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Seasonal Variation of Water Qualities in River, Lake and Waterfall in Rangamati and Khagrachhari Hill Tracts, Bangladesh

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Abstract

This study was conducted to investigate the seasonal variation of water qualities for drinking and conservation of aquatic organisms from river, lake and waterfalls in Chattogram Hill Tracts of Bangladesh during pre-monsoon, monsoon and post-monsoon seasons from the period of March 2021 to February 2022. Water samples were collected from four sampling locations and analysed in the research laboratory of the Department of Environmental Science and Resource Management, Mawlana Bhashani Science and Technology University. Results were recorded on the parameters like temperature, EC, TDS, DO, BOD, pH, total alkalinity and total hardness in Kaptai Lake, Chengi River, and Shuvolong and Risang Waterfalls. The study revealed that the temperature, EC, TDS, BOD and pH were higher in pre-monsoon than monsoon followed by post-monsoon seasons. On the other hand, total alkalinity and total hardness were higher in post-monsoon than monsoon followed by pre-monsoon seasons. In the waterfalls, DO was higher in monsoon season when compared to pre-monsoon and post-monsoon seasons. The study provides baseline data on physiochemical water qualities in lake, river and waterfalls at the Chattogram Hill Tracts, which contributes to the long-term conservation of those aquatic ecosystems for human consumption and fisheries management.

Keywords

Seasonal variation; Water quality; Kaptai Lake; Chengi River; Shuvolong and Risang Waterfall; Chittagong Hill Tracts

Introduction

The Chattogram Hill Tracts (CHT), comprising three slope regions of Rangamati, Bandarban and Khagrachhari, is located in the southeast part ($21^0$25'N to $23^0$45'N latitude and $91^0$54'E to $92^0$50'E longitude) of Bangladesh, with an area of 13,294 km^2, bordering with India and Myanmar. The estimated population of CHT is 1.6 million, approximately a quarter of the population is made up of 11 ethnic groups such as Bawm, Chak, Chakma, Khumi, Khyang, Lushei, Marma, Mro, Pangkhua, Tanchangya and Tripura, with distinct languages, cultures, social frameworks, and rituals (Chowdhury *et al*., 2019). The CHT is geologically distinct from most of the plain land of Bangladesh that is characterized by extremely steep, rocky and sloping terrain parts. It is a low-thickness region with a population density of only 136/km^2, in stark contrast to the rest of the country (968/km^2). Because of the uneven and occasionally distant topography, the vast majority of the people lives in small dispersed habitats known as paras, which are difficult to reach (Karmakar *et al.*, 2012; UNICEF, 2019).

The majority of surface water is found in streams, rivers, springs, ponds, lakes, and reservoirs. Surface water is collected from rain in watershed areas, runs through streams and rivers, and settles in ponds and lakes (Manahan, 2010; Shil, Singh and Mehta, 2019). Apart from drinking water, this is the world's principal source of water for agriculture, animal husbandry, ranger service, current consumption, hydroelectric projects, fisheries, and other new purposes (Khan *et al*, 2016; Tyagi *et al.*, 2020). The residents of the CHT rely on a variety of surface water sources for their housing and drinking needs. Several lakes, waterfalls, and rivers are the main sources of water for the people of CHT. The Kaptai Lake, one of Southeast Asia's largest man-made freshwater lakes, is Rangamati's principal supply of water (Fernando, 1980; Rahman *et al*., 2014). The main rivers of CHT are the Chengi, Kassalong, Maini, Matamuhuri, Rankhyong and Sangu. The Chengi River is the main source of water for the residents of Khagrachhari district (Karim and Rafi, 2010; Latifa *et al.,* 2019). Waterfalls are common on surrounding hills in CHT, which serve as the only and primary supply of water for hilly people in Bangladesh, where over 12.6% of the land is slopy land (Ahmed, Rahman and Mandal, 2013). Waterfalls can be found in both hills and lowlands, where permeable soils or fractured rock formations allow water to flow onto the ground surface. Another type of water source that largely meets the requirement for drinking water during the extended rainy season is the storage of water in geological compartments (Palmer, 1991).

Nowadays, surface water that was exposed to anthropogenic impacts and pollutant deposition in the atmosphere become a very sensitive and critical issue (Kumar and Singh, 2018). Anthropogenic impacts, geochemical causes, river basin chemical composition and natural processes such as water interaction with lithogenic structure through which the river runs decrease surface water quality, rendering it unfit for drinking, industry, agriculture, and other uses (Kazi *et al*., 2009; Şener, Şener and Davraz, 2017). Natural processes and anthropogenic activities, such as industrial sewage discharge, household wastewater, and agricultural drainage degrade the region's surface water quality. On the other hand, the main causes of water contamination include industrial sewages, household wastewater, and agricultural drainage water (Barakat *et al.*, 2016; Kumar, Singh and Ojha, 2019). During the dry months, the waterfalls provide drinking water to the hillside communities for a very short period of time (Ahmed, 2016), which is highly troubling because the water from the waterfalls is extremely valuable to the hilly people (Hanif, Siddik and Ali, 2020; Nongmaithem and Basudha, 2017). Over 90% of people in the CHT live in rural regions and rely on surface water, particularly waterfalls, lakes and rivers (Karmakar *et al.*, 2011).

There are few critical investigations conducted chiefly about water quality and its fish biodiversity in various wellsprings in the CHT; however, the pollution of the water is slowly increasing day by day. As a result, comprehensive water quality monitoring is a useful instrument not only for determining the long-term sustainability of surface water for household and agricultural purposes, but also for ensuring efficient water resource management and aquatic life protection in the hilly region (Etteieb, Cherif and Tarhouni, 2017).

Several researchers have already completed investigations on the water quality of Kaptai Lake (Ahmed, Haque and Haque, 2001; Islam *et al*., 2021; Islam, Hossain and Majed, 2021), but no analysis has yet been conducted on the Chengi River, Shuvolong, or Risang waterfalls. As a result, the conservation and management of these water bodies are not properly addressed due to a lack of information regarding their water characteristics. A large number of people rely on numerous wellsprings of water, the assurance of a variable range of water quality in various sources in CHT is critical for the sustainable uses. The study was carried out in the Kaptai Lake, Chengi River, and Shuvolong and Risang waterfalls that encompass a large magnitude of CHT's hilly terrain and supply the main source of water in the region. Information about water quality indicators is extremely beneficial for water quality monitoring and long-term management of those resources in the CHTs. Thus, the current research was carried out i) to assess the seasonal and spatial variations of physicochemical properties of the hilly river, lake and waterfalls, and ii) to evaluate the suitability for drinking and fisheries purposes as well as the aquatic ecosystem management.

Materials and Methods

Study area

The study was conducted in the Rangamati and Khagrachhari district at the Chattogram Hill Tracts of Bangladesh (Figure 1), where Rangamati hill district lies at 22°27' to 23°44'N latitudes and 91°56' to 92°33'E longitudes and Khagrachhari hill district lies at 22°38' to 23°44'N latitudes and 91°44' to 92°11'E longitudes (Banglapedia, 2015). The study area was divided into two regions as Rangamati and Khagrachhari, and four sampling locations were selected, each with three stations mentioned as Kaptai Lake, Chengi River, Shuvolong Waterfall and Risang Waterfall.

