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Assessment of water quality of the Dhuppani waterfall and its advantages for the inhabitants of the Rangamati Hill Tracts, Bangladesh

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ABSTRACT

The present investigation aimed to evaluate seasonal fluctuations in water quality parameters of the Dhuppani waterfall, located in Rangamati, Bangladesh, with the goal of supporting local inhabitants and aquatic ecosystem conservation. Sampling was carried out over a one-year period from July 2022 to June 2023, encompassing the pre-monsoon, monsoon, and post-monsoon seasons. Water samples were collected from three designated stations and analyzed at the Water Quality Laboratory of the Department of Environmental Science and Resource Management, Mawlana Bhashani Science and Technology University, Tangail, Bangladesh. The parameters assessed included temperature, water transparency, electrical conductivity (EC), total dissolved solids (TDS), dissolved oxygen (DO), biological oxygen demand (BOD), pH, total alkalinity (TA), and total hardness (TH). The measured values ranged as follows: temperature (12.10 to 23.10°C), transparency (25 to 130 cm), EC (155 to 217 µS/cm), TDS (71 to 111 mg/L), DO (5.8 to 8.7 mg/L), BOD (0.49 to 1.05 mg/L), pH (6.10 to 8.20), TA (125 to 212 mg/L), and TH (72 to 185 mg/L). Analysis revealed that temperature, TDS, and BOD peaked during the pre-monsoon period and gradually declined through the monsoon and post-monsoon seasons. Conversely, EC and pH levels were found to be highest in the post-monsoon season, followed by the pre-monsoon and monsoon periods. Total alkalinity was at its maximum during the monsoon season, decreasing progressively in the post-monsoon and pre-monsoon phases. In contrast, total hardness showed a peak in the post-monsoon, followed by monsoon, with the lowest values recorded during the pre-monsoon season. In the waterfalls, DO was higher in the monsoon season when compared to the post-monsoon and pre-monsoon seasons. Those physicochemical parameters furnish insights into water quality, ecosystem health, and potential water-related activities. The study provides baseline data on water quality from waterfalls in the Rangamati hill regions, which contributes to the long-term conservation of these aquatic ecosystems for human consumption and aquatic resource management.

Keywords: Water quality, Dhuppani waterfall, Rangamati Hill Tracts

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Introduction

Water is an essential component of natural ecosystems, which forms the core of ecosystems and is crucial for various economic activities such as agriculture, forestry, industry, hydropower production, and aquaculture (Tyagi *et al.*, 2020; Hayashi, 2004). It is the primary element in all living things, serving as the fundamental building block for cells, tissues, organs, and making its quality essential for residential and commercial purposes (Jéquier and Constant, 2010; Islam *et al.*, 2014; Ayodele, 2015; Hall *et al.*, 2007). Growing population has increased the demand for freshwater, while water pollution negatively impacts human health and water quality (Muralidharan *et al.*, 2018; Lojen *et al.*, 2004). Population growth, urbanization and agricultural expansion are contaminating water sources, leading to degradation and some areas have experienced a rise in illness and mortality due to deteriorating health conditions (Jain *et al.*, 2007). One of the key elements of environmental resources that are at risk from exploitation and contamination as a result of human activities is water (Efe, 2001; Singh and Bhardwaj, 2019). In connection to all other hydrological parameters, the water quality considers the physical, chemical, and biological features (Chhatwal, 1998; Chowdhury *et al.*, 2019). Emerging nations face water shortage due to environmental degradation and contamination with most waterfalls formed by high-altitude streams or rivers (Gilmore and Grennan, 2003; Hossain, 2013).

The Chittagong Hill Tracts (CHT) in Bangladesh's southeast, spanning 13184 km^2, is renowned for its ethnic and cultural diversity, stunning scenery, and distinctiveness, bordering Myanmar, Tripura, Mizoram, and Chittagong districts (Hossain, 2013; Karmakar *et al.*, 2012). According to Uddin *et al.* (2010), 13 ethnic subgroups with unique cultures and ways of life live in the Chittagong Hill Tracts. Bangladesh is home to diverse indigenous communities, including Chakma, Marma, Tripura, Tangchangya, Bawm, Murong, Khumi, Chhak, Pankhoa, Kuki, Khyang, Lushai, and Sautal, many of whom live in socioeconomically marginalized conditions (Mohsin, 2003; Shelley, 1992). Individuals' water requirements and purity criteria vary, making it crucial for irrigation, recreation, and other impounded purposes (Hussen *et al.*, 2018; Akomeah *et al.*, 2011). A waterfall is the precipitous descent of a river or other body of water over a formation of rocks into a pool below (Nongmaithem and Basudha, 2017).

