SPATIO-TEMPORAL VARIATION OF WATER QUALITY PARAMETERS, SEDIMENTS ORGANIC CARBON AND ORGANIC MATTER OF DIFFERENT STATIONS OF KAPTAI LAKE, RANGAMATI

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LIST OF ABBREVIATION

Words	Abbreviation
mg	Milligram
g	Gram
ft	Feet
m	meter
μm	Micro Meter
°C	Degree Celsius
DO	Dissolve oxygen
OM	Organic matter
EDTA	Ethylenediaminettraacetic acid

Abstract

This research delves into the physical and chemical conditions of Kaptai Lake in Bangladesh. The study spanned six months (March - August), involving the collection of water samples monthly from four distinct sampling points: Jolojan Ghaat, Kandemu, Shubholong Jhorna, and Shubholong Bazar. Throughout this period, notable temporal fluctuations in various physical and chemical parameters were observed. July 2022 recorded the highest water temperature at 32±0.68 °C, while the lowest was noted in March 2022 at 26.87±2.11 °C. The concentration of dissolved oxygen (DO) ranged between approximately 5.14 to 8.8 mg/L. Conversely, the pH levels consistently indicated an alkaline nature, oscillating between 7.0 and 8.3. Total alkalinity demonstrated variability, ranging from 40 mg/l in July to 82 mg/l in May, while water hardness exhibited fluctuations from 36 mg/l in August to 86 mg/l in June. Concentrations of NH_3-N spanned roughly from 0.50 to 1.50 mg/L. Deeper sampling stations exhibited higher organic matter content, with Kandemu showcasing the greatest depth at 54.167±6.145 ft and organic matter content at 3.488±1.618 %. In contrast, Jolojan Ghaat displayed lower values, with a depth of 18.417±6.003 ft and organic content of 1.756±1.618 %. Surface water indicated elevated temperatures and dissolved oxygen levels, while bottom water stood out with higher total dissolved solids (TDS) content. These findings collectively affirmed that the lake's physical and chemical attributes fell within ranges conducive to supporting aquatic life, including the thriving ecosystem necessary for fish production by providing comprehensive baseline data on the monthly dynamics of Kaptai Lake's physical and chemical parameters, this study offers invaluable insights for the sustainable management and preservation of this vital ecosystem.

Keywords: Kaptai Lake, Physicochemical Parameters, Organic matter

Chapter: 01

Introduction

Recognized as the largest wetland globally inundated with water and the third-largest aquatic biodiversity in Asia, Bangladesh is a prime region for fisheries (Shamsuzzaman et al., 2017). It is a significant contributor to Asia's fish production (FAO, 2020). The fisheries sector in Bangladesh contributes 3.57% to the national GDP, 25.30% to the agricultural GDP, and engages 11% of the population either fully or partially (DoF, 2018). The inland culture fisheries account for 56.24% of the total fish production, with the remainder coming from inland and marine capture. Bangladesh holds the third position in inland water capture fisheries and the fifth position in freshwater culture fisheries, and it is third in tilapia culture development in Asia (FAO, 2018). Fish is the second-most valuable crop in Bangladesh, contributing to the livelihood and employment of millions. The people of Bangladesh, often referred to as "Macche-Bhate Bangali" or "a Bengali made of rice and fish," consume fish as a popular food product. The culture and consumption of fish significantly contribute to Bangladesh's national income and food security (Ghose, 2014). The diverse aquatic ecosystem of Bangladesh is home to 289 freshwater fish species, 475 marine fish species, 24 prawn species, 36 shrimp species, and 12 exotic fish species (Khan et al., 2013).