Sample collection

Water samples were collected from Kaptai Lake (3 stations), Chengi River (3 stations), and Shuvolong and Risang Waterfalls during pre-monsoon (March to June), monsoon (July to October) and post-monsoon (November to February) seasons from the period of March 2021 to February 2022. Samples were collected in 1,000 ml plastic bottles that were cleaned with de-ionized distilled water where the sampling bottles were rinsed at least three times with sample water at each sampling station. Following the sampling, the bottles were carefully screwed shut and labeled with the appropriate identification number of sampling station. To avoid photosynthesis while collecting the samples, the bottles were covered with dark plastic wrap. The bottles were kept under the water and allow overflowing for 2 to 3 minutes to ensure that no air bubbles were trapped and carefully screwed with respective identification number. The samples were stored in an incubator to keep it oxygenated and O_2 stress free. The sample bottles were transported to the laboratory and carefully preserved until analysis.

Sample analysis

The physicochemical qualities of water samples like pH, biological oxygen demand (BOD), electrical conductivity (EC), total dissolved solids (TDS), total alkalinity (TA), and total hardness (TH) were examined in the research laboratory of the Department of Environmental Science and Resource Management, Mawlana Bhashani Science and Technology University. Temperature and dissolved oxygen (DO) were estimated promptly in the spot with a thermometer and dissolved oxygen meter, respectively. The transparency of the lake and river water was also measured in the spot with a Secchi disc. The water samples were analyzed using standard water quality measurement procedures (Table 1).

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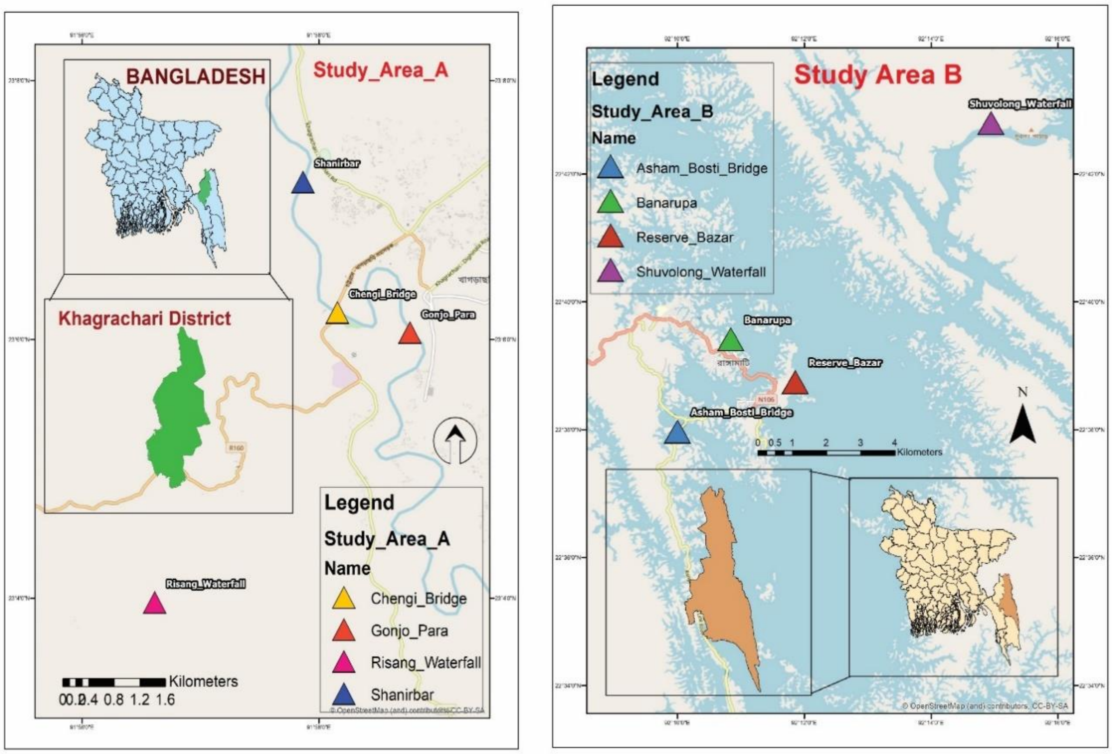

Figure 1: Map showing the study area at Khagrachhari and Rangamati hill tracts in Bangladesh (Banglapedia, 2016).

Table 1: Water quality parameters, methods and instruments used for analysis

Water qualities	*Units*	*Methods and instruments used*
Temperature	^{0}C	Digital Thermometer (Model: SH-113V1)
Transparency	cm	Secchi disc method
Electrical conductivity (EC)	µS/cm	Digital EC meter (Model: HI98304, HANNA)
Total dissolved solids (TDS)	mg/L	Digital TDS meter (Model: HI98301, HANNA)
Dissolved oxygen (DO)	mg/L	Digital DO meter (Model: DO-5509)
Biological oxygen demand (BOD)	mg/L	Incubation method (BOD=BOD1-DO5)
pH	-	Digital pH meter (Model: HI98107, HANNA)
Total alkalinity (TA)	mg/L	Titrimetric method
Total hardness (TH)	mg/L	EDTA titrimetric method

Statistical analysis

The collected data were compiled and tabulated in proper form and were subjected to statistical analysis. The Microsoft Excel 2016 and IBM SPSS 22 software was used to present and interpret the collected data.

Results and Discussion

Temperature

The highest temperature (32.5^{0}C) was recorded during the pre-monsoon season, while the lowest was found during the post-monsoon season in the Kaptai Lake (Table 2, Figure 2). In the Kaptai Lake, Ahmed, Haque and Haque (2001) showed the highest temperature 33.8^{0}C in May and the lowest (25^{0}C) in February, which was similar to the findings of Rahman *et al*. (2014) and Chowdhury *et al*. (2019), while Islam *et al*. (2021) and Islam, Hossain and Majed (2021) found mean water temperature 25.37^{0}C. The temperature of the present study was nearly similar to the Bogakain, Foy's and Joydia Lake (Khondker *et al*., 2010) and higher than the Dhanmondi Lake (Sarker *et al*., 2019). Water temperature was nearly same to that of Victoria, Tanganyika, and Tana Lakes, but higher than that of Lysimachia Lake (Table 5).

The highest water temperature (29.7^{0}C) was recorded during the pre-monsoon season, while the lowest (15^{0}C) was found in post-monsoon season in the Chengi River (Table 3, Figure 3). In the Chengi River, Latifa *et al*. (2019) found a significant positive association between air and water temperature. The present study's water temperature was approximately identical to that of the Karnaphuli, Korotoa, Padma, Halda, Shitalakhya, and Rupsa Rivers, and was higher than the Meghna and Turag Rivers, but lower than the Jamuna and Buriganga Rivers. Moreover, temperature of the Chengi River was similar to that of the Mkomon and Soan Rivers, but greater than that of the Maron, Nile, and Yellow Rivers (Table 6).

The highest water temperature (21.1^{0}C) was found at Shuvolong in pre-monsoon, whereas the lowest (12^{0}C) was found at both studied waterfalls during post-monsoon season (Table 4, Figure 4). Hussen *et al*. (2018) also found same relationship in terms of temperature and season among the investigated waterfalls. This might be due to the effect of water turbulence and a shabby environment in the vicinity of waterfalls (Oyekanmi, Bello-Olusoji and Akin-Obasola, 2017). The temperatures of the present study were compared to other country's waterfalls and found similar to the Coban Rondo Waterfall and lower than the Olumirin Waterfall (Table 7).

