps remain in this field.

This research seeks to address that gap by focusing on Khulna University, one of the country's leading public institutions. By conducting a comprehensive assessment of drinking water in student residential halls, the study integrates physico-chemical and microbial testing with multivariate statistical methods and QMRA. The objectives are fourfold: (1) to evaluate water quality against World Health Organization (WHO) and Bangladesh standards, (2) to identify microbial contamination, with a focus on coliforms and *E. coli* as indicators of fecal pollution, (3) to trace contamination pathways using PCA and related approaches, and (4) to assess probabilistic health risks through QMRA. By adopting this integrated approach, the study contributes both locally and globally. For Khulna University, the findings will provide actionable insights for ensuring safe drinking water in high-density residential environments. Nationally, the research highlights the dimension of water, sanitation, and hygiene (WASH) planning: the safety of water in educational institutions.

2. Methodology

2.1. Study Area

Khulna University, located in Gollamari, Khulna, Bangladesh (22.802°N, 89.533°E), sits along Sher-E-Bangla Road and covers 106 acres of land beside the scenic Mayur River. The campus lies only 3.4 km from the city center, offering both a peaceful academic environment and convenient access to urban amenities. Within the campus, five residential halls, three for males and two for females, provide accommodation for approximately 2,500 students. Among the female dormitories, Aparajita (AP) Hall houses around 678 students, while Bangamata Begum Fazilatunnesa Mujib (BBFM) Hall accommodates 492. For this study, the two female residential halls (AP and BBFM) were selected as the sampling sites to assess drinking water quality. These halls were chosen to represent the female student living environment, and the re-

sults reflect the conditions in these specific halls. Water supply in these dormitories plays a critical role in ensuring the health and well-being of residents. The location of the study area is illustrated in Figure 1.

2.2. Sampling Procedure

To evaluate drinking water quality, samples were systematically collected from the reservoirs of BBFM and AP Halls. Each hall has its own submersible tube wells and main storage tanks, and groundwater is first pumped into the main tank. It is then distributed to reservoirs on each floor, which may result in minor variations in water quality between floors. Sampling was conducted fortnightly, in the morning, throughout the study period to capture temporal variations. During each session, nine water samples were collected using pre-cleaned 500 mL high-grade plastic bottles, which were carefully labeled to ensure accurate identification.

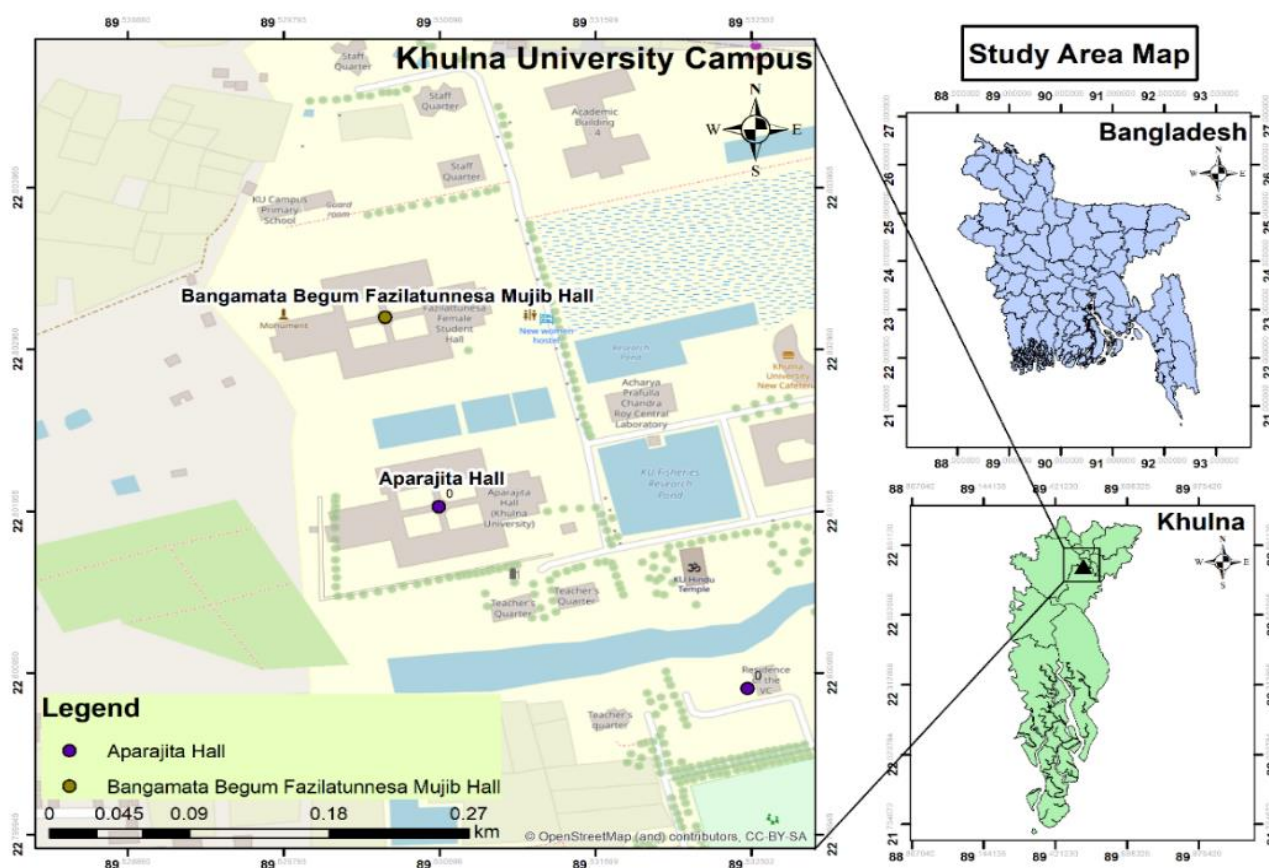


Figure 1. Location of the female students' hall, Khulna University.

To reduce the risk of external contamination, each bottle was rinsed three to four times with reservoir water before sampling. For microbiological testing, sterilized (autoclaved) bottles were employed, and analyses were carried out immediately after collection to prevent alterations in microbial populations. All procedures for collection, preservation, and

transportation followed the guidelines of the Standard Methods for the Examination of Water and Wastewater [36, 37]. After collection, the samples were transported under controlled conditions to the Environmental Science Discipline Laboratory at Khulna University, where both physico-chemical and microbial analyses were performed (Table

1).

Table 1. Physico-chemical and microbial parameters with analytical methods and instruments.