Waterfalls serve as natural monuments and a source of tourism revenue, attracting indigenous and alien species to settle downstream. They aerate stagnant water bodies, benefiting aquatic ecosystems and preventing fish migration (Latifa *et al.*, 2019). The presence and abundance of species in aquatic ecosystems are influenced by environmental interactions and population processes (Groot *et al.*, 2010; Prasetyo *et al.*, 2017). Researchers worldwide neglect waterfalls as inland freshwater sources, despite their potential as ecotourism destinations and water sources for drinking, agriculture, and domestic use. Knowledge of waterfall systems is confined to hydrological and geological aspects (Hussen *et al.*, 2018; Benedict and Zivadinov, 2011). Tourism managers and planners heavily explore waterfalls as travel destinations due to their stunning landscape, wildlife, and benefits for aquatic ecology, such as clean water, pollution reduction, and essential chemical components (Offem and Ikpi, 2011; Hussen *et al.*, 2018). Human activities can negatively impact water ecosystems, potentially reduce environmental benefits and decrease travelers' enthusiasm. This can lead to habitat destruction, pollution, wildlife decline, and exotic species invasion. Managing waterfalls is crucial in a rapidly increasing interest in natural areas (Mustacisa *et al.*, 2017). The research emphasized the significance of understanding and assessing the water quality, highlighting factors influencing it and its implications for ecological systems and human welfare. It assessed the physicochemical parameters of Dhuppani waterfall and highlighted human habitation in relation to the waterfall.

Materials and Methods

Study area

The research was carried out in Belaichari Upazila, located within the Rangamati Hill District, which spans approximately 6,113.16 square kilometers, making it the largest district in Bangladesh (Banglapedia, 2012). The Chittagong Hill Tracts, situated in the southeastern region of the country, are noted for their rugged topography, rich cultural diversity, and scenic landscapes. This region comprises three administrative districts: Rangamati, Bandarban, and Khagrachari. Geographically, Rangamati is positioned between latitudes 22°27′ and 23°44′ N and longitudes 91°56′ and 92°33′ E. The district shares its northern boundary with India’s Tripura and Mizoram states, is bordered to the south by Bandarban and Myanmar, to the east by Mizoram, and to the west by Chittagong and Khagrachari districts. The Belaichari Upazila is known for its stunning natural beauty, encompassing hills, forests, rivers, and waterfalls. The area is predominantly inhabited by indigenous communities, including the Chakma, Marma, Tripura, and others. Sampling site of the study area was selected in three stations in the Dhuppani waterfall at Belaichari of the Rangamati hill tracts region on the basis of topography and vegetation (Fig. 1, Table 1).