Transparency

The depth to which light will enter the water is determined by its transparency. The transmission of light into a waterway is critical since the sun is the essential wellspring of energy for every single organic peculiarity (Oyekanmi, Bello-Olusoji and Akin-Obasola, 2017). Photosynthesis, an interaction that produces oxygen and sustenance for organisms, requires light (Ahmed, Rahman and Mandal, 2013; Offem and Ikpi, 2011). The highest transparency was recorded 230 cm during the pre-monsoon, while the lowest was 87 cm during the monsoon season in Kaptai Lake (Table 2, Figure 2). Similar result was also found by Bashar *et al.* (2015). The range of transparency was in between 97 and 243 cm found by Rahman *et al.* (2014). The transparency of the present study was higher than the Joydia Lake, and more or less similar to the Victoria, Tanganyika and Tana Lake (Table 5).

The highest transparency was recorded 230 cm during the pre-monsoon season, while the lowest was 31 cm in monsoon season in Chengi River (Table 3, Figure 3). Transparency of the present study was higher than the Jamuna, Meghna and Halda River and nearly similar to the Nile River (Table 6). In waterfalls, the highest transparency was 90 cm during the post-monsoon season, while the lowest was 29 cm during the monsoon season (Table 4, Figure 4), similar to the Agbokum Waterfall but lower than the Olumirin Waterfall (Table 7).

Electrical Conductivity (EC)

The highest EC (180 µS/cm) was recorded during the post-monsoon season, while the lowest (90 µS/cm) was recorded during the monsoon season in the Kaptai Lake (Table 2, Figure 2). Rahman and Huda (2018) found the EC value of Kaptai Lake water ranged from 170 to 200 µS/cm. The current study's EC was compared to those of other Bangladeshi studies, and it was revealed that EC was higher than Bogakain and Foy's Lake and lower than Joydia and Ramna Lake (Table 5). The EC of the present study was extremely close to that of Victoria Lake and was lower than that of Tanganyika, Chandlodia, and Tana Lakes (Table 5).

Table 2: Water quality parameters (mean ± SD) in the Kaptai Lake (ranges are in parentheses)

Parameters	*Pre-monsoon*			*Monsoon*			*Post-monsoon*		
	Station 1	*Station 2*	*Station 3*	*Station 1*	*Station 2*	*Station 3*	*Station 1*	*Station 2*	*Station 3*
Temp. (^{0}C)	29.55±0.42 (29-30)	31.17±1.24 (29.5-32.5)	30.75±1.34 (29.7-30.7)	26.17±0.80 (25.1-27)	28.40±0.52 (27.9-120)	26.97±1.19 (25.8-28.5)	18.43±1.09 (17-20)	16.7±1.26 (15-18)	18.41±2.10 (16-21)
Trans. (cm)	194±24.5 (156.8-217)	181.2±43.3 (123-225)	231.4±42 (170-230)	97.8±10.1 (87-110)	102.2±12.4 (90-120)	111.2±13.9 (97-130)	111.4±7.4 (100-120)	133.4±15.3 (112-150)	152.2±22.8 (118-180)
EC (µS/cm)	112±9 (100-120)	113±4 (110-120)	115±12 (100-130)	97±9 (90-110)	107±9 (100-120)	112±17 (90-130)	174±5 (170-180)	164±5 (160-170)	176±5 (170-180)
TDS (mg/L)	69.25±4.34 (65-75)	67.50±1.91 (66-70)	69.5±2.08 (67-72)	58.25±3.30 (55-62)	58.75±0.95 (58-60)	59.75±2.75 (57-63)	59.58±1.15 (58-61)	58.56±1.17 (57-60)	59.94±0.75 (59-61)
DO (mg/L)	6.06±0.62 (5.4-6.9)	6.14±0.70 (5.5-7.0)	6.56±0.18 (6.4-6.8)	6.96±0.42 (6.5-7.5)	6.62±0.50 (5.8-7.1)	6.6±0.40 (6.2-7.2)	6.66±0.37 (6.1-7.4)	6.32±0.21 (6.0-6.5)	6.38±0.5 (5.6-7.0)
BOD (mg/L)	1.61±0.98 (1.5-1.73)	1.67±0.05 (1.6-1.72)	1.30±0.87 (1.67-1.8)	1.08±0.12 (1.07-1.10)	1.06±0.40 (1.0-1.09)	0.98±0.12 (0.97-1.0)	1.0±0.1 (0.98-1.02)	1.05±0.23 (1.02-1.08)	1.05±0.06 (0.95-1.10)
pH	7.55±0.28 (7.2-7.9)	7.22±0.27 (6.9-7.5)	7.35±0.20 (7.1-7.6)	6.6±0.42 (6.2-7.2)	6.9±0.66 (6.0-7.5)	6.62±0.35 (6.1-6.9)	6.84±0.11 (6.8-7.0)	7.1±0.15 (6.9-7.3)	6.9±0.16 (6.7-7.7)
TA (mg/L)	86.0±2.94 (83-90)	87.5±2.88 (84-91)	95.5±4.12 (90-100)	108±2.16 (105-110)	127.5±6.45 (120-135)	136.0±4.54 (130-140)	119.96±3.02 (117-125)	128.34±4.71 (122-133)	130.48±5.93 (121-135)
TH (mg/L)	47.25±3.09 (45-52)	48.75±0.95 (48-50)	50.75±1.70 (49-53)	106.75±4.57 (100-110)	109.25±3.09 (105-112)	105.75±2.21 (104-109)	128.34±4.28 (121-132)	129.10±4.95 (123-135)	120.56±5.13 (112-125)

Note: AT = Air Temperature, WT = Water Temperature.

Table 3: Water quality parameters (mean ± SD) in the Chengi River (range are in parentheses)