Parameter Type	Parameters	Analytical Methods	Instrument/Technique
Physico-chemical	pH	Electrometric	pH meter (M106MAX, Milwaukee)
	EC, TDS	Electrometric	EC/TDS meter (AD 332, Adwa)
	Turbidity	Nephelometric	Turbidity meter
	DO	Electrometric	DO meter
	Ca ²⁺ , Mg ²⁺	Titrimetric (EDTA method)	Manual titration
	Cl ⁻ , HCO ₃ ⁻	Titrimetric	Manual titration
	SO ₄ ²⁻ , NO ₃ ⁻ , PO ₄ ³⁻	Turbidimetric	UV-Visible spectrophotometer
	Na ⁺ , K ⁺	Flame photometric	Flame photometer
Microbial	Total coliform (TC)	Membrane Filtration	Autoclaved MF unit
	Fecal coliform (FC)	Membrane Filtration	Autoclaved MF unit
	E. coli	Membrane Filtration	Autoclaved MF unit

2.3. Integrated Indices and Statistical Tools for Water Quality Assessment

Table 2 represents five complementary tools that together provide a well-rounded picture of drinking water safety. The Water Quality Index (WQI) condenses multiple physico-chemical parameters into a single score, classifying water from excellent to unfit for consumption [38-40]. The Pollution Index of Groundwater (PIG) goes a step further by quantifying contamination from both natural and human-induced sources, offering clear thresholds from insignificant to very high pollution [41]. Principal Component

Analysis (PCA) helps untangle complex datasets, pinpointing the major pollution drivers such as agricultural runoff or geogenic influences [42-44]. Quantitative Microbial Risk Assessment (QMRA) translates microbial data into tangible health risks, estimating infection probabilities from *E. coli* against WHO's safety benchmark of $\leq 10^{-4}$ annual risk [32, 35, 45, 46]. Lastly, the Chemical Health Risk Assessment, focusing on non-carcinogenic risks evaluates the potential health implications of nitrate (NO₃⁻) and sodium (Na⁺) intake through drinking water [46, 47]. Together, these approaches provide a comprehensive framework for understanding and safeguarding water quality.

Table 2. Indices and statistical tools applied in the study.

Index/Analysis	Formula/Model	Purpose	Classification/Threshold
Water Quality Index (WQI)	i) $WQI = \frac{\sum_{n=1}^n w_n Q_n}{\sum_{n=1}^n w_n}$	Composite evaluation of chemical safety	Excellent (0-25); Good (26-50); Poor (51-75); Very Poor (76-100); Unfit (>100)
	ii) $Q_n = [(v_n - v_i) / (S_n - v_i)] \times 100$		
	iii) $W_n = K / S_n$		
	iv) $K = \frac{1}{\sum (\frac{1}{S_n})}$		
Pollution Index of Groundwater (PIG)	i) $W_p = R_w / \sum R_w$	Assess geogenic and anthropogenic pollution	Insignificant (<1); Low (1-1.5); Moderate (1.5-2); High (2-2.5); Very high (>2.5)
	ii) $S_c = C/D_s$		
	iii) $O_w = W_p \times S_c$		
	iv) $PIG = \sum O_w$		
Principal Component	Eigenvalue decomposition of the correla-	Identify dominant pollu-	Factors with eigenvalue >1 con-

Index/Analysis	Formula/Model	Purpose	Classification/Threshold
Analysis (PCA)	tion matrix	tion sources	sidered significant
Quantitative Risk Assessment (QMRA)	i) $d = C \times V \times f_p$	Estimate microbial infection risk from <i>E. coli</i>	WHO benchmark: $\leq 10^{-4}$ annual risk
	ii) $P_{inf} = 1 - (1 + \frac{d}{N_{50}} (2^{\frac{1}{\alpha}} - 1))^{-\alpha}$		
	iii) $P_{annual} = 1 - (1 - P_{inf})^{365}$		
Chemical Health-Risk Assessment	i) $CDI = (C_N \times IR) / BW$	Evaluate potential health risks from for nitrate (NO_3^-), and sodium (Na^+) intake	The WHO guideline for dietary sodium is $< 2,000$ mg/day for adults. $HQ < 1$ indicates no significant health risk
	ii) $HQ = CDI / RfD$		
	iii) $Na \text{ intake (mg/day)} = Na \text{ (mg/L)} \times IR$		

3. Results and Discussion

3.1. Physical Attributes

Table 3 presents the physical properties of water samples collected from BBFM and AP Halls. The pH results indicate that water in both halls was neutral to slightly alkaline. BBFM Hall showed values between 7.81 and 8.07 with mean of 7.96, while AP Hall ranged from 7.79 to 7.86 (mean 7.83). Both lie well within the WHO-recommended limit of 6.5-8.5 [46]. The marginally higher pH at BBFM suggests stronger carbonate buffering, a common feature of groundwater aquifers. Similar findings of mildly alkaline water, driven by bicarbonate dominance, have been reported in Bangladesh and elsewhere

in South Asia [48], emphasizing regional consistency. Electrical conductivity exhibited slight but notable hall-to-hall variation. BBFM Hall recorded higher EC, varied from 868.77-876.32 $\mu S/cm$ with mean value of 873.48 $\mu S/cm$ compared to AP Hall (820.33-825.35 $\mu S/cm$; mean 823.56 $\mu S/cm$). Elevated EC indicates higher ionic strength and dissolved mineral load, likely influenced by aquifer geochemistry or soil leaching. Although both remain within acceptable drinking water thresholds [46], the relatively higher EC at BBFM mirrors patterns documented in coastal aquifers, where salinity intrusion and lithological differences shape water chemistry [20]. Consistent with EC, TDS levels were also slightly higher in BBFM (mean 410.53 mg/L) than in AP (mean 386.22 mg/L). Both, however, remain safely below the WHO guideline of 500 mg/L.

Table 3. Physical attributes of collected water samples, Khulna University.

Halls	Sample ID	pH	EC	TDS	DO	Turbidity	Color
	Unit	-	$\mu S/cm$	mg/L		NTU	-
BBFM Hall	BBFM1*	8.07	876.32	410.33	3.12	1.3	Colourless
	BBFM2	7.94	874.67	409.33	3.03	0.93	
	BBFM3	7.95	874.97	411.33	3.21	0.88	
	BBFM4	7.98	868.77	411.50	4.82	1.25	
	BBFM5	7.99	874.25	410.50	2.63	0.98	
	BBFM6	7.81	871.92	410.17	3.72	1.03	
	Mean	7.96	873.48	410.53	3.42	1.06	
	Std.	0.08	2.72	0.80	0.77	0.17	
	Max	8.07	876.32	411.50	4.82	1.3	
	Min	7.81	868.77	409.33	2.63	0.88	
AP Hall	AP1	7.79	820.33	384.83	2.90	0.93	Colourless
	AP2	7.83	825.35	387.50	3.51	1.5	
	AP3	7.86	825.00	386.33	3.21	0.83	

Halls	Sample ID	pH	EC	TDS	DO	Turbidity	Color
	Unit	-	$\mu\text{S/cm}$	mg/L		NTU	-
	Mean	7.83	823.56	386.22	3.21	1.09	-
	Std.	0.04	2.80	1.34	0.31	0.36	-
	Max	7.86	825.35	387.50	3.51	1.5	-
	Min	7.79	820.33	384.83	2.90	0.83	-

*This represents the average of all samples collected fortnightly over a six-month period of data analysis

The strong correlation between EC and TDS confirms that ionic strength drives these differences. Such moderate TDS values are typical in Bangladeshi groundwater, usually reflecting natural mineralization rather than pollution [49, 50]. Importantly, TDS levels below 500 mg/L not only meet safety standards but also ensure palatability [46]. Dissolved Oxygen (DO) values range from 2.63 to 4.82 mg/L in BBFM Hall and 2.90 to 3.51 mg/L in AP Hall, reflecting low oxygen levels likely due to limited aeration or organic matter presence. Turbidity remains low in all samples (0.83-1.5 NTU), well within the WHO limit of 5 NTU, indicating good clarity. All samples were reported as colourless, confirming the absence of visible contamination. The minor variations in water quality observed between BBFM and AP Halls, and among reservoirs on different floors, can be attributed to the water distribution system. Differences in storage duration, water stagnation, and interactions with pipes and tanks can cause slight differences in pH, EC, TDS, and other parameters across floors, even when the source water originates from the same aquifer. To conclude, the water in both halls satisfies

key standards and appears suitable for consumption, though the low DO levels call for regular monitoring.