Freshwater aquaculture in Bangladesh is primarily practiced in ponds, lakes, and other water bodies. Kaptai Lake, the largest manmade freshwater resource in South-East Asia, is a significant freshwater body in Bangladesh (Halder et al., 1991). Created in 1961 by damming the river Karnaphuli near Kaptai in the Rangamati district, the lake serves multiple purposes, including hydroelectric power generation, navigation, flood control, and freshwater fish production. The lake, with a surface size of 68,800 hectares and a maximum depth of 32 meters, has an average depth of approximately 9 meters (Halder et al., 1991; Alamgir and Ahmed et al., 2008). The lake's shoreline and basin are highly irregular (Halder et al., 1991). Despite being primarily built for electricity generation, the lake also aids in navigation, flood control, and the production of a significant number of freshwater fish. The water from the lake is used for various purposes, including domestic chores, agriculture, boat maintenance, and fishing, which could potentially contaminate the lake ecosystem. Commercial fishing in the lake has increased from 1200 metric tons in 1965–

1966 to up to 8,648 MT today (DoF, 2018). The Bangladesh Fisheries Development Corporation has limited control over the water level changes in the lake as fishing is a secondary industry (Bashar et al., 2014). The Kaptai Lake fisheries have recently contributed, albeit mostly with undesirable species. The principal carp species that were most valued (Labeo rohita, Catla catla, Cirrhinus cirrhosus, Labeo calbasu, and Tor tor) have dramatically decreased from the initial 81 percent recorded in 1965/66 to roughly 5 percent at this time (Alamgir and Ahmed, 2008). The small forager fish, which has minimal value (e.g., Corica soborna, Gonialosa sp, Ompok pabda) have increased dramatically from the initial 3 percent in 1965/66 to roughly 92 percent at this time (Alamgir and Ahmed, 2008).

Halder et al. (1991) reported a total of 71 fish species in Kaptai Lake, including two varieties of prawn and five foreign fish species. In 1986, the Aquatic Research Group (ARG) counted 49 native fish species and 5 invasive fish species. Surface water quality is critical for long-term use as it impacts community health, inhibits aquaculture techniques, and causes aesthetic issues in the area. Each usage of water requires a unique level of water quality to ensure that the user is not harmed (Kabir et al., 2020). This freshwater resource is currently being negatively impacted by land use changes, urban human settlement, navigation on inland waterways, large development schemes in the context of roads, bridges, and other construction works (Rubel et al., 2019; Kabir and Naser, 2011). Generally speaking, water quality refers to the element of water that is essential for aquatic creatures for satisfactory growth (Ahatun et al., 2020). The primary productivity of a water body is the expression of its biological production. Directly or indirectly, phytoplankton is the basis of the primary output in all aquatic ecosystems. Primary production largely depends on the Physico-chemical properties of water like temperature, dissolved oxygen, alkalinity, hardness, pH, free CO2, nitrate, phosphate, soil organic matter, etc. Fishes are primarily dependent on water temperature, pH, dissolved oxygen, free CO2, alkalinity, and some other salts for growth and development (Ahmed et al., 1999). The Physico-chemical factors of water and soil affect plankton periodicity (Haque, 1978). In most water bodies, the factors that determine healthy growth include dissolved oxygen (DO), hardness, turbidity, alkalinity, nutrients, temperature, etc., and these factors become more concentrated as a result of human activity and an Environmentally unregulated