Parameters	*Pre-monsoon*			*Monsoon*			*Post-monsoon*		
	Station 1	*Station 2*	*Station 3*	*Station 1*	*Station 2*	*Station 3*	*Station 1*	*Station 2*	*Station 3*
Temp. (^{0}C)	25.82±1.23 (24.3-27.1)	25.92±0.60 (25-26.5)	26.07±0.30 (25.8-26.5)	24.27±1.55 (23-26.5)	26.27±2.23 (24.5-29.5)	26.87±2 (25.1-29.7)	16.4±1.21 (15-18)	17.81±1.07 (16-19)	18.05±0.79 (17-19)
Trans. (cm)	158.7± 39 114.6-200)	185.8±28.1 (154-215)	183.6±12.3 (167-198)	72±16.7 (50-92)	53.4±18.3 (31-81)	53±19.4 (31-79)	106.6±8.47 (90-110)	120.4±7.3 (112-130)	151.8±19.52 (120-170)
EC (µS/cm)	132± 15 (120-150)	130±8 (120-140)	117±9 (110-130)	95±5 (90-100)	105±12 (90-120)	100±8 (90-110)	154±5 (150-160)	164±5 (160-170)	156±5 (150-160)
TDS (mg/L)	80.75±7.18 (72-88)	84.25±2.21 (82-87)	81.75±2.50 (79-85)	42.5±2.08 (40-45)	47.25±2.21 (45-50)	46.0±3.16 (42-49)	72.2±0.9 (71-73)	73±1.0 (72-74)	70.7±1.2 (69-72)
DO (mg/L)	5.3±0.88 (4.4-6.5)	5.96±0.48 (5.4-6.6)	5.72±0.52 (4.9-6.3)	6.1±0.45 (5.4-6.7)	5.94±0.40 (5.5-6.5)	6.0±0.75 (5-6.8)	6.56±0.31 (6.2-7.0)	6.18±0.55 (5.5-6.8)	6.08±0.08 (7.0-7.2)
BOD (mg/L)	1.74±0.02 (1.71-1.76)	1.68±0.01 (1.67-1.7)	1.71±0.04 (1.71-1.72)	1.05±0.02 (1.02-1.09)	1.01±0.05 (0.98-1.1)	1.03±0.02 (1.03-1.05)	1.06±0.04 (0.99-1.10)	1.1±0.3 (1.05-1.13)	1.15±0.05 (1.06-1.20)
pH	7.82±0.17 (7.6-8.01)	7.52±0.25 (7.2-7.8)	7.52±0.26 (7.3-7.9)	6.27±0.26 (5.9-6.5)	6.20±0.18 (6-6.4)	6.57±0.35 (6.1-6.9)	7.02±1.3 (6.9-7.2)	7.16±0.18 (7.0-7.4)	6.7±0.15 (6.5-6.9)
TA (mg/L)	90.25±3.59 (85-93)	92±3.38 (90-100)	92.5±4.79 (88-98)	165±12.9 (150-180)	173.75±11 (160-185)	178.75±8.53 (170-190)	106.96±3.99 (100-110)	114.98±4.55 (109-120)	112.22±5.04 (105-118)
TH (mg/L)	49.5± 3.69 (45-53)	52.25±4.42 (48-57)	53.0±2.58 (50-56)	112.75±2.21 (110-115)	115.25±2.5 (112-118)	118.75±2.62 (115-121)	121.76±6.02 (115-130)	129.28±5.34 (120-133)	125.3±12.47 (110-139)

The highest EC (170 µS/cm) was recorded during the post-monsoon season, while the lowest (90 µS/cm) was recorded during the monsoon season in Chengi River (Table 3, Figure 3). The EC of the present study was lower than the Shitalakhya, Buriganga, Turag and Rupsa, Karnaphuli, Dhaleshwari, Padma, Meghna and Halda River. On the other hand, the EC of the present study was lower than the Mkomon, Maron, Nile and Doyang River (Table 6). The highest EC (210 µS/cm) was recorded during the post-monsoon season, while the lowest (150 µS/cm) was recorded during the monsoon season in Shuvolong and Risang waterfalls (Table 4, Figure 4).

Table 4: Water quality parameters (mean ± SD) in the Shuvolong and Risang Waterfalls (ranges are in parentheses)

Parameters	*Pre-monsoon*		*Monsoon*		*Post-monsoon*	
	Shuvolong	*Risang*	*Shuvolong*	*Risang*	*Shuvolong*	*Risang*
Temp. (^{0}C)	21±0.31 (20.8-21.1)	21.56±0.51 (21.5-22.01)	19.64±1.02 (18.3-20.8)	20.62±1.05 (19.2-21.8)	13.06±1.20 (12-15)	13.11±0.77 (12-14)
Trans. (cm)	Nd	Nd	46±14 (30-69)	49±13.7 (29-50)	80±4.52 (75-85)	80±7.9 (70-90)
EC (µS/cm)	185±12 (170-200)	182±15 (170-200)	162±12 (150-180)	175±12 (160-190)	204±5 (200-210)	194±5 (190-200)
TDS (mg/L)	108.25±5.56 (100-112)	109.5±6.40 (100-114)	92.5±2.38 (90-95)	96.25±1.12 (95-98)	76.7±1.2 (75-78)	75±0.79 (74-76)
DO (mg/L)	6.64±0.25 (6.5-7.0)	5.9±0.44 (5.4-6.5)	8.72±0.54 (8-9.5)	8.48±0.46 (7.8-9.2)	8.16±0.52 (7.5-8.8)	8.04±0.79 (6.9-8.7)
BOD (mg/L)	0.97±0.21 (0.95-1.0)	0.98±0.21 (0.97-1.0)	0.81±0.07 (0.75-0.86)	0.69±0.06 (0.63-0.76)	0.61±0.07 (0.5-0.7)	0.67±0.11 (0.5-0.8)
pH	7.87±0.25 (7.6-8.2)	7.58±0.41 (7.05-8.06)	7.12±0.33 (6.8-7.5)	6.87±0.33 (6.5-7.3)	8.08±0.13 (7.9-8.2)	7.52±0.23 (7.2-7.8)
TA (mg/L)	125.75±4.34 (120-130)	129.5±4.20 (125-135)	201±10.03 (190-210)	186.5±5.06 (180-191)	153.9±4.99 (180-200)	214.98±9.81 (200-223)
TH (mg/L)	80.75±3.09 (78-85)	79.75±3.40 (75-83)	147.75±4.85 (145-155)	139.75±4.11 (135-145)	175.42±11.26 (160-190)	190.1±7.98 (180-200)

Note: Nd = Not detected.

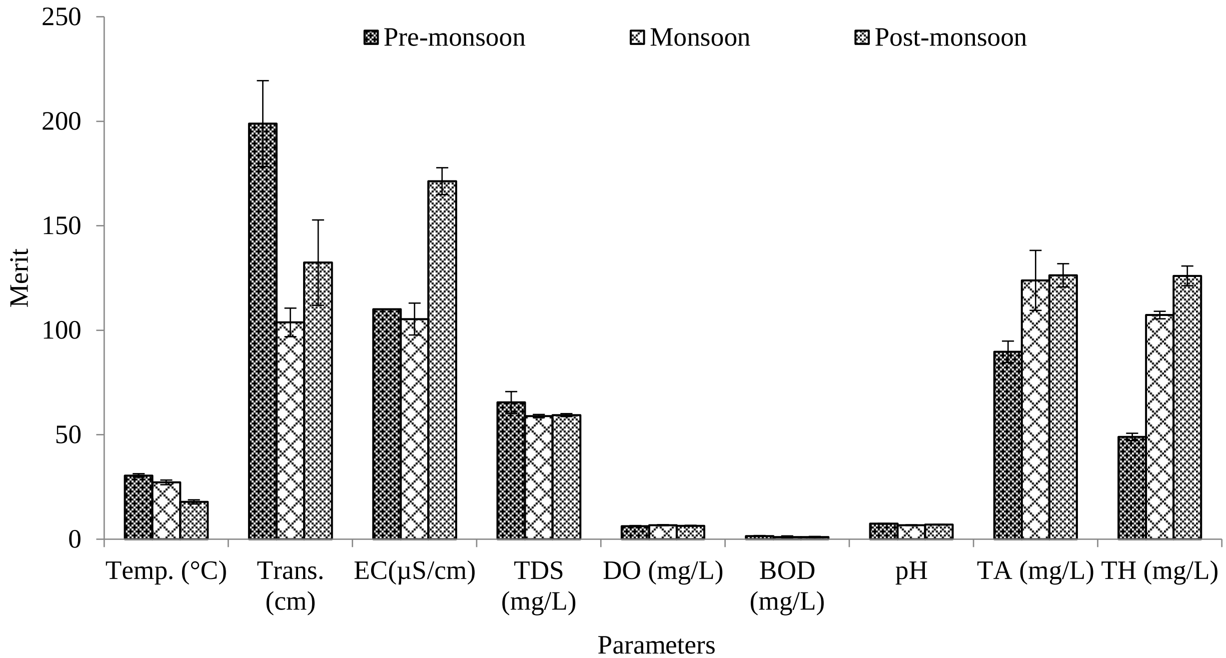

Figure 2: Water quality parameters in the Kaptai Lake during pre-monsoon, monsoon and post-monsoon season.