3.2. Chemical Attributes

The chemical analysis of BBFM and AP Hall water samples shows both commonalities and site-specific differences as shown in Table 4. Sodium (Na^+) levels were relatively high (157.02 mg/L in BBFM; 151.53 mg/L in AP). Though still below the WHO guideline of 200 mg/L, they suggest salinity influence that could worsen over time. Chloride (Cl^-) concentrations followed a similar trend (164.67 mg/L in BBFM; 141.94 mg/L in AP), remaining under the 250 mg/L limit but close enough to indicate a potential salinization risk. This $\text{Na}^+\text{-Cl}^-$ dominance reflects saline intrusion processes widely reported in coastal Bangladesh [51, 52]. Calcium (Ca^{2+}) and magnesium (Mg^{2+}) were within safe limits, contributing to hardness without exceeding WHO standards. BBFM showed greater Ca^{2+} variability (42.81-64.77 mg/L), likely driven by localized carbonate dissolution.

Table 4. Chemical attributes of collected water samples, Khulna University.

Halls	Sample ID	Ca^{2+}	Mg^{2+}	Na^+	K^+	Cl^-	HCO_3^-	NO_3^-	PO_4^{3-}	SO_4^{2-}
	Unit	mg/L								
	BBFM1*	47.72	21.30	150.87	5.8	156.37	555.1	0.618	0.0162	3.34
	BBFM2	50.99	23.52	150.58	5.38	177.42	500.2	0.715	0.0164	3.19
BBFM	BBFM3	64.77	21.80	169.70	3.15	172.45	506.3	0.913	0.0166	3.41
Hall	BBFM4	46.14	20.53	160.94	6.45	177.37	524.6	0.762	0.0160	3.27
	BBFM5	48.13	15.95	169.93	4.75	161.21	518.5	0.745	0.0174	3.60
	BBFM6	42.81	22.27	140.12	3.53	143.21	481.9	0.813	0.0184	3.56
	Mean	50.09	20.89	157.02	4.84	164.67	514.43	0.761	0.0168	3.39
	Std.	7.67	2.62	11.90	1.30	13.61	24.90	0.099	0.0009	0.16
	Max	64.77	23.52	169.93	6.45	177.42	555.1	0.913	0.0184	3.60
	Min	42.81	15.95	150.58	3.15	143.21	481.9	0.618	0.0160	3.19

Halls	Sample ID	Ca ²⁺	Mg ²⁺	Na ⁺	k ⁺	Cl ⁻	HCO ₃ ⁻	NO ₃ ⁻	PO ₄ ³⁻	SO ₄ ²⁻
	Unit	mg/L								
AP Hall	AP1	57.29	21.53	132.90	4.77	154.65	469.7	0.603	0.0154	3.97
	AP2	35.39	22.08	168.39	3.57	130.34	475.8	0.480	0.0168	3.81
	AP3	38.03	23.37	153.29	5.29	140.83	488	0.445	0.0171	3.55
	Mean	43.57	22.33	151.53	4.54	141.94	477.83	0.510	0.0164	3.77
	Std.	11.95	0.95	17.81	0.88	12.20	9.32	0.083	0.0009	0.21
	Max	57.29	23.37	168.39	5.29	154.65	488	0.603	0.0171	3.97
	Min	35.39	21.53	132.90	3.57	130.34	469.7	0.445	0.0154	3.55

*This represents the average of all samples collected fortnightly over a six-month period of data analysis

Elevated bicarbonate (HCO₃⁻) levels in both halls (514.43 mg/L in BBFM; 477.83 mg/L in AP) further support carbonate weathering, consistent with South Asian aquifer studies [52]. Nitrate (NO₃⁻) concentrations were low (0.761 mg/L in BBFM; 0.510 mg/L in AP), far below the WHO limit of 50 mg/L, indicating minimal agricultural or sewage inputs. Similarly, phosphate (PO₄³⁻) levels were negligible, and sulfate (SO₄²⁻) remained low (3.39-3.77 mg/L), well within the 500 mg/L guideline. The elevated levels of some chemical attributes are most likely geogenic, resulting from carbonate dissolution in aquifer rocks, as documented in coastal Bangladesh and India [20, 53]. The slight variations in certain chemical parameters between BBFM and AP Halls, such as Na⁺, Cl⁻, and Ca²⁺, can be partially attributed to the independent water distribution systems of each hall.

3.3. Microbiological Parameters

In BBFM Hall, Total Coliform (TC) levels ranged from 72 to 112 CFU/100 mL while AP Hall had slightly lower and more variable TC values, ranging from 60 to 102 CFU/100 mL. Both halls exceed the WHO guideline of 0 CFU/100 mL for drinking water, indicating potential contamination from environmental sources or issues within the water distribution system (Figure 2). Fecal Coliforms, which serve as indicators of potential fecal contamination, were found in slightly higher concentrations in BBFM Hall compared to AP Hall. In BBFM Hall, FC levels ranged from 27 to 38 CFU/100 mL and in contrast, AP Hall showed a narrower range of 26 to 30 CFU/100 mL.

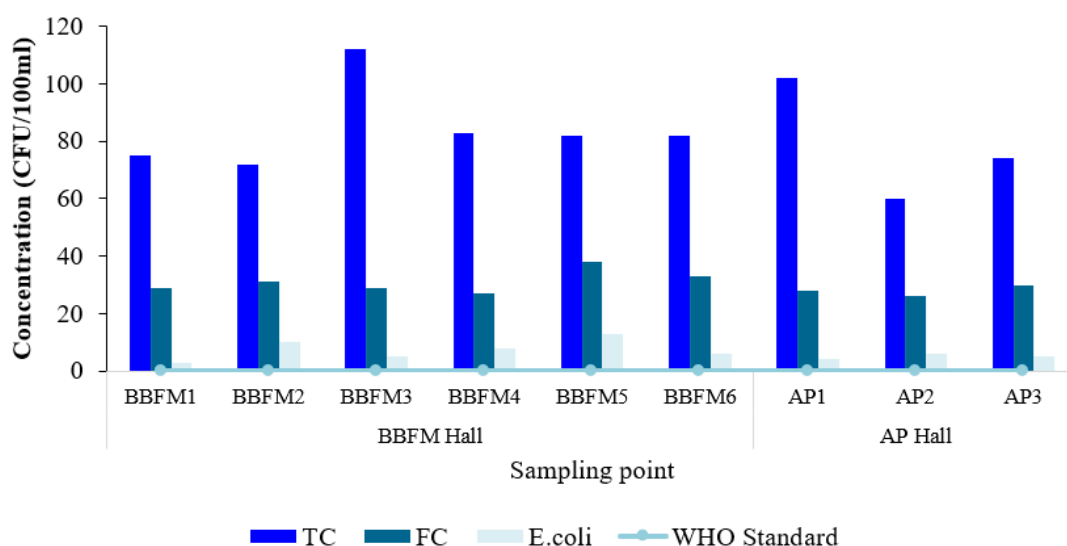


Figure 2. Microbial parameters of water from two hall along with WHO standard.