(Ehiagbonare and Ogunrinde, 2010). Since rivers, lakes, and artificial reservoirs are utilized to provide domestic, industrial, agricultural, and fish cultures, evaluating the quality of each region's water resources is a crucial component of developmental operations (Pal et al., 2015). Nutrients are the most important components for maintaining a productive and healthy aquatic ecosystem (Ahatun et al., 2020). Nutrients are essential for the survival, growth, and reproduction of all aquatic species, including fish. Some nutrients are correlated with the quantity of chlorophyll in the water, which is a measure of the amount of phytoplankton present (Shukla et al., 2013). As a result, nutrient availability is proportional to the water body's productivity (Rahaman et al., 2013). The water body is unproductive due to a lack of nutrients. Eutrophication is brought on by an excess of nutrients which speeds up the growth of algae and makes the water harmful. All aquatic ecosystems depend on algae because they give all living things in water bodies the initial nutrients and energy they need to survive. Algal blooms, an unnatural and excessive growth of algae, would be harmful (Ghorbani et al., 2014; Stauffer et al., 2019). As a result, nutrient concentrations should be kept below allowable limits in order to maintain a healthy aquatic environment and increase the production of marine species such as fish and marine aquatic organisms (Senthilkumar et al., 2008). The availability of nutrients depends on the water quality and organic matter of sediment. So regular study is needed on the lake's limnological parameters and sediment profile for sustainable management. To observe this, Numerous scholars also investigated the limnological characteristics of this lake. For example, Sandercock (1966) documented this lake's Physical and chemical parameters and phytoplankton. Chowdhury (1980), Chowdhury and Mazumder (1981), Chowdhury and Khair (1982) and ARG (1986), described the hydrobiology. Nonetheless, Jenkins (1985) proposed a prolonged study effort to ensure the lake ecosystem's maintenance. The reservoir's morphometric details were then documented by Rahman et al. (2014), and Characterization of the Kaptai Lake's limnology and primary production by Halder et al. (1991) and Bashar et al. (2015). However, these studies were only undertaken for a brief time.

Any aquatic habitat must include soil because it provides water for aquatic life and enriches the water body with a variety of nutrients needed for biological production (Saha, 2003). Minerals, water, air, organic matter (OM), and living substances make up sediments, which are variables in space and time (Adesuyi et al., 2015). Clay, silt, sand, and gravel are examples of minerals found in sediment, whereas organic matter (OM) might include shells and decomposing organic waste (Gupte and Shaikh, 2014). The wastes play a role in nutrient turnover (Kiani et al., 2021; Cardoso et al., 2019) by organic matter degradation (Hopkinson et al., 1999) which eventually improves biological processes (Kumar, 1996; Gupta et al., 2001) and supports plant growth in the natural medium. Due to its active function as a raw buffer through carbon cycling, sediment may potentially have an impact on environmental quality (Cardoso et al., 2019) and filtering method for water's physical cycle (Singare et al., 2011) and exchange of micronutrients between a deposit and nearby aquatic bodies (Abowei, 2010). If the water quality parameter and the nutrients are in nice condition then the lake's primary production and ultimate production will be good. So, without regular observation, it’s impossible to manage and increase the primary productivity of the Kaptai Lake. A good environment is a must for great primary production. Therefore, this research aims to provide data on variations of physicochemical parameters and organic matter of the Kaptai Lake over six months to provide baseline information to assist management decisions of the Lake Ecosystem.

1.1 Significance of the research:

This study aims to elucidate the physical, chemical, and biological attributes of Kaptai Lake, thereby providing a comprehensive understanding of its limnological aspects. These parameters are crucial for maintaining a robust ecosystem and productivity within the lake. Both phytoplankton and zooplankton are integral to a balanced aquatic ecosystem, providing food and oxygen to fish and other aquatic species. Kaptai Lake, the largest man-made lake ecosystem in South-East Asia, plays a pivotal role in fish production and supports the livelihoods of numerous individuals in the Rangamati District. Ensuring high primary productivity and a thriving ecosystem is essential for sustaining the lake's fish production. This study will assess the monthly variations of physicochemical parameters across different locations within the lake. The findings from this research will provide valuable insights into the overall circumstance of the lake's ecosystem, thereby informing policy decisions aimed at enhancing fish production in Kaptai Lake.

1.2 Objectives:

1. To observe the spatio-temporal variation of water quality parameters of Kaptai Lake

2. To assess the variation of organic carbon and organic matter of Kaptai Lake

Chapter: 02

Review of Literature

2. Review of Literature

Before undertaking any research, it is crucial to gather information from previously conducted studies related to the subject. Here, we present a review of relevant research on the spatio-temporal variation of water quality parameters, sediment organic carbon, and organic matter in Kaptai Lake. Numerous investigations have focused on the lake's ecological health, human impacts, and the significance of monitoring and managing water quality.