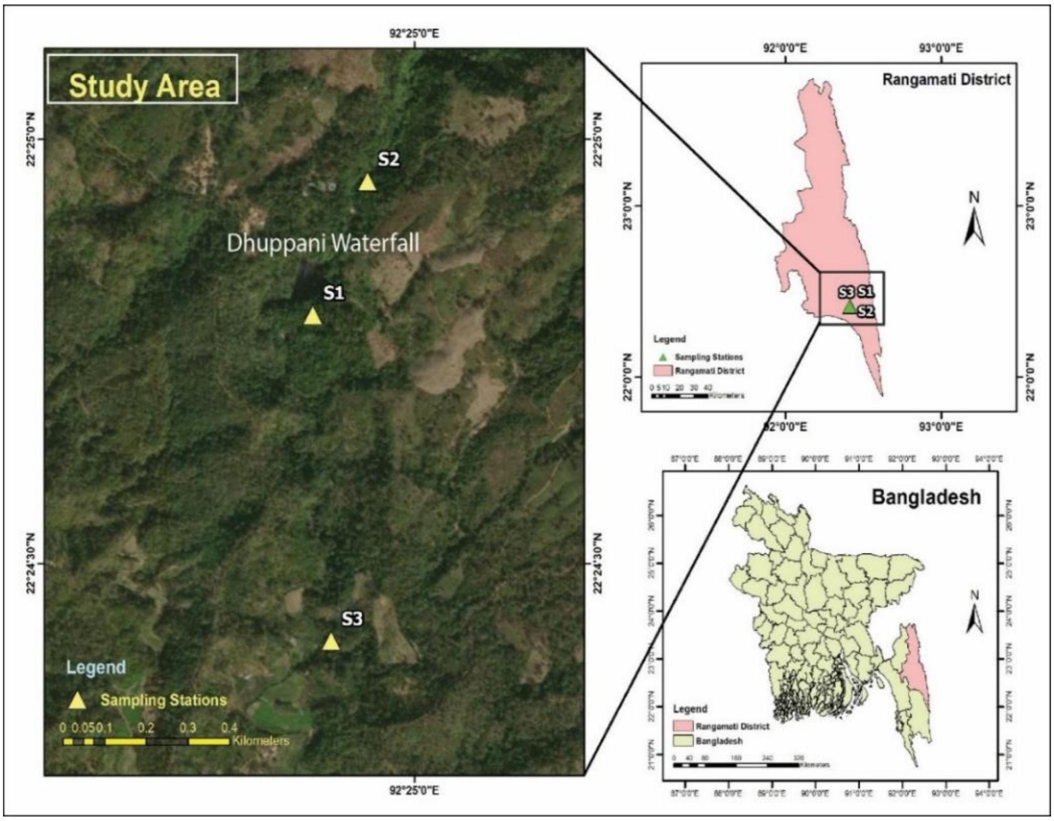

Fig. 1. Map showing the geographical locations of sampling stations in Dhuppani waterfall, Rangamati.

Table 1. Geographical position of sampling locations in Dhuppani waterfall, Rangamati.

Sampling stations		Geographical position	
		Latitude	Longitude
Dhuppani waterfall	Station 1	22°24’47.59” N	92°24’52.13” E
	Station 2	22°24’48.05” N	92°24’49.88” E
	Station 3	22°24’24.54” N	92°24’53.55” E

Sample collection

A total of 27 water samples were collected from three designated stations, with nine samples gathered per station during each of the three distinct seasons: pre-monsoon (March–June), monsoon (July–October), and post-monsoon (November–February), covering the period from July 2022 to June 2023. For sampling, 1000 ml plastic bottles were used, thoroughly pre-cleaned using deionized distilled water. At each site, the bottles were rinsed three times with the respective water sample to ensure consistency. During collection, the bottles were submerged and allowed to overflow for 2–3 minutes to eliminate trapped air bubbles. To minimize light exposure and prevent photosynthetic activity, the containers were wrapped in dark plastic. After securely sealing, each bottle was labeled according to its sampling station ID. To maintain sample integrity, the collected water was stored in an incubator under controlled oxygen conditions and later transported to the laboratory for proper preservation and subsequent analysis.

Sample analysis

The analysis of various physicochemical parameters of the collected water samples including temperature, transparency, electrical conductivity (EC), total dissolved solids (TDS), dissolved oxygen (DO), biological oxygen demand (BOD), pH, total alkalinity (TA), and total hardness (TH) was carried out at the Water Quality Laboratory, Department of Environmental Science and Resource Management, Mawlana Bhashani Science and Technology University, Tangail, Bangladesh. On-site measurements of temperature, transparency, and DO were performed immediately using a standard thermometer, a Secchi disc, and a portable dissolved oxygen meter, respectively. All collected samples were then subjected to laboratory analysis following standard protocols for water quality assessment, as summarized in Table 2.

Table 2. Water quality parameters, methods of analysis and instruments used with the model.

Parameters	Units	Methods	Instruments used
Temperature	^{0}C	Instrumental method	Digital Thermometer, Model: SH-113V1
Transparency	cm	Secchi Disc	Secchi Disc
EC	µS/cm	Instrumental method	EC meter, Model: HI98304, HANNA instruments
TDS	mg/L	Instrumental method	TDS meter, Model: HI98301, HANNA instruments
DO	mg/L	Instrumental method	DO meter, Model: DO-5509
BOD	mg/L	Incubation method	$BOD=BOD_1-DO_5$
pH	-	Instrumental method	pH meter, Model: HI98107, HANNA instruments
TA	mg/L	Titrimetric method	-
TH	mg/L	EDTA titrimetric method	-

Statistical analysis

The gathered data were organized systematically and formatted into appropriate tables for analysis. Microsoft Excel 2016 and IBM SPSS version 22 were utilized to analyze, visualize, and interpret the results effectively.