The presence of fecal coliforms confirms possible fecal contamination, posing significant health risks and warranting

immediate remedial action. *E. coli*, the most direct indicator of fecal pollution and potential pathogens, was present in all

samples from both halls, violating the WHO standard for drinking water (which requires 0 CFU/100 mL). BBFM Hall had higher *E. coli* values, ranging from 3 to 13 CFU/100 mL. AP Hall showed lower and more consistent *E. coli* levels, ranging from 4 to 6 CFU/100 mL. These results indicate a potential health risk if the water is consumed untreated. Differences in microbial counts between halls and among floor reservoirs are likely due to the water distribution and storage system. Factors such as storage duration, stagnation, tank maintenance, pipe interactions, and handling practices can introduce or amplify contamination, including *E. coli* and fecal coliforms. To reduce these risks, regular inspection and disinfection of storage tanks and pipelines, as well as chlorination or filtration before consumption, are recommended [31, 54].

3.4. Pearson's Correlation

Pearson's correlation matrix, shown in Table 5, reveals important interdependencies among physicochemical parameters, offering perceptions into the hydrochemical processes

shaping water quality in the study area. EC and TDS showed a very strong positive correlation ($r = 0.993$), confirming their close relationship as indicators of ionic strength and salinity. This strong linkage aligns with other hydrochemical studies in Bangladesh and South Asia, where EC and TDS are widely recognized as reliable proxies for salinity stress [55, 56]. The finding is particularly significant for coastal Bangladesh, where salinity intrusion driven by climate change and upstream water diversion, remains a critical challenge to safe drinking water [51, 57, 58]. pH exhibited a strong correlation with bicarbonate ($r = 0.971$) and moderate associations with sodium ($r = 0.451$) and chloride ($r = 0.585$). These associations indicate the influence of carbonate buffering and saline intrusion on groundwater alkalinity, consistent with previous studies that highlight the dominant role of bicarbonate in stabilizing aquifer chemistry in South Asia [6, 59, 60]. Chloride's strong correlation with calcium ($r = 0.678$) and nitrate ($r = 0.667$) further indicates combined saline mixing and anthropogenic inputs, particularly from fertilizer runoff and sewage.

Table 5. Pearson's Correlation among the parameters.

Pa- ra- me- ters	pH	EC	TDS	DO	Turbid- ity	Ca ²⁺	Mg ²⁺	Na ⁺	k ⁺	Cl ⁻	HCO ₃ ⁻	NO ₃ ⁻	PO ₄ ³⁻	SO ₄ ²⁻
pH	1													
EC	0.711	1												
TDS	0.694	0.993	1											
DO	0.009	0.107	0.208	1										
Turbidity	0.166	-0.050	-0.015	0.431	1									
Ca ²⁺	0.217	0.344	0.334	-0.276	-0.491	1								
Mg ²⁺	-0.403	-0.306	-0.329	0.178	-0.072	-0.107	1							
Na ⁺	0.451	0.246	0.266	0.076	0.268	-0.056	-0.419	1						
k ⁺	0.501	0.105	0.118	0.272	0.084	-0.151	-0.084	-0.164	1					
Cl ⁻	0.585	0.647	0.663	0.144	-0.306	0.678	-0.177	0.141	0.408	1				
HCO ₃ ⁻	0.971	0.691	0.682	0.101	0.235	0.144	-0.376	0.318	0.543	0.492	1			
NO ₃ ⁻	0.300	0.789	0.817	0.165	-0.282	0.655	-0.270	0.150	-0.240	0.667	0.266	1		
PO ₄ ³⁻	-0.193	0.252	0.241	-0.030	-0.115	-0.428	-0.107	0.133	-0.478	-0.411	-0.164	0.184	1	
SO ₄ ²⁻	-0.711	-0.766	-0.760	-0.317	0.057	-0.124	-0.131	-0.240	-0.445	-0.674	-0.673	-0.436	-0.026	1

Similar chloride–nitrate linkages have been reported in coastal aquifers influenced by both seawater intrusion and fertilizer application [27, 61, 62]. The positive NO₃⁻-EC relationship ($r = 0.789$) supports this interpretation, consistent with earlier studies in coastal Bangladesh [62]. Conversely,

magnesium (Mg²⁺) showed negative correlations with Na⁺ ($r = -0.419$) and HCO₃⁻ ($r = -0.376$), suggesting distinct geochemical origins or ion-exchange processes, patterns also noted in other saline-prone aquifers [55]. Sulfate (SO₄²⁻) also correlated negatively with pH, EC, and TDS, implying limited

geogenic sulfate sources or possible dilution effects in the studied sites, which differs from patterns seen in regions with intensive industrial or agricultural activities [8]. Nutrient signals were generally weak, with phosphate (PO_4^{3-}) showing negligible correlations across variables, consistent with studies where phosphate mobility is low due to strong adsorption to sediments [63]. Inclusively, the correlation patterns point to salinity, carbonate buffering, and localized anthropogenic inputs as dominant hydrochemical drivers in the study area. These findings align closely with broader regional evidence documenting the interplay of natural geogenic controls, climate-induced salinity stress, and human activities in coastal groundwater systems [51, 55, 57].

3.5. Water Quality Index (WQI)

The Weighted Arithmetic Water Quality Index (WQI) provides an integrated assessment of drinking water quality in BBFM and AP Halls. Table 6 represent the Weighted Arithmetic WQI of Water Samples from BBFM and AP Hall. The calculated values ranged from 42.66 to 51.71, with most samples classified as Good (25-50). The only exception was BBFM4 (WQI = 51.71), which slightly exceeded the threshold and fell into the Poor category, indicating that while the water is generally safe for consumption, localized issues warrant closer attention.

Table 6. Weighted Arithmetic WQI of Water Samples from BBFM and AP Hall.