Total Dissolved Solid (TDS)

The highest TDS (75 mg/L) was recorded during the pre-monsoon season, while the lowest (53 mg/L) was recorded during the monsoon season in Kaptai Lake (Table 2, Figure 2). TDS levels in Kaptai Lake were determined in between 47.8 to 57.6 mg/L by Chowdhury *et al.* (2019), which is comparable to the current study. The TDS of the present study was higher than the Bogakain and Foy's Lake and lower than the Ramna Lake (Table 5). On the other hand, the EC of the present study was lower than the Tanganyika, Chandlodia and Tana Lake (Table 5).

The highest TDS (88 mg/L) was recorded during the pre-monsoon season, while the lowest (40 mg/L) was recorded during the monsoon season in the Chengi River (Table 3, Figure 3). Latifa *et al.* (2019) found the Chengi river water TDS was in between 51 and 53 mg/L. The TDS of the present study was just about similar to the Halda River, and lower than the Karnaphuli, Padma, Shitalakhya, Dhaleshwari, Meghna, Buriganga, Turag and Rupsa River. On the other hand, the TDS of the present study was nearly similar to the Doyang River, and lower than Nile River, and higher than the Mkomon and Soan River (Table 6). The highest TDS (114 mg/L) was recorded during the pre-monsoon season, while the lowest (74 mg/L) was recorded during the post-monsoon season in Shuvolong and Risang waterfalls (Table 4, Figure 4). Offem and Ikpi (2011) found the TDS values 88.4 mg/L in the waterfalls. The TDS of the present study were compared to other country's waterfalls and found that the TDS in present study was lower than the Olumirin and Agbokum Waterfall (Table 7).

Dissolved Oxygen (DO)

The highest DO (7.5 mg/L) was recorded at the monsoon season, on the other hand, the lowest (5.4 mg/L) was recorded during the pre-monsoon season in Kaptai Lake (Table 2, Figure 2). Rahman and Huda (2018) found the DO in Kaptai Lake varied from 8.28 to 9.59 mg/L which was much higher than present study. Bashar *et al.* (2015) found the mean DO content 6.4 and 5.74 mg/L during 2012-13 and 2013-14, respectively, which was comparable to the present study. Barua *et al.* (2016) found the DO level of Kaptai Lake in between 4.1 and 4.8 mg/L which was below the recommended guideline values as well as lower than present study. The DO of the present study was found analogous to the Joydia and Dhanmondi Lake, and higher than the Bogakain and Ramna Lake, and lower than Foy's Lake (Table 5). On the other hand, the DO of the present study was found similar to the Victoria Lake and Tanganyika Lake and lower than the Lysimachia Lake, and higher than Chandlodia and Tana Lake (Table 5).

The highest DO (7.2 mg/L) was recorded during the post-monsoon season, while the lowest (4.4 mg/L) was recorded during the pre-monsoon season in Chengi River (Table 3, Figure 3). The DO of Chengi River was 5.3 to 5.8 mg/L reported by Latifa *et al.* (2019), which is similar to the present study. The DO of the present study was similar to the Halda River, and lower than the Padma and Meghna River, and higher than the Karnaphuli, Shitalakhya, Dhaleshwari, Buriganga, Turag and Korotoa River. On the other hand, the DO of the present study was compared to other country's river and found that the DO in present study is similar to the Soan River and lower than the Doyang, Nile and Yellow River, and higher than the Mkomon River (Table 6).

The highest DO (9.5 mg/L) was recorded during the monsoon season, while the lowest (5.4 mg/L) was recorded during the pre-monsoon season in waterfalls of Shuvolong and Risang (Table 4, Figure 4). The DO of the present study was compared to other country's waterfalls and found that the DO in present study was similar to the Coban Rondo and Agbokum Waterfall (Table 7).

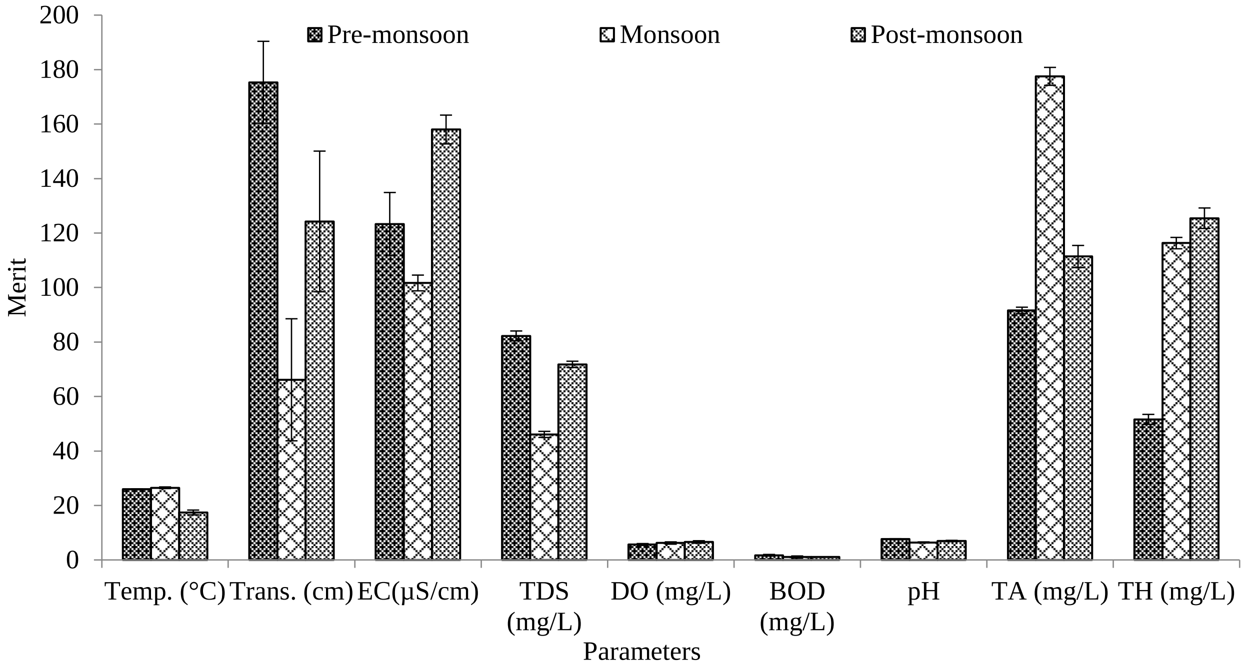

Figure 3: Water quality parameters in Chengi River during pre-monsoon, monsoon and post-monsoon season.

Biological Oxygen Demand (BOD)

The highest BOD (1.8 mg/L) was recorded during the pre-monsoon season, while the lowest (0.95 mg/L) was recorded during the post-monsoon season in Kaptai Lake (Table 2, Figure 2). Rahman and Huda (2018) found similar result to the present study. Chowdhury *et al*. (2019) found that the BOD of Kaptai Lake was in between 0.2 and 0.5 mg/L, which was lower than the current study. The BOD of the present study was lower than the Dhanmondi and Ramna Lake, and similar to the Foy's Lake (Table 5). On the other hand, the BOD of the present study was lower than the Tanganyika and Chandlodia Lake (Table 5).