Results and Discussion

Water quality parameters

Temperature

The Dhuppani waterfall experienced varying water temperatures throughout the pre-monsoon, monsoon, and post-monsoon seasons. The lowest temperature is recorded in the post-monsoon season (12.10°C), while the highest is in the pre-monsoon season (23.10°C) (Table 3). The study compared the water temperature to other waterfalls in both national and international countries, finding it lower than Olumirin Waterfall (Oyekanmi *et al.,* 2017*)* and similar to Shuvolong, Risang, Coban Rondo, Sahastrakund, and Shikhar waterfalls (Islam *et al.*, 2022; Hussen *et al.*, 2018; Shaikh *et al.*, 2013; Dwivedi, 2020) (Table 4). Temperature, or how hot or cold a water sample is, affects dissolved oxygen levels, contributes to the formation of thermal stratification, and affects how aquatic organisms behave and flourish (Jane *et al.*, 2021). Temperature plays a crucial role in determining both the solubility of substances in water and the intensity of biological processes (Adejuwon and George, 2024).

Transparency

The water transparency of Dhuppani waterfall varied from 90 to 99 cm in the pre-monsoon season, 25 to 39 cm in the monsoon season, and 115 to 130 cm in the post-monsoon season. The lowest transparency value was found 25 cm in the monsoon season, while the highest was found 130 cm in the post-monsoon season (Table 3). The water transparency of the current study was compared to waterfalls in both national and international countries. It was discovered that the temperature is lower than Olumirin Waterfall (Oyekanmi *et al.*, 2017*)*, greater than Agbokum Waterfall (Offem and Ikpi, 2011), and similar to Shuvolong Waterfall, Risang Waterfall (Islam *et al.*, 2022) (Table 4). The first-order description of water quality is water transparency, which is typically indicated by Secchi disk depth (SSD) and has significant effects on aquatic life variety and production (Liu *et al.*, 2020).

Electrical conductivity (EC)

The Dhuppani waterfall's EC fluctuated between 180 and 215 µS/cm during the pre-monsoon season, 155 to 210 µS/cm during the monsoon season, and 192 to 217 µS/cm during the post-monsoon season. The monsoon season recorded the lowest EC value of 155 µS/cm, while the post-monsoon season recorded the highest EC value of 217 µS/cm (Table 3). The study found that the water conductivity is lower than that of other waterfalls in national and international countries (Table 4). Electrical conductivity (EC), on the other hand, serves as a useful indicator of water quality by revealing the level of dissolved salts and ions, thus reflecting the water's ability to carry electrical current. Conductivity also indirectly provides information about nutrient concentrations, acting as a stand-in for possible pollution from pollutants (Adjovu *et al.*, 2023). Although this might vary, EC in drinking water should generally be less than 800 µS/cm (Dhanasekarapandian *et al.*, 2016).

Table 3. Variation of water quality parameters in Dhuppani waterfall during pre-monsoon, monsoon and post-monsoon seasons.