Parameters	WHO Std.	Unit weight (W_n)	BBFM Hall (BBFM1 to BBFM6)						AP Hall (AP1 to AP3)		
			1	2	3	4	5	6	1	2	3
			$W_n Q_n$	$W_n Q_n$	$W_n Q_n$	$W_n Q_n$	$W_n Q_n$	$W_n Q_n$	$W_n Q_n$	$W_n Q_n$	$W_n Q_n$
PH	8.5	0.174	16.57	16.30	16.32	16.38	16.40	16.03	15.99	16.07	16.14
EC	1500	0.001	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.05	0.05
TDS	500	0.003	0.24	0.24	0.24	0.24	0.24	0.24	0.23	0.23	0.23
Turbidity	5	0.297	7.71	5.52	5.22	7.42	5.81	6.11	5.52	8.90	4.92
DO	8	0.185	7.23	7.02	7.44	11.17	6.09	8.62	6.72	8.13	7.44
Na ⁺	200	0.007	0.56	0.56	0.63	0.60	0.63	0.52	0.49	0.62	0.57
K ⁺	12	0.124	5.97	5.54	3.24	6.64	4.89	3.64	4.91	3.68	5.45
Ca ²⁺	75	0.020	1.26	1.34	1.71	1.22	1.27	1.13	1.51	0.93	1.00
Mg ²⁺	50	0.030	1.26	1.40	1.29	1.22	0.95	1.32	1.28	1.31	1.39
Cl ⁻	250	0.006	0.37	0.42	0.41	0.42	0.38	0.34	0.37	0.31	0.33
HCO ₃ ⁻	120	0.012	5.72	5.15	5.21	5.40	5.34	4.96	4.84	4.90	5.03
SO ₄ ²⁻	250	0.006	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
NO ₃ ⁻	11	0.135	0.76	0.88	1.12	0.93	0.91	1.00	0.74	0.59	0.55
$\sum W_n$		1.00									
$\sum W_n Q_n$			47.72	44.44	42.91	51.71	43.00	43.98	42.66	45.74	43.10
$WQI = \sum W_n Q_n / \sum W_n$			47.72	44.44	42.91	51.71	43.00	43.98	42.66	45.74	43.10
WQI Status (25-50) with Rank			Good (B)	Good (B)	Good (B)	Poor (C)	Good (B)	Good (B)	Good (B)	Good (B)	Good (B)

Variability was more pronounced in BBFM Hall, where BBFM4 recorded the highest WQI, largely due to elevated dissolved oxygen (11.17 mg/L) and turbidity (7.42 NTU).

Because these parameters carry higher weights in the index, even small fluctuations can strongly influence the overall score. This sensitivity of WQI to health and aesthetic related

indicators has been noted in other studies in Bangladesh and globally [16, 30]. In contrast, AP Hall displayed more consistent water quality, with WQI values ranging from 42.66 to 45.74, suggesting relatively stable conditions. Salinity-related parameters such as sodium (Na^+), chloride (Cl^-), and bicarbonate (HCO_3^-) also contributed moderately to the index. Elevated bicarbonate levels are consistent with carbonate weathering processes typical of South Asian aquifers [50]. Although sodium and chloride remained within WHO guidelines, their presence reflects the underlying salinity pressures widely reported in coastal Bangladesh [20, 57]. Generally, the WQI analysis suggests that water from both halls is largely suitable for drinking. However, continuous monitoring is essential to address risks associated with salinity intrusion and turbidity fluctuations. Similar conclusions have been drawn in other regional studies, which stress proactive management to ensure long-term drinking water safety [7, 64].

3.6. Principal Component Analysis (PCA)

The Principal Component Analysis (PCA) extracted five

components explaining 89.55% of the total variance, underscoring its effectiveness in simplifying complex hydrochemical datasets while retaining key variability (Table 7). Such explanatory power has been similarly reported in groundwater studies across South Asia [50, 65]. PC1, accounting for 39.84% of the variance, is dominated by TDS, EC, pH, bicarbonate, and chloride, with a strong negative loading from sulfate, reflecting ionic strength and mineralization processes typical of saline intrusion and carbonate weathering. Similar ionic associations ($\text{EC-TDS-Cl}^--\text{HCO}_3^-$) have been documented in recent research on saline-prone aquifers of Khulna and Satkhira [20, 44]. The inverse sulfate trend may indicate sulfate reduction or dilution, a pattern also observed in updated coastal aquifer studies. PC2 (17.10%) shows dominant positive loading of turbidity and potassium with negative loading from calcium and nitrate, suggesting nutrient-particulate interactions influenced by surface runoff and organic loading. Similar turbidity-nutrient dynamics have been highlighted by contemporary studies examining agricultural runoff and domestic wastewater influence in southwestern Bangladesh [21, 50].

Table 7. Results of PCA for Physico-chemical parameters.

Principal Component	Eigenvalue (Total)	% Variance	Cumulative% Variance	Top Eigenvector Coefficients and associated variables
PC1	5.578	39.84	39.84	0.926 (TDS), 0.919 (EC), 0.863 (pH), 0.823 (HCO_3^-), 0.822 (Cl^-), and $-0.817 (\text{SO}_4^{2-})$
PC2	2.394	17.10	56.94	0.746 (Turbidity), 0.602 (K^+), $-0.689 (\text{Ca}^{2+})$, $-0.567 (\text{NO}_3^-)$, and 0.455 (DO)
PC3	2.024	14.46	71.40	0.851 (PO_4^{3-}), 0.493 (Na^+), 0.282 (Turbidity), 0.267 (TDS), and 0.257 (EC)
PC4	1.511	10.79	82.19	0.694 (Mg^{2+}), 0.635 (DO), $-0.383 (\text{Na}^+)$, 0.291 (pH), and $-0.192 (\text{Ca}^{2+})$
PC5	1.030	7.36	89.55	0.485 (DO), 0.421 (Turbidity), 0.316 (Na^+), $-0.143 (\text{pH})$, and $-0.071 (\text{Mg}^{2+})$

PC3 (14.46%) is driven by phosphate and sodium, indicative of anthropogenic nutrient enrichment associated with fertilizer leaching, detergent discharge, and sanitation leakage. Recent studies continue to link phosphate enrichment to poor wastewater management and agricultural intensification [30, 65]. PC4 (10.79%) shows strong contributions from magnesium and dissolved oxygen, reflecting geogenic mineral inputs and aeration, with moderate negative associations with

sodium and pH that may signal ion-exchange or rock-water interactions [4, 66]. Finally, PC5 (7.36%) captures residual variation through dissolved oxygen, turbidity, and sodium, suggesting localized or episodic influences such as short-term contamination or seasonal mixing [44]. These findings mirror regional evidence that groundwater quality in coastal Bangladesh is shaped by the combined pressures of saline intrusion, agricultural inputs, and sanitation challenges [7, 64].

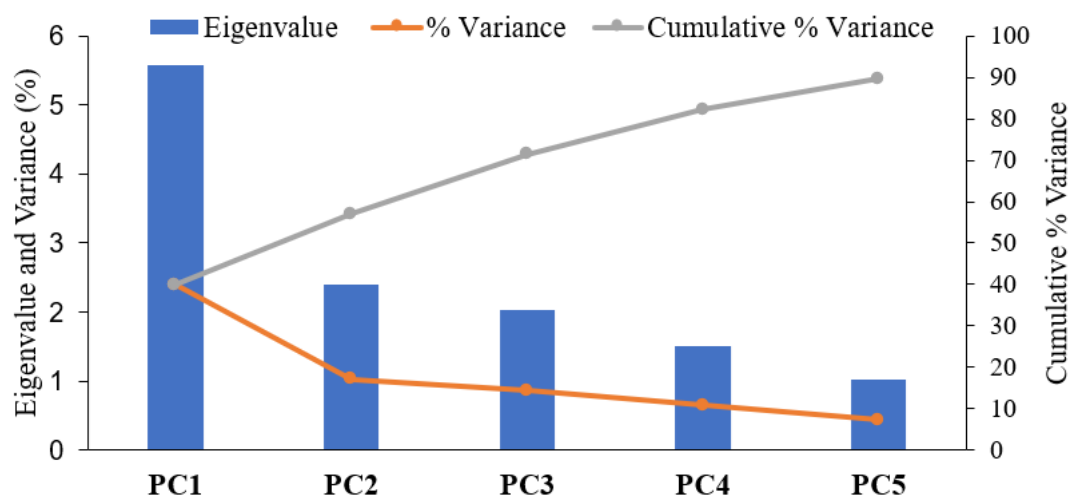


Figure 3. Scree plot for principal component analysis of physico-chemical parameters.