2.1 History of Kaptai Lake:

Fernando (1980) characterized the Kaptai reservoir in Bangladesh as a significant man-made freshwater body in Southeast Asia. This reservoir is nestled in the Kaptai Upazila, within the Rangamati District of the Chattogram Division. The creation of this lake in 1961 was a result of the Karnaphuli River's damming in Kaptai, a strategic move for the Karnaphuli Hydro-electric Project. This project aimed to harness hydropower for electricity generation.

The dam, a key feature of the reservoir, extends over 670.8 meters and stands 54.7 meters tall. It incorporates a 745-foot (227-meter) long spillway with 16 gates, allowing a water flow of 5,250,000 cu ft/s (149,000 m3/s). The reservoir spans approximately 58,300 ha (expanding to 68,800 ha when fully supplied), making up 46.8% of the total pond area in Bangladesh. This makes it a crucial part of the country's inland water resources.

However, the dam's construction led to the submersion of 40% of the region's cultivable land. Government-owned forests, along with an additional 234 square miles (610 km2) of forest area, were also inundated. The project necessitated the relocation of around 18,000 families, amounting to nearly 100,000 individuals. Notably, the palace of the Chakmas king was also submerged and remains underwater to this day.

2.2 Key theories and trends in Kaptai Lake:

Researchers have explored various key theories and trends concerning the spatio-temporal variation of water quality parameters and the presence of organic carbon and organic matter in Kaptai Lake. Some of the key theories and trends include:

1. Anthropogenic Impact on Water Quality: Researchers have investigated the influence of anthropogenic activities, such as agricultural runoff, industrial discharges, and urbanization, on the spatio-temporal variation of water quality parameters in Kaptai Lake. These activities can introduce pollutants and nutrients into the lake, affecting its water quality and the presence of organic carbon and organic matter (Haque et al., 2018).

2. Seasonal Variation of Water Quality: Studies have shown that the water quality parameters in Kaptai Lake exhibit significant seasonal variations. Seasonal changes, such as monsoon and post-monsoon periods, can influence factors like temperature, dissolved oxygen, and nutrient concentrations, impacting the distribution of organic carbon and organic matter in the lake (Haque et al., 2018; Islam, 2021).

3. Impact on Fish and Aquatic Ecosystems: Researchers have explored the relationship between water quality parameters, organic carbon, organic matter, and their effects on fish and other aquatic organisms in Kaptai Lake. Changes in water quality and the availability of organic matter can influence the diversity and abundance of fish species and overall aquatic ecosystem health (Ahmed et al., 2006; Hoque et al., 2021).

4. Sediment-Water Interactions: Studies have investigated the interactions between sediments and water in Kaptai Lake. Sediments can act as sources or sinks of nutrients and organic matter, affecting water quality and nutrient cycling in the lake ecosystem (Adesuyi et al., 2015; Hoque et al., 2021).

5. Impact on Local Communities: Researchers have also explored the socioeconomic implications of changes in water quality and the presence of organic carbon and organic matter in Kaptai Lake. The lake's water quality and fishery resources are

vital to the livelihoods of the local communities surrounding the lake (Ahmed et al., 2001; Hoque et al., 2021).

2.3 Fisheries of the Kaptai Lake:

The fisheries of Kaptai Lake in Bangladesh have been the subject of various studies. Ahmed et al. (2006) examined the challenges hindering the development of the lake's fishing resources. They found that the catch composition has significantly changed since the lake's formation. The production of high-value fish has been declining, and the lake's potential for providing such fish has been underutilized due to administrative, social, and environmental issues. These include degradation of natural breeding grounds, environmental damage, ineffective regulation enforcement, outdated fish farming technology, and poor management practices.

A study by Ahmed et al. (1999) found that the average harvest from Kaptai Lake was 242 kg/brush, with major carps, catfish, clupeid, feather back, and tilapia making up significant portions of the catch. They also noted that 23% of the major carps harvested from brush shelters were less than 23 cm in length. Uddin et al. (2014) reported that Siluriformes (catfish) were the most abundant order, followed by Cypriniformes, Perciformes, Osteoglossiformes, Synbranchiformes, small prawns, and others.