Parameters	Pre-monsoon			Monsoon			Post-monsoon		
	St-1	St-2	St-3	St-1	St-2	St-3	St-1	St-2	St-3
Tem. (ºC)	20.91±0.77 (20.1-22.2)	20.80±0.7 (19.8-21.9)	22.60±0.32 (22.1-23.1)	18.50±0.86 (17.2-19.8)	19.34±0.60 (18.5-20.6)	19.81±0.77 (19.1-21.5)	12.96±0.59 (12.1-13.8)	13.47±0.59 (12.8-14.1)	13.87±0.45 (13.5-14.4)
Trans (cm)	93.54±3.77 (90-100)	94.40±2.22 (92-99)	91.6±2.80 (89-97)	29.63±3.20 (25-35)	33.50±3.37 (30-39)	29.90±1.91 (27-33)	123±2.26 (120-126)	119.8±2.78 (115-124)	126.50±2.76 (123-130)
EC (µS/cm)	188.00±5.75 (180-197)	193.60±7.48 (182-205)	199.40±8.04 (190-215)	165.30±8.27 (155-177)	168.70±5.77 (160-198)	197.40±5.99 (191-207)	199.20±6.7 (192-212)	199.60±7.32 (193-215)	202.90±7.92 (195-217)
TDS (mg/L)	102.60±4.03 (97-111)	100.00±3.30 (95-105)	101.40±3.71 (98-110)	91.90±3.38 (89-97)	92.40±2.80 (90-97)	92.70±3.65 (89-100)	73.70±1.25 (72-75)	74.00±2.21 (71-79)	81.10±2.92 (78-85)
DO (mg/L)	6.42±0.26 (6.1-6.9)	6.16±0.25 (5.8-6.5)	6.27±0.26 (6.0-6.8)	7.86±0.25 (7.5-8.3)	7.66±0.32 (7.2-8.1)	7.82±0.40 (7.2-8.7)	7.53±0.35 (7.00-7.90)	7.18±0.23 (6.90-7.50)	7.66±0.42 (7.66-8.30)
BOD (mg/L)	0.99±0.07 (0.97-1.05)	1.00±0.01 (0.99-1.02)	0.98±0.01 (0.95-1.00)	0.78±0.06 (0.70-0.89)	0.78±0.04 (0.72-0.85)	0.76±0.04 (0.69-0.85)	0.60±0.08 (0.49-0.71)	0.62±0.06 (0.51-0.69)	0.60±0.04 (0.52-0.65)
pH	7.21±0.46 (6.7-8.0)	7.23±0.27 (7.0-7.9)	7.45±0.40 (7.00-8.01)	6.76±0.42 (6.2-7.3)	6.86±0.45 (6.1-7.4)	6.90±0.36 (6.4-7.2)	7.97±0.13 (7.8-8.2)	7.78±0.22 (7.3-8.0)	7.71±0.17 (7.5-7.9)
TA (mg/L)	127.30±2.11 (125-131)	131.20±2.30 (129-135)	129.70±1.64 (126-132)	193.10±6.37 (187-205)	197.40±8.08 (190-210)	201.40±6.90 (192-212)	183.20±5.29 (175-190)	180.00±5.10 (172-187)	182.50±4.62 (178-191)
TH (mg/L)	76.50±3.43 (72-82)	77.30±4.92 (73-89)	82.60±4.30 (78-90)	145.50±4.62 (140-152)	141.30±3.74 (135-148)	147.20±1.93 (145-150)	173.50±8.40 (161-185)	168.50±6.20 (159-175)	170.40±5.56 (162-178)

Note: Tem. = Temperature, Trans. = Transparency, EC = Electrical Conductivity, TDS = Total Dissolved Solid, DO = Dissolved Oxygen, BOD = Biological Oxygen Demand, TA = Total Alkalinity, TH = Total Hardness.

Total dissolved solid (TDS)

In this study, TDS levels in water collected from Dhuppani waterfall varied seasonally. The concentration ranged between 97 and 111 mg/L during the pre-monsoon, 89 to 100 mg/L in the monsoon, and 71 to 85 mg/L post-monsoon, with the highest concentration recorded before the monsoon and the lowest after it (Table 3). The TDS was found to be lower in the study when compared to waterfalls in both domestic and foreign nations, such as Sahastrakund, Agbokum, Olumirin, Shikhar, Selangor, Shuvolong, and Risang (Islam *et al.*, 2022; Offem and Ikpi, 2011; Shaikh *et al.*, 2013; Dwivedi, 2020; Nurhidayah *et al.*, 2016) (Table 4). The total concentration of dissolved materials in water, such as metals, salts, minerals, and organic molecules, is represented by the TDS (van der Aa, 2003). When it comes to nutrient levels, corrosion potential, and whether water is suitable for drinking, industrial operations, and aquatic ecosystems, TDS tests provide valuable information (Chitrakshi and Haritash, 2022).