3.7. Pollution Index of Groundwater (PIG)

The Pollution Index of Groundwater (PIG) assessment provides a clear evaluation of groundwater safety across BBFM and AP Halls. The calculated PIG values ranged between 0.688-0.830 in BBFM and 0.678-0.758 in AP, all falling below the threshold of 1.0, which indicates insignificant pollution (Table 8). Each parameter was assigned a standard limit (WHO), a relative weight (Rw) reflecting its health impact, and a weight parameter (Wp) calculated from Rw ($\sum R_w = 43$). The weighted concentration status (WpSc) for

each parameter was computed, and the PIG value for each sample obtained by summing WpSc. All samples from BBFM (0.688-0.830) and AP (0.678-0.758) Halls had PIG values <1.0, indicating insignificant pollution [41]. Among the parameters, HCO_3^- contributed most prominently to the overall index, reflecting its geogenic origin from carbonate weathering, a process widely reported in South Asian aquifers [17, 41, 50]. This result confirms that the water is generally suitable for drinking, with minimal health risk, consistent with the WHO standards [18].

Table 8. Results of PIG for Physico-chemical Parameters.

Parameters	Ds	Rw	Wp	BBFM Hall (BBFM1 to BBFM6)						AP Hall (AP1 to AP3)		
				1	2	3	4	5	6	1	2	3
				WpSc*	WpSc	WpSc	WpSc	WpSc	WpSc	WpSc	WpSc	WpSc
PH	8.5	3	0.075	0.071	0.070	0.070	0.070	0.071	0.069	0.069	0.069	0.069
EC	1500	5	0.125	0.073	0.073	0.073	0.072	0.073	0.073	0.068	0.069	0.069
TDS	500	5	0.125	0.103	0.102	0.103	0.103	0.103	0.026	0.023	0.097	0.097
DO	8	2	0.050	0.020	0.019	0.020	0.030	0.016	0.023	0.018	0.022	0.020
Na^+	200	4	0.100	0.075	0.075	0.085	0.080	0.085	0.070	0.066	0.084	0.077
K^+	12	1	0.025	0.012	0.011	0.007	0.013	0.010	0.007	0.010	0.007	0.011
Ca^{2+}	75	2	0.050	0.032	0.034	0.043	0.031	0.032	0.029	0.038	0.024	0.025
Mg^{2+}	50	2	0.050	0.021	0.024	0.022	0.021	0.016	0.022	0.022	0.022	0.023
Cl^-	250	4	0.100	0.063	0.071	0.069	0.071	0.064	0.057	0.062	0.052	0.056
HCO_3^-	120	3	0.075	0.347	0.313	0.316	0.328	0.324	0.301	0.294	0.297	0.305
SO_4^{2-}	250	4	0.100	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.002	0.001
NO_3^-	11	5	0.125	0.007	0.008	0.010	0.009	0.008	0.009	0.007	0.005	0.005

Parameters	Ds	Rw	Wp	BBFM Hall (BBFM1 to BBFM6)						AP Hall (AP1 to AP3)		
				1	2	3	4	5	6	1	2	3
				WpSc*	WpSc	WpSc	WpSc	WpSc	WpSc	WpSc	WpSc	WpSc
$\sum R_w$		40										
$W_p = R_w / \sum R_w$			1.00									
$\sum O_w$				0.825	0.801	0.820	0.830	0.804	0.688	0.678	0.750	0.758
$PIG = \sum O_w$				0.825	0.801	0.820	0.830	0.804	0.688	0.678	0.750	0.758
PIG Status (<1)				Insignificant Pollution								

Note: Ds=WHO Std., Rw=Relative weight Wp=Weight parameter and *Sc was calculated as C divided by Ds, where C values of physico-chemical parameters are from [Tables 3 and 4](#).

Elevated bicarbonate levels often enhance buffering capacity but also signal natural mineralization, as observed in coastal Bangladesh [20]. By contrast, SO_4^{2-} and NO_3^- showed minimal contributions, suggesting negligible influence from industrial or agricultural pollution. The low nitrate levels, in particular, indicate limited impact of fertilizer leaching or sewage infiltration, which aligns with findings from other groundwater studies in Khulna and peri-urban Bangladesh [27]. The low PIG values also highlight that despite the broader concerns of salinity intrusion and water stress in coastal Bangladesh [57], the groundwater in these locations remains largely unpolluted. Similar insignificant PIG levels have been reported in other parts of Bangladesh where natural geochemical processes dominate over anthropogenic contamination [7]. Continued monitoring remains essential, however, given the long-term risks posed by climate-induced salinity intrusion and growing anthropogenic pressures [21].

3.8. Quantitative Microbial Risk Assessment (QMRA)

The Quantitative Microbial Risk Assessment (QMRA) of drinking water from BBFM and AP sites ([Table 10](#)) provides a clear picture of the infection risks associated with *E. coli*. At BBFM, concentrations ranged from 3 to 13 CFU/100 mL, corresponding to adjusted doses of 0.075-0.325 CFU. Although the probability of infection per single exposure was very low (0.00037-0.00159), annual infection risks rose sharply, from 12.5% (BBFM1) to 43.9% (BBFM5), illustrating how repeated exposure amplifies cumulative risk ([Figure 4](#)). Similarly, AP site samples, with slightly lower concentrations (4-6 CFU/100 mL) and doses (0.100-0.150 CFU), showed single-exposure infection probabilities of 0.00049-0.00073 and annual risks of 16.4%-23.5% ([Figure 4](#)).

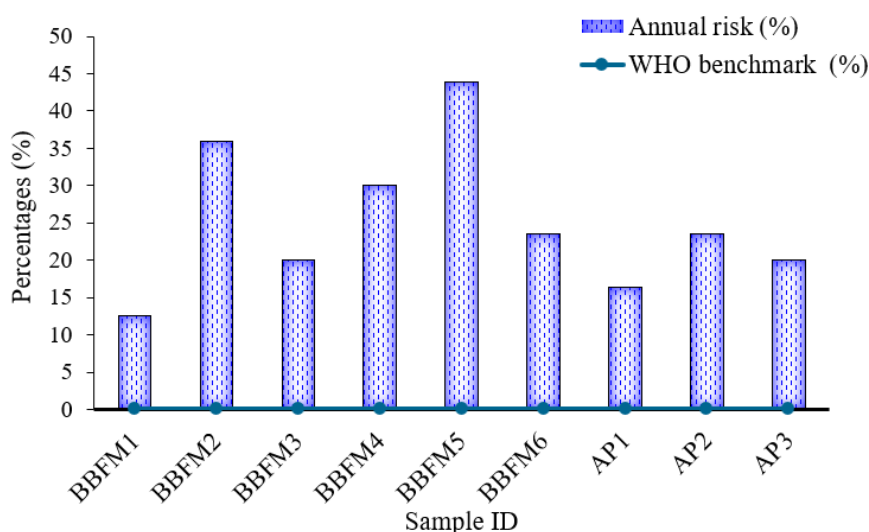


Figure 4. Quantitative Microbial Risk Assessment of samples showing annual risk percentages.