The highest BOD (1.76 mg/L) was recorded during the pre-monsoon season, while the lowest (0.95 mg/L) was recorded during the monsoon season in Chengi River (Table 3, Figure 3). The BOD of the present study was similar to the Surma and Shitalakhya River, and lower than the Karnaphuli, Dhaleshwari, Korotoa, Padma and Meghna River. On the other hand, the BOD of the present study was similar to the Yellow River and lower than the Doyang, Nile and Mkomon River (Table 6). The highest BOD (1.7 mg/L) was recorded during the post-monsoon season, while the lowest (0.63 mg/L) was recorded during the monsoon season in Shuvolong and Risang waterfalls (Table 4, Figure 4). The BOD of the present study was compared to other country's waterfalls and found that the BOD in present study is lower than Coban Rondo Waterfall and Agbokum Waterfall (Table 7).

pH

The highest pH (7.9) was recorded during the pre-monsoon season, while the lowest (6.0) was recorded during the monsoon season in Kaptai Lake (Table 2, Figure 2). Rahman and Huda (2018) were found similar result to the present study. The pH was 6.9 to 8.2 as observed by Bashar *et al*. (2015) that was alkaline to nature. The pH of the present study was similar to the Dhanmondi and Ramna Lake and lower than the Bogakain, Joydia and Foy's Lake and lower than the Joydia and Ramna Lake (Table 5). On the other hand, the pH of the present study was lower than the Victoria, Lysimachia, Tanganyika, Chandlodia and Tana Lake (Table 5). Kaptai Lake's water pH ranges between 7.46 to 7.75, which was within acceptable limits (Barua *et al*., 2016).

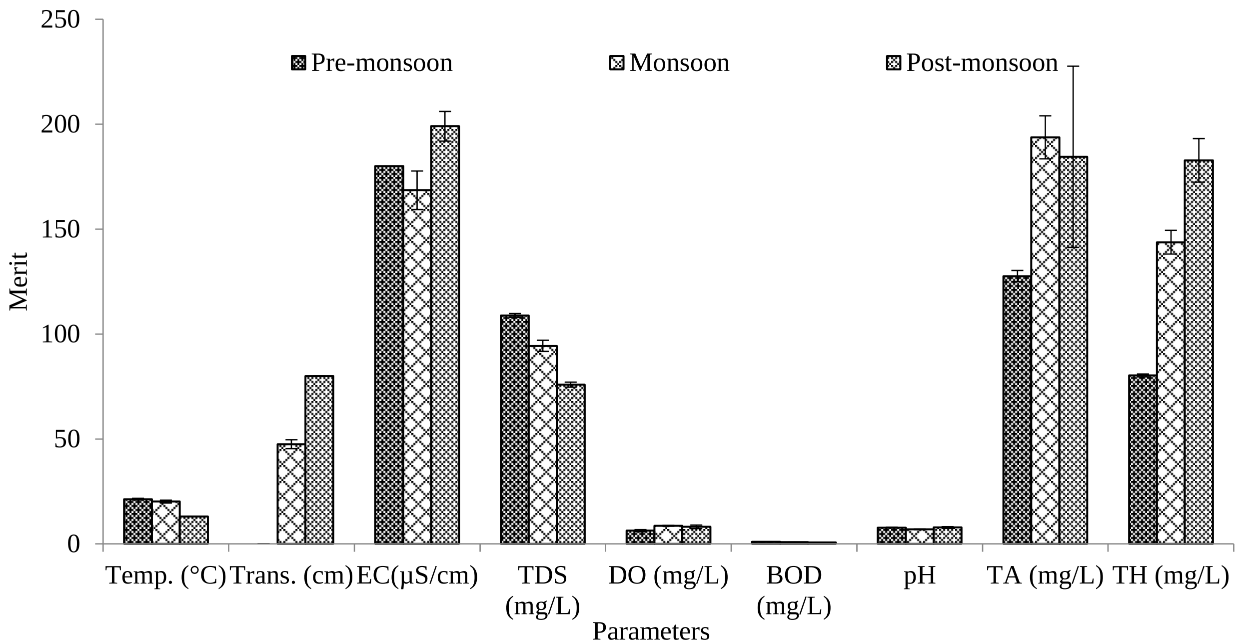

Figure 4: Water quality parameters in Shuvolong and Risang waterfalls during pre-monsoon, monsoon, and post-monsoon season.

The highest pH (8.01) was recorded during the pre-monsoon season, while the lowest (5.9) was recorded during the monsoon season in Chengi River (Table 3, Figure 3). Hoque *et al*. (2013) demonstrated that the lower pH levels during the monsoon season were due to the diluting of river water by rain and runoff. The pH of the present study was similar to the Jamuna, Dhaleshwari, Surma, Padma, Meghna, Halda, Buriganga, Turag and Shitalakhya River, and lower than the Rupsa River, and higher than the Karnaphuli River. On the other hand, the pH of the present study was similar to the Maron and Doyang River and lower than the Nile, Yellow, and Soan River, and higher than the Mkomon River (Table 6).

The highest pH (8.2) was recorded during the post-monsoon season, while the lowest (6.5) was recorded during the monsoon season in Shuvolong and Risang waterfalls (Table 4, Figure 4). Olumirin Waterfalls have a pH of 7.25 was found by Oyekanmi, Bello-Olusoji and Akin-Obasola (2017). The pH of the present study was compared to other country's waterfalls and found that the pH in present study is similar to Coban Rondo Waterfall and Olumirin Waterfall (Table 7).

Total Alkalinity (TA)

The highest TA (140 mg/L) was recorded during the monsoon season, while the lowest (83 mg/L) was recorded during the pre-monsoon season in Kaptai Lake (Table 2, Figure 2). Ahmed, Haque and Haque (2001) stated that the total alkalinity level in the lake water was varied somewhat from month to month (47.6 to 60.1 mg/L). Islam *et al*. (2021) found the total alkalinity of Kaptai Lake range from 35 to 190 mg/L. Bashar *et al.* (2015) revealed that TA values that were similar to those observed in the current investigation. The total alkalinity of the present study was similar to the Dhanmondi and Ramna Lake, and higher than the Foy's Lake, and lower than the Bogakain Lake (Table 5). On the other hand, the total alkalinity of the present study was similar to the Victoria Lake and lower than the Tanganyika, Chandlodia and Tana Lake (Table 5).

The highest TA (140 mg/L) was recorded during the monsoon season, while the lowest (83 mg/L) was recorded during the pre-monsoon season in the Chengi River (Table 3, Figure 3). In the Bansi River, Hoque *et al.* (2013) discovered that total alkalinity ranging from 46 to 155 mg/L across various seasons. The total alkalinity of the present study was similar to the Korotoa, Padma, Meghna, and Rupsa River, and lower than the Shitalakhya and Turag River, and higher than the Karnaphuli and Surma River. On the other hand, the total alkalinity of the present study was similar to the Doyang River and higher than the Soan River (Table 6).

The highest total alkalinity (223 mg/L) was recorded during the post-monsoon season, while the lowest (120 mg/L) was recorded during the pre-monsoon season in Shuvolong and Risang waterfalls (Table 4, Fig. 4). The total alkalinity of the present study was compared to other country's waterfalls and found that the total alkalinity in present study is similar to Olumirin Waterfall (Table 7).