Dissolved oxygen (DO)

The water from the Dhuppani waterfall had varying DO levels in the pre-monsoon (5.80 to 6.90 mg/L), monsoon (7.20 to 8.70 mg/L), and post-monsoon (6.90 to 8.30 mg/L) seasons. The pre-monsoon season had the lowest DO value (6.1 mg/L), while the monsoon season had the highest DO value (8.7 mg/L) (Table 3). According to the study, the Dhuppani waterfall has less dissolved oxygen than other waterfalls in both domestic and foreign locations. Its levels are comparable to those of Shuvolong, Risang, and Olumirin waterfalls (Islam *et al.*, 2022; Oyekanmi *et al.*, 2017) (Table 4). One of the most significant aspects of water quality is DO. Aquaculture and Wastewater Treatment Facilities (WWTPs) both greatly benefit from maintaining the DO concentration at a desirable level (Kisi *et al.*, 2020; Li *et al.*, 2022).

Table 4. Comparison of physicochemical parameters in water samples of the present study of Dhuppani waterfall with other waterfalls.

Waterfall	Temp. (ºC)	Trans. (cm)	EC (µS/cm)	TDS (mg/L)	DO (mg/L)	BOD (mg/L)	pH	TA (mg/L)	TH (mg/L)	Reference
National										
Dhuppani	12.1-23.1	25-130	155-217	71-111	5.8-8.7	0.49-1.05	6.1-8.2	125-212	72-185	Present study
Shuvolong	12.0-21.1	30-85	150-210	75-112	6.5-9.5	0.5-1.0	6.8-8.2	120-210	78-190	Islam *et al.* (2022)
Risang	12.0-22.1	29-90	160-200	74-114	5.4-9.2	0.5-1.0	6.50-8.06	125-223	75-200	Islam *et al.* (2022)
International										
CobanRondo, Indonesia	20.5	-	111	-	8-11	13.8-15.6	6.9-7.4	-	-	Hussen *et al.* (2018)
Agbokum, Nigeria	-	28.8	69.0	178.60	9.6	4.8	-	-	74.5	Offem and Ikpi (2011)
Olumirin, Nigeria	22-31.5	70-220	80-86.8	131-882	5.3-8.9	-	6.08-8.50	94-278	-	Oyekanmi *et al.* (2017)
Olumirin, Nigeria	26.83	-	19.33	10	-	-	8.96	163.97	105.27	Adejuwon and George (2024)
Sahastrakund, India	25.0	-	260	327	-	-	8.05	160	170	Shaikh *et al.* (2013)
Shikhar, India	18.0	-	105	180	-	-	7.9	125	-	Dwivedi (2020)
Selangor, Malaysia	24.06	-	28.66	15.71	2.62	5.27	7.97	-	-	Nurhidayah *et al.* (2016)

Note: "-" means no data.

Biological oxygen demand (BOD)

The BOD showed noticeable fluctuations. During the pre-monsoon period, BOD ranged from 0.97 to 1.05 mg/L, while it decreased to 0.69 to 0.89 mg/L during the monsoon and further dropped to 0.49 to 0.71 mg/L post-monsoon. The maximum BOD (1.05 mg/L) was observed during the pre-monsoon, indicating higher levels of organic matter in that season, while the lowest (0.49 mg/L) appeared post-monsoon (Table 3). The BOD of the present study was compared to waterfalls in national as well as international countries, and it was found that the BOD is lower compared to that of Coban Rondo Waterfall, Agbokum Waterfall, Selangor Waterfall (Hussen *et al*., 2018; Offem and Ikpi, 2011; Nurhidayah *et al*., 2016) and is similar to Shuvolong waterfall and Risang waterfall (Islam *et al*., 2022) (Table 4). One of the most popular standards for evaluating the quality of water is the BOD. It gives details about the portion of the organic load in water that is readily biodegradable (Lokman *et al*., 2021). The results may differ depending on the laboratory (20%), mostly because of variations in the microbial diversity of the inoculum utilized, and this analytical approach is time-consuming (usually 5 days, BOD_5) (Jouanneau *et al*., 2014).

pH

The pH of the water exhibited notable seasonal variation as well. Values ranged from 6.20 in the monsoon to 8.20 in the post-monsoon season, with fluctuations also observed during the pre-monsoon period (Table 3). The study found that the pH of various waterfalls in national and international countries is higher than that of Shikhar and Selangor waterfalls (Dwivedi, 2020; Nurhidayah *et al*., 2016) (Table 4). pH levels influence various water properties, such as taste, smell, and corrosiveness. Water with high pH may not only be unpalatable but can also cause damage to pipes and plumbing systems. Moreover, certain pollutants become more mobile or toxic depending on the pH level (Cheng *et al*., 2004).