These results emphasize that even low-level contamination can pose significant long-term health threats, consistent with previous studies showing chronic exposure to fecal pathogens elevates infection risk [46]. The findings also align with QMRA studies in South Asian urban water systems, where daily ingestion of contaminated water notably increased annual infection probabilities [50]. Variability among samples further reflects differences in water handling and storage practices, highlighting the need for continuous monitoring and improved sanitation measures [67]. Largely, the QMRA emphasizes the importance of addressing persistent *E. coli* contamination, even at low concentrations, to minimize cumulative infection risks and protect public health in institu-

tional settings.

3.9. Chemical Health Risk Assessment

Figure 5 illustrates the comparative daily health risks associated with nitrate (expressed as Hazard Quotient, HQ) and sodium intake (expressed as a percentage of the WHO guideline) for water samples. The HQ values for nitrate are exceptionally low, ranging from 0.0021 to 0.0043 well below the threshold value of 1.0, indicating no potential non-carcinogenic health risk from nitrate exposure (Table 11) [46]. Among the samples, BBFM3 (0.00429) recorded the highest HQ, while AP3 (0.00210) showed the lowest.

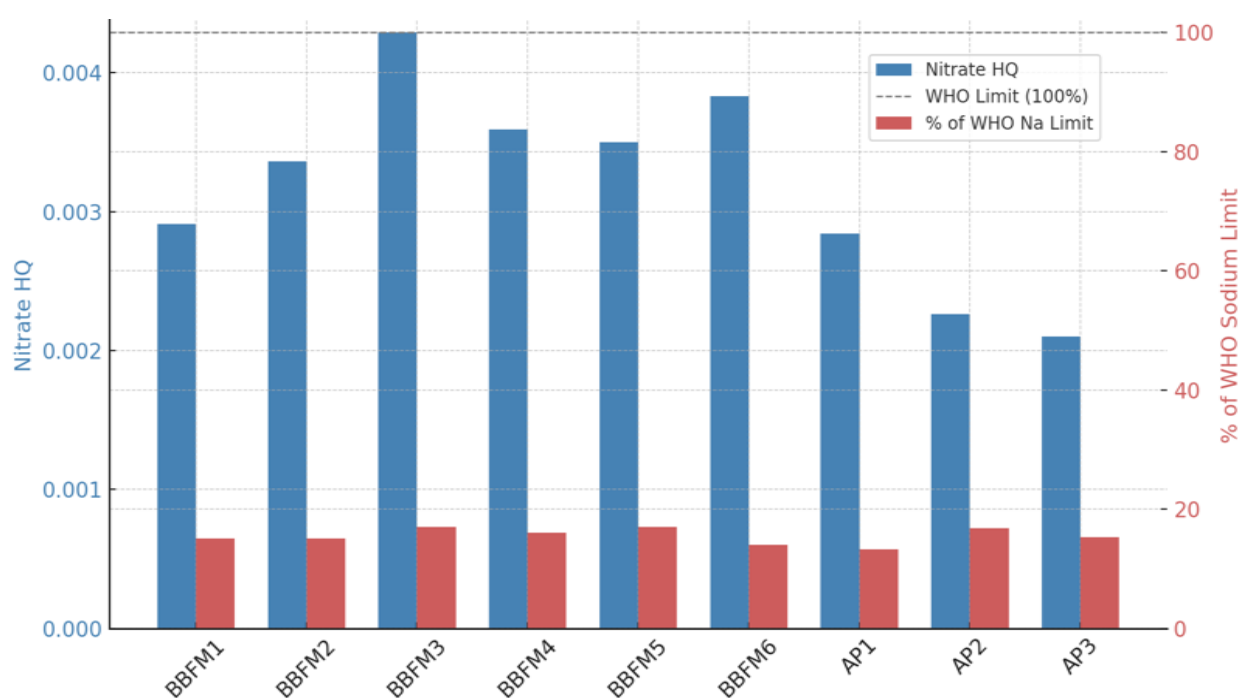


Figure 5. Health Risk Assessment of Nitrate and Sodium in Water from Two Residential Halls: Chemical and Salinity Impacts.

Sodium intake levels were also within the safe range, contributing between 13.29% and 16.99% of the WHO-recommended daily intake of 2000 mg/day [46]. The highest sodium contribution was observed in BBFM5 (16.99%), whereas AP1 (13.29%) recorded the lowest. Sodium concentration (expressed as% of the drinking-water guideline) was included to represent salinity exposure, as sodium is a major indicator of seawater intrusion in coastal groundwater. Presenting Na together with nitrate HQ allows comparison between chemical health risks and salinity-related impacts across the same sampling sites. The slightly higher HQ values in BBFM samples suggest marginally elevated nitrate concentrations compared to AP samples; however, all remain within safe limits. Inclusive, all samples fall below the WHO guideline values for both nitrate and sodium, indicating no significant non-carcinogenic health risks from daily water consumption. The figure therefore supports that the drinking

water from both halls is chemically safe and suitable for human consumption [46].

3.10. Ensuring Safe Water in BBFM and AP Halls

Table 9 outlines a comprehensive, multi-tiered action plan designed to ensure safe water in BBFM and AP Halls through immediate, short-to-mid-term, and long-term interventions aimed at mitigating both microbial and chemical contamination risks. These strategies are not isolated but rather inter-linked, forming an integrated water safety management framework that combines rapid protection with sustainable system improvement. Immediate actions such as boiling water before consumption, applying point-of-use filtration, and chlorinating storage tanks serve as the first line of defense

against acute microbial exposure. These low-cost and easily implementable measures provide immediate protection to residents while establishing the foundation for a culture of water safety awareness. Short-to-mid-term measures focus on system strengthening and behavioral transformation. The introduction of UV disinfection units and centralized filtration systems enhances treatment efficiency at the point of supply. Routine microbiological and chemical monitoring, combined with awareness and hygiene campaigns, helps institutionalize safe water practices among residents and hall authorities. These measures bridge the gap between emergency responses and long-term resilience by embedding water safety within hall management protocols and regular maintenance schedules. Long-term strategies address the structural and environmental causes of contamination. Upgrading old and cor-

roded supply lines, installing onsite water treatment units, improving drainage and wastewater systems, and adopting environmentally sustainable practices (e.g., rainwater harvesting and source protection) ensure a durable improvement in water quality. Integrating these interventions within a Water Safety Plan (WSP) framework will enable continuous risk assessment, preventive maintenance, and performance monitoring [46]. Collectively, these layered actions create a dynamic management approach immediate measures provide rapid risk reduction, short-to-mid-term actions ensure system reliability and community participation, and long-term investments secure sustainable water quality. Through such an integrated management model, BBFM and AP Halls can achieve consistent access to safe, potable water and align with national and WHO drinking water quality standards.