Table 5: Comparison of water qualities among Kaptai Lake and those of previous studied other lakes

Lakes	*Temp. (^0C)*	*Trans. (cm)*	*EC (µS/cm)*	*TDS (mg/L)*	*DO (mg/L)*	*BOD (mg/L)*	*pH*	*TA (mg/L)*	*TH (mg/L)*	*Reference*
National										
Kaptai	16.0-32.5	87-230	90-180	53-75	5.4-7.5	0.95-1.8	6.0-7.9	83-140	45-135	Present study
Bogakain	22.3-27.0	Nf	74-80	39-42	0.61-11.9	Nf	7.8-9.1	880-1240	Nf	Khondker *et al.* (2010)
Foy's	29.0-30.3	Nf	66.0-72.8	33.0-36.4	7.7-8.8	0.2-1.7	7.5-8.0	20.8-25.19	30.0-32.3	Chowdhury *et al.* (2019)
Joydia	28.83	17.93	377.35	Nf	7.07	Nf	8.57	Nf	Nf	Chowdhury, Bulbul and Bisshash (2016)
Dhanmondi	24.0	Nf	283.67	Nf	5.55	21.33	7.63	117.33	Nf	Sarker *et al.* (2019)
Ramna	Nf	Nf	179.7	85.6	4.64-4.84	1.47-2.23	6.71-6.72	95.32-96.45	60.40-60.76	Sarker *et al.* (2019)
International										
Victoria, Kenya	25.11-25.57	145	105.92-107.25	Nf	6.17-6.51	Nf	7.92-8.03	47	24	Mwamburi *et al.* (2020)
Lysimachia, Greece	10-31	Nf	348-2197	Nf	6.3-10.6	Nf	8.19-8.77	Nf	Nf	Avramidis *et al.* (2013)
Tanganyika, Africa	27.1-29.4	110-210	Nf	440.8-453.5	7.16-7.71	5.0-10.6	8.5-8.8	Nf	Nf	Niyoyitungiye, Giri and Mishra (2020)
Chandlodia, India	Nf	Nf	2150-3470	1008-1224	3.13-5.89	1.78-3.22	8.2-8.9	204-224	310-340	Maurya (2015)
Tana, Ethiopia	17.5-30.3	28-163	37-373	28-211	3.83-8.86	Nf	6.5-9.2	Nf	Nf	Tibebe *et al.* (2019)

Note: Nf= Not found, Temp. = Temperature, Trans. = Transparency, EC = Electrical Conductivity, TDS = Total Dissolved Solid, DO = Dissolved Oxygen, BOD = Biological Oxygen Demand, TA = Total Alkalinity, TH = Total Hardness.

Total Hardness (TH)

The highest total hardness (135 mg/L) was recorded during the post-monsoon season, while the lowest (45 mg/L) was recorded during the pre-monsoon season in Kaptai Lake (Table 2, Figure 2). The current study's findings are comparable to those of a prior study by Bashar *et al.* (2015). The total hardness of the present study was higher than the Ramna and Foy's Lake (Table 5). On the other hand, the total hardness of the present study was higher than the Victoria Lake and lower than Chandlodia Lake (Table 5).

Table 6: Comparison of water qualities among Chengi River and those of previous studies

Rivers	*Temp. (^0C)*	*Trans. (cm)*	*EC (µS/cm)*	*TDS (mg/L)*	*DO (mg/L)*	*BOD (mg/L)*	*pH*	*TA (mg/L)*	*TH (mg/L)*	*References*
National										
Chengi	15-29.7	31.0-200.0	90-170	40-88	4.4-7.2	0.98-1.76	5.9-8.01	85-190	45-139	Present study
Karnaphuli	27.88-28.3	Nf	213-9140	143.6-6292.6	2.98-3.96	2.4-12.9	6.52-7.22	39.88-60.92	37.5-467.4	Hossen *et al.* (2019)
Jamuna	32.7-35.9	12.3-15.7	Nf	Nf	2.4-2.76	Nf	7.27-7.60	Nf	Nf	Anwar *et al.* (2017)
Korotoa	19.36-32.36	Nf	Nf	Nf	1.2-3.5	1.73-3.70	Nf	50.66-207.30	46.66-112.00	Ahatun *et al.* (2020)
Dhaleshwari	Nf	Nf	1709.34	1364.6	2.05	26.44	8.04	Nf	Nf	Islam *et al.* (2021)
Surma	Nf	Nf	Nf	100-200	Nf	1-1.6	7.5-7.72	45-56	20-35	Uddin *et al.* (2020)
Padma	20.17-33.84	Nf	130.45-161.81	117.78-220.55	4.93-8.70	1.07-4.86	6.86-7.94	93.32-130.89	106.53-152.76	Haque, Jewel and Sultana (2019)
Meghna	25.1-26.6	44.3-49	284.5-466	153.6-229.9	7.3-7.5	5.4-6.1	7.8-8.4	110.7-119.6	107.2-143.7	Alam *et al.* (2016)
Halda	28.9-29.3	24.2-27.9	127.3-175.3	63.2-87.3	4.5-5.8	Nf	7.0-7.2	Nf	Nf	Parvez *et al.* (2019)
Shitalakhya	29.9-32.5	Nf	443-1175	269-573	1.3-1.7	0.55-1.3	7.4-7.7	204-350	65.9-86	Irin *et al.* (2017)
Buriganga	28.00-38.0	Nf	312-1208	402-1719	0.14-2.13	21.36-27.5	6.48-8.02	Nf	Nf	Ahammed *et al.* (2016)
Turag	24.0-26.1	Nf	1323-1710	1181-1567	1.3-3.5	Nf	7.48-7.9	525.25-864.0	659.0-827.32	Tahmina *et al.* (2018)
Rupsa	29.7	Nf	16705	8638	Nf	Nf	8.5	90.45	2063	Islam *et al.* (2018)
International										
Maron, Iran	19.6-23.3	Nf	2037-3435	Nf	Nf	Nf	7.94	Nf	2.78-5.01	Tabari, Marofi and Ahmadi (2011)
Nile, Egypt	18.0-26.31	118.6-160.9	269.0-298.18	154.9-324.64	7.2-9.5	2.8-3.4	7.5-8.6	Nf	Nf	Abdel-Satar (2005)
Yellow, China	13.6-17.3	Nf	Nf	Nf	8.9-10.3	1.1-2.3	8.2-8.4	Nf	Nf	Hou *et al.* (2016)
Mkomon, Nigeria	28.3-28.8	Nf	3490-5620	17.5-47.5	2.9-4.0	2.6-3.3	5.7-6.5	Nf	75.5-83.2	Augustine (2018)
Soan, Pakistan	9.0-31.0	Nf	Nf	0.53-4.83	4.6-9.3	Nf	8.0-9.0	19.0-36.0	Nf	Iqbal *et al.* (2004)
Doyang, India	Nf	Nf	139.42-271.49	64.0-134.42	7.75-11.38	0.88-3.34	6.75-8.29	77.50-141.2	63.5-111.3	Lkr, Singh and Puro (2020)

Note: Nf= Not found, Temp. = Temperature, Trans. = Transparency, EC = Electrical Conductivity, TDS = Total Dissolved Solid, DO = Dissolved Oxygen, BOD = Biological Oxygen Demand, TA = Total Alkalinity, TH = Total Hardness.