Total alkalinity (TA)

The TA in the samples also varied significantly across seasons. Measurements ranged from 125 to 135 mg/L before the monsoon, increased to 187 to 212 mg/L during the monsoon, and were between 172 and 191 mg/L post-monsoon. The lowest alkalinity was found in the pre-monsoon samples, while the highest value was recorded during the monsoon season (Table 3). The study compared TA of various waterfalls in national and international countries, finding similarity in TA to Shuvolong, Risang, Coban Rondo, Olumirin, Shikhar, Selangor, and Sahastrakund waterfalls (Islam *et al*., 2022; Hussen *et al*., 2018; Oyekanmi *et al*., 2017; Shaikh *et al*., 2013; Nurhidayah *et al*., 2016) (Table 4). The ability of water to withstand pH shifts caused by the addition of acids is known as alkalinity, and it aids in stabilizing pH variations (Leiva *et al*., 2021). It enables comprehension of the water chemical balance and how it affects ecosystem health and human activity (Dhoke, 2023).

Total hardness (TH)

Likewise, TH ranged between 72 and 82 mg/L before the monsoon, increased 140 to 152 mg/L in the monsoon, and reached between 145 and 150 mg/L after the monsoon. The hardest water sample (185 mg/L) was recorded during the post-monsoon season (Table 3). The study found that the TH of waterfalls in national and international countries is higher than that of Agbokum Waterfall (Offem and Ikpi, 2011) and similar to Shuvolong, Risang, and Sahastrakund Waterfalls (Islam *et al*., 2022; Shaikh *et al*., 2013) (Table 4). The concentration of particular minerals, primarily calcium and magnesium, determines the total hardness (TH) of water, which can make it hard (WHO, 2011).

Correlation matrix (CM) among water quality parameters

A correlation matrix is nothing more than a table displaying the correlation coefficients among different variables. The correlation between every conceivable pair of values in a table is shown by the matrix (Rusydi, 2018). It is an effective tool for condensing a sizable dataset and for finding and visualizing patterns in the provided information (Steiger, 1980; Cudeck, 1989). To assess the relationship between water quality parameters, Pearson's correlation coefficient was used, which helps to quantify the strength and direction of linear associations between two numerical variables (Bensty *et al*., 2008; Sedgwick, 2012). In the pre-monsoon period, strong positive correlations were observed between temperature and EC, temperature and pH, temperature and TH, transparency and BOD, EC and pH, EC and TH, TDS and DO, and pH and TH.

Conversely, negative correlations were found between DO and TA, BOD and pH, BOD and TH, temperature and transparency, temperature and BOD, transparency and pH, and transparency and TH. During the monsoon season, negative relationships emerged between transparency and DO, transparency and TH, TDS and BOD, and BOD and TA, while positive associations were recorded among temperature and EC, temperature and TDS, temperature and pH, temperature and TA, EC and TDS, EC and TA, TDS and pH, TDS and TA, DO and TH, and pH and TA. Post-monsoon data indicated a strong negative relationship between BOD and TA and between DO and BOD, whereas transparency showed positive correlation with EC, TDS, and DO. EC and TDS were also positively correlated in this season (Table 5).

Table 5. Correlations of water quality parameters in the pre-monsoon, monsoon and post-monsoon seasons of Dhuppani waterfall.