Table 9. Action Plan for Ensuring Safe Water in two females Halls.

Action Category	Specific Action	Timeframe (months)	Importance*	Practical Considerations	Key Remarks	Targeted Water Quality Indicators
Immediate Actions	Boil water before drinking		5	Focus on quick elimination of microbial risk	Easy to implement immediately and no infrastructure needed	TC, FC, <i>E. coli</i>
	Use point-of-use water filters (UV/ceramic)	<3 months	4	Portable units recommended for residents	Filters should be maintained and replaced regularly	TC, FC, <i>E. coli</i> ; Turbidity
	Chlorinate and clean storage tanks regularly		5	Prevent bacterial buildup in stored water	Requires staff training for proper dosing and cleaning	TC, FC, <i>E. coli</i> ; Cl^-
	Install UV water purifiers in common areas		3	Chemical-free pathogen elimination	Requires electrical connection and maintenance	TC, FC, <i>E. coli</i>
Short-to-Mid-Term Actions	Centralized multi-stage filtration systems at entry points	3–12 months	5	Improves water quality	The initial investment is high and reduces long-term risk	TC, FC, <i>E. coli</i> ; Turbidity; TDS, Na^+ , Cl^-
	Monthly water quality testing (microbial and chemical)		4	Monitoring ensures safe water consistently	Helps track trends and identify contamination early	pH, EC, TDS, DO, Turbidity, Na^+ , Cl^- , TC, FC, <i>E. coli</i>
	Awareness campaigns on safe water handling and hygiene		3	Education supports behavior change	Increases compliance with water safety practices	TC, FC, <i>E. coli</i> (indirectly)
Long-Term Actions	Replace or upgrade water supply lines	>12 months	5	Prevents leaks and contamination	May require significant planning and budget	TC, FC, <i>E. coli</i> ; Turbidity; TDS, Na^+ , Cl^-
	Build onsite water		5	Ensures scalable	long-term invest-	TC, FC, <i>E. coli</i>

Action Category	Specific Action	Timeframe (months)	Importance*	Practical Considerations	Key Remarks	Targeted Water Quality Indicators
	treatment units			purification	ment that reduces dependency on external water sources	<i>coli</i> ; Turbidity; TDS, Na ⁺ , Cl ⁻ ; DO
	Improve drainage and waste management systems		4	Reduces environmental contamination risk	Supports overall environmental health and sustainability	TC, FC, <i>E. coli</i> ; NO ₃ ⁻ , PO ₄ ³⁻ ; Turbidity

* Likert Scale (1–5): 1-Very Low Importance, 2- Low Importance, 3-Moderate Importance, 4-High Importance, and 5- Must Implement

4. Conclusion

This study aimed to evaluate the drinking water quality in the BBFM and AP Halls, with a focus on microbiological safety and overall groundwater quality. The analyses revealed that physico-chemical parameters across all samples fell within acceptable limits, with Pollution Index of Groundwater (PIG) values consistently below 1.0, indicating minimal chemical contamination as well as chemical health risks from nitrate and sodium are negligible. In contrast, microbial assessment through Quantitative Microbial Risk Assessment (QMRA) highlighted that even low-level *E. coli* contamination could result in significant annual infection risks, particularly with repeated exposure. BBFM samples exhibited the highest cumulative risk, reaching up to 43.9%, whereas AP samples showed slightly lower but notable risks, up to 23.5%. The integration of chemical and microbial assessments provides a comprehensive understanding of water safety, demonstrating that chemical compliance does not necessarily guarantee protection against pathogenic risks. Limitations of this study include the relatively small sample size and the focus on two specific institutional sites, which may constrain the generalizability of results to broader urban or rural contexts. Future research should expand to diverse locations, incorporate seasonal variability, and explore additional pathogens to provide a more holistic risk assessment. Moving forward, policymakers and practitioners should focus on continuous microbial monitoring, enforce comprehensive water safety protocols, and incorporate QMRA into routine water quality assessments. Protecting university residents’ health requires a proactive strategy that combines chemical quality evaluation with microbial risk management, integrating immediate protective measures with long-term infrastructure improvements. The findings emphasize that routine microbiological monitoring and proper water handling are essential for reducing infection risks. Practical interventions, such as regular

disinfection and secure water storage, can significantly enhance safety and promote better health outcomes for campus populations.

Abbreviations

BBFM	Bangamata Begum Fazilatunnessa Mujib Hall
AP	Aparajita Hall
WQI	Water Quality Index
PCA	Principal Component Analysis
PIG	Pollution Index of Groundwater
QMRA	Quantitative Microbial Risk Assessment
EC	Electrical Conductivity
TDS	Total Dissolve Solid
TC	Total Coliform
FC	Fecal Coliform
WHO	World Health Organization
HQ	Hazard Quotient

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Hridita Sarkar: Data curation, Formal Analysis, Investigation, Methodology, Visualization, Writing – review & editing

Sadhon Chandra Swarnokar: Methodology, Validation,

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Salma Begum: Conceptualization, Funding acquisition, Validation, Visualization, Writing – review & editing

Conflicts of Interest

The authors confirm that there is no conflict of interest with the publication of this article.

Appendix

Table 10. Quantitative Microbial Risk Assessment (QMRA) of drinking water samples.

Sample ID	E. coli (CFU/100 mL)	Adjusted dose d (CFU)	P _{inf}	P _{Annual}	P _{Annual} (%)
BBFM1	3	0.075	0.000367	0.125420	12.54
BBFM2	10	0.250	0.001221	0.359686	35.97
BBFM3	5	0.125	0.000611	0.200063	20.01
BBFM4	8	0.200	0.000977	0.300119	30.01
BBFM5	13	0.325	0.001585	0.439560	43.96
BBFM6	6	0.150	0.000733	0.234931	23.49
AP1	4	0.100	0.000489	0.163585	16.36
AP2	6	0.150	0.000733	0.234931	23.49
AP3	5	0.125	0.000611	0.200063	20.01

Table 11. Daily Intake and Health Risk of Nitrate and Sodium for respondents.

Sample ID	NO ₃ ⁻ (mg/L)	NO ₃ as N (mg N/L)	CDI (mg/kg-day)	HQ	Na (mg/L)	Na intake (mg/day)	% of WHO 2000 mg/day
BBFM1	0.618	0.13955	0.00465	0.00291	150.87	301.74	15.09
BBFM2	0.715	0.16145	0.00538	0.00336	150.58	301.16	15.06
BBFM3	0.913	0.20616	0.00687	0.00429	169.70	339.40	16.97
BBFM4	0.762	0.17207	0.00574	0.00359	160.94	321.88	16.09
BBFM5	0.745	0.16823	0.00561	0.00350	169.93	339.86	16.99
BBFM6	0.813	0.18358	0.00612	0.00383	140.12	280.24	14.01
AP1	0.603	0.13616	0.00454	0.00284	132.90	265.80	13.29
AP2	0.480	0.10839	0.00361	0.00226	168.39	336.78	16.84
AP3	0.445	0.10048	0.00335	0.00210	153.29	306.58	15.33

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