Table 7: Comparison of water qualities among Shuvolong and Risang waterfall and those of previous studies

Waterfall	*Temp. (^0C)*	*Trans. (cm)*	*EC (µS/cm)*	*TDS (mg/L)*	*DO (mg/L)*	*BOD (mg/L)*	*pH*	*TA (mg/L)*	*TH (mg/L)*	*Reference*
National										
Shuvolong, Bangladesh	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	Present study
Risang, Bangladesh	12.0-22.1	29-90	160-200	74-114	5.4-9.2	0.5-1.0	6.5-8.06	125-223	75-200	Present study
International										
Coban Rondo, Indonesia	20.5	Nf	111	Nf	8-11	13.8-15.6	6.9-7.4	Nf	Nf	Hussen *et al*. (2018)
Agbokum, Nigeria	Nf	28.8	69	178.6	9.6	4.8	Nf	Nf	74.5	Offem and Ikpi (2011)
Olumirin, Nigeria	22.0-31.5	70-120	800-868	131-882	Nf	Nf	6.08-8.50	94.0-278.0	Nf	Oyekanmi, Bello-Olusoji and Akin-Obasola (2017)

Note: Nf= Not found, Temp. = Temperature, Trans. = Transparency, EC = Electrical Conductivity, TDS = Total Dissolved Solid, DO = Dissolved Oxygen, BOD = Biological Oxygen Demand, TA = Total Alkalinity, TH = Total Hardness.

The highest total hardness (139 mg/L) was recorded during the post-monsoon season, while the lowest (45 mg/L) was recorded during the pre-monsoon season in the Chengi River (Table 3, Figure 3). The total hardness of the present study was similar to the Korotoa River and lower than the Karnaphuli, Padma, Meghna, Turag and Rupsa River, and higher than the Surma and Shitalakhya River. On the other hand, the total hardness of the present study was similar to the Mkomon and Doyang River and higher than the Maron River (Table 6).

The highest total hardness (200 mg/L) was recorded during the post-monsoon season, while the lowest (75 mg/L) was recorded during the pre-monsoon season in Shuvolong and Risang waterfalls (Table 4, Figure 4). The total hardness of the present study was compared to other country's waterfalls and found that the total hardness in present study is similar to Agbokum Waterfall (Table 7).

A correlation matrix is useful for displaying relationships between variables by expressing the data set's overall contribution (Li *et al*., 2011). Pearson's correlation analysis is a useful statistical method for demonstrating the degree to which one variable is dependent on the others (Belkhiri, Boudoukha and Mouni, 2011). It specifies the relationship between various variables and parameters, indicating strong (>0.7) and moderate (0.5 to 0.7) relationships (Mudgal, Kumari and Sharma, 2009; Shil, Singh and Mehta, 2019). For statistical analysis, the real values of the variables (temperature, transparency, EC, TDS, DO, BOD, TA and TH) were used (Table 8). The correlation matrix (Table 8) showed the actual Pearson's correlation coefficient values. Strong positive correlations exist between temperature-transparency, EC-TDS, EC-TA, EC-TH, TDS-TA, TDS-TH, TA-TH, etc., during the pre-monsoon season. The analysis showed a strong positive association between temperature-BOD, EC-TDS, EC-DO, EC-TH, TDS-DO, TDS-TH, TDS-pH, DO-pH, DO-TH and TA-TH during the monsoon season (Table 8). Analysis showed strong positive correlations between temperature-transparency, temperature-BOD, transparency-BOD, EC-DO, EC-pH, EC-TA, EC-TH, DO-pH, DO-TA, DO-TH, pH-TH and TA-TH in the post-monsoon season (Table 8). This indicates that the variables are changing in a direct proportional relationship. A reasonable and considerable negative correlation was also identified for some parameters, showing that they change in an inverse proportionate manner.

Table 8: Correlations of water qualities in different seasons among lake, river and waterfall

Quality	*Temp.*	*Trans.*	*EC*	*TDS*	*DO*	*BOD*	*pH*	*TA*	*TH*
Pre-monsoon									
Temp.	1								
Trans.	0.883**	1							
EC	-0.913**	-0.974**	1						
TDS	-0.972**	-0.943**	0.971**	1					
DO	0.069	-0.158	0.203	0.091	1				
BOD	0.612	0.799*	-0.839**	-0.757*	-0.593	1			
pH	-0.762*	-0.578	0.621	0.636	-0.210	-0.298	1		
TA	-0.834*	-0.940**	0.962**	0.934**	0.335	-0.932**	0.454	1	
TH	-0.865**	-0.964**	0.973**	0.952**	0.330	-0.901**	0.493	0.991**	1
Monsoon									
Temp.	1								
Trans.	0.660	1							
EC	-0.857**	-0.512	1						
TDS	-0.802*	-0.334	0.965**	1					
DO	-0.845**	-0.331	0.927**	0.982**	1				
BOD	0.857**	0.556	-0.979**	-0.918**	-0.870**	1			
pH	-0.465	-0.044	0.702	0.811*	0.814*	-0.576	1		
TA	-0.707*	-0.918**	0.608	0.411	0.389	-0.634	0.157	1	
TH	-0.915**	-0.776*	0.900**	0.825*	0.831*	-0.870**	0.607	0.821*	1
Post-monsoon									
Temp.	1								
Trans.	0.830*	1							
EC	-0.749*	-0.637	1						
TDS	-0.651	-0.612	0.316	1					
DO	-0.859**	-0.678	0.788*	0.635	1				
BOD	0.918**	0.821*	-0.915**	-0.488	-0.881**	1			
pH	-0.896**	-0.778*	0.830*	0.598	0.738*	-0.847**	1		
TA	-0.785*	-0.597	0.770*	0.359	0.753*	-0.894**	0.609	1	
TH	-0.925**	-0.780*	0.856**	0.596	0.906**	-0.969**	0.830*	0.913**	1

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

Conclusion

The present study is a preliminary assessment of the seasonal fluctuations of physicochemical water properties in the Kaptai Lake, Chengi River, and Shuvolong and Risang Waterfalls, which provides significant information for the protection and conservation of these hilly aquatic ecosystems. During the pre-monsoon and monsoon seasons, the temperature, transparency, EC, TDS, DO, BOD, and pH were all within Bangladesh requirements, which is a good sign of a healthy aquatic ecosystem. Furthermore, total alkalinity in these water bodies remained constant during the pre-monsoon season but increased somewhat during the monsoon and post-monsoon seasons. In the pre-monsoon, the TH of water in both Kaptai Lake and the Chengi River was soft, though moderate in waterfalls. The study thereby concluded that appropriate surface water management initiative in the CHT need to be taken by concern authorities to safeguard these water bodies, which may include regular monitoring, proper management and promote consciousness through awareness and research.

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Authors' Declarations and Essential Ethical Compliances

Authors' Contributions (in accordance with ICMJE criteria for authorship)

Contribution	Author 1	Author 2	Author 3	Author 4	Author 5	Author 6	Author 7
Conceived and designed the research or analysis	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Collected the data	Yes	Yes	Yes	Yes	No	No	No
Contributed to data analysis & interpretation	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Wrote the article/paper	Yes	Yes	Yes	Yes	Yes	No	No
Critical revision of the article/paper	Yes	Yes	Yes	Yes	No	Yes	Yes
Editing of the article/paper	Yes	No	No	Yes	No	Yes	Yes
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