Parameters		Temp	Trans	EC	TDS	DO	BOD	pH	TA	TH
Pre-monsoon	Temp	1								
	Trans	-0.969**	1							
	EC	0.851**	-0.695*	1						
	TDS	0.029	-0.276	-0.499	1					
	DO	-0.034	-0.214	-0.553	0.998**	1				
	BOD	-0.892**	0.976**	-0.522	-0.478	-0.421	1			
	pH	0.992**	-0.929**	0.912**	-0.100	-0.163	-0.826**	1		
	TA	0.078	0.171	0.589	-0.994**	-0.999**	0.381	0.206	1	
	TH	0.985**	-0.911**	0.930**	-0.146	-0.208	-0.799**	0.999**	0.251	1
Monsoon	Temp	1								
	Trans	0.222	1							
	EC	0.832**	-0.357	1						
	TDS	1.000**	0.204	0.842**	1					
	DO	-0.345	-0.992**	0.235	-0.327	1				
	BOD	-0.774*	0.445	-0.995**	-0.786*	-0.327	1			
	pH	0.951**	0.512	0.620	0.945**	-0.618	-0.541	1		
	TA	0.990**	.083	0.901**	0.993**	-0.209	-0.855**	0.898**	1	
	TH	0.122	-0.941**	0.652	0.140	0.890**	-0.722*	-0.191	0.260	1
Post-monsoon	Temp	1								
	Trans	0.448	1							
	EC	0.564	0.827**	1						
	TDS	0.563	0.861**	0.998**	1					
	DO	0.330	0.960**	0.636	0.684*	1				
	BOD	-0.205	-0.853**	-0.412	-0.469	-0.965**	1			
	pH	-0.407	-0.285	-0.774*	-0.733*	-0.004	-0.257	1		
	TA	0.102	0.726*	0.214	0.275	0.890**	-0.978**	0.453	1	
	TH	-0.118	0.352	-0.234	-0.173	0.601	-0.789*	0.797*	0.900**	1

*Note: ** = Correlation is significant at the 0.01 level (2-tailed), * = Correlation is significant at the 0.05 level (2-tailed).*

Relationship between human habitation and waterfalls in CHT

The Chittagong Hill Tracts (CHT) is a region located in southeastern Bangladesh, known for its hilly terrain, diverse indigenous communities, and abundant natural beauty. Waterfalls are a prominent feature of this region and play a significant role in the relationship between human habitation and the local environment. The relationship between human habitation and waterfalls in the CHT are:

i. Cultural and spiritual significance: Waterfalls hold cultural and spiritual importance for the indigenous communities living in the CHT, and they are often considered sacred and are associated with various religious and traditional practices. These communities have a deep connection with nature and often consider waterfalls as places of worship and sources of divine blessings.

ii. Water supply: Waterfalls contribute to the water supply in the region. They serve as natural sources of freshwater, which is crucial for human habitation, agriculture and sustenance of local ecosystems. The waterfalls help in maintaining a stable water supply for communities residing near them.
iii. Tourism and recreation: The presence of waterfalls in the CHT attracts tourists and visitors, contributing to the local economy. People from various parts of Bangladesh and abroad visit the region to witness the natural beauty and engage in recreational activities such as swimming, picnicking, and photography near the waterfalls. Tourism activities associated with waterfalls provide livelihood opportunities for local communities, such as hospitality services and handicraft sales.
iv. Biodiversity and ecosystems: Waterfalls create unique habitats and support diverse ecosystems. The flowing water, along with the moist environment and surrounding vegetation, provides a suitable niche for various plant and animal species. Waterfall areas often have rich biodiversity, including endemic species, and are important for conservation efforts. Human habitation near waterfalls needs to be managed sustainably to avoid disturbing the delicate ecosystems they support.
v. Challenges and environmental impact: Human habitation near waterfalls can pose challenges and have an impact on the environment. Unregulated tourism and improper waste management can lead to pollution of water bodies, affecting the ecological balance. Overexploitation of natural resources, such as deforestation for agriculture or infrastructure development, can disrupt the ecosystems associated with waterfalls. Sustainable practices, including responsible tourism, conservation efforts, and community involvement, are crucial to minimizing negative impacts.

Conclusion

The physicochemical features of the Dhuppani waterfall reveal seasonal variations and water quality characteristics. Temperature impacts species composition, ecological dynamics, and waterfall health. Transparency varies with seasons, with higher levels during monsoons. Electrical conductivity, total dissolved solids, and dissolved oxygen concentrations vary. Monsoons have higher DO concentrations due to improved aeration and water flow. The variations of pH, total alkalinity, and total hardness affect the water quality. Understanding these changes is crucial for efficient water resource management and conservation. Waterfalls in the CHT have cultural, environmental, and economic significance, as they provide water supply, recreational opportunities, and contribute to biodiversity and ecosystem conservation. It is important to balance human habitation and development with sustainable practices to ensure the preservation of waterfalls and the well-being of local communities. Continuous monitoring and analysis are essential for sustainable water resource management and protection of the Dhuppani waterfall.

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