Suman et al. (2021) observed an increase in fish production in Kaptai Lake from 1,200 metric tons (MT) in 1965-1966 to 10,577 MT in 2018-2019. Small fish, particularly Gudusia chapra, Gonialosa manmina, and Corica soborna, dominated the lake's productivity in 2018-2019, accounting for 64% of total production. They also noted that the highest fish yield in the past 11 years was 10,577 MT in 2018-2019, and the lowest was 5,578 MT in 2008-2009.

Ahmed et al. (2001) estimated the current annual fishery contribution from Kaptai Lake to be around 6,000 MT, with significant yearly fluctuations. The lake's performance is hindered by various environmental, social, and management issues. Despite its socioeconomic importance, previous research on Kaptai Lake has primarily focused on the biological and limnological aspects of fishing.

The Department of Fisheries (DoF, 2018) reported that the lake's current fish production is 10,152 MT, accounting for 0.24% of the country's total fish production of 4.277 million MT. Suman et al. (2021) noted a significant increase in total fish production from the lake over five decades, with production capacity reaching 181.42 kg/ha in 2018-2019. However, they also highlighted the concerning decline of Indian major carps (IMC) and other native carps. In 2018-2019, Corica soborna, Gonialosa manmina, and Gudusia chapra together contributed 63.76% of the total fish yield from the lake, while different carp species contributed only 1.56%.

2.4 Hydrology & primary productivity:

Bashar et al. (2015) reported that the average water temperature in Kaptai Lake fluctuated between 21.04 and 31.52°C, with a mean value of 28.17±1.13°C. Haldar et al. (1992) found a correlation between air and water temperatures in the lake.

Chowdhury and Maztunder (1981) found that the highest oxygen levels were recorded during the winter season, with no significant changes (1.0-2.4 mg/1) from the surface to the bottom of the water column. Rani et al. (2004) observed lower dissolved oxygen levels in Kaptai Lake during the summer due to increased organic matter decomposition and reduced water flow resulting from high temperatures. Ahmed et al. (1999) found that the dissolved oxygen levels ranged between 6.4-9.1 mg/l, with a mean value of 7.15±0.39 mg/l.

Carbon dioxide (CO2), the most prevalent greenhouse gas on earth, plays a crucial role in global change studies due to its ability to move across the air-water or sediment-water interface. It is often used as a measure of the overall ecosystem productivity or metabolism of the aquatic system. Ahmed et al. (1999) reported that free carbon dioxide levels in Kaptai Lake ranged between 4.7 ± 0.3 and 6.0 ± 0.3 mg/1, never exceeding 6.2 mg/1 and remaining relatively uniform throughout the year.

Hopkinson et al. (1985) noted that carbon dioxide, the end product of organic carbon decomposition in almost all water bodies, is often used as a measure of the ecosystem's net metabolic rate.

According to Barua et al. (2016), the pH of Kaptai Lake's water ranged between 7.46 and 7.75, which is within the optimal range of 6.5 to 9 for freshwater (EPA, 2017). Islam et al.

(2021) found that the pH of the lake's water varied from 6.82 to 7.96, with the highest pH recorded during the pre-monsoon season and the lowest during the post-monsoon season.

The average total dissolved solids (TDS) in Kaptai Lake varied by season, ranging from 44.5 to 80.5 mg/l, with the highest TDS recorded post-monsoon and the lowest during the monsoon season (Islam et al., 2021). Compared to Bogakain Lake, a natural high-altitude lake in Bangladesh with TDS concentrations of 39 to 42 mg/l, Kaptai Lake had higher TDS concentrations of 52 to 54 mg/l (Barua et al., 2016; Khondker et al., 2010). Kambole et al. (2003) suggested that high TDS levels were due to the presence of various minerals and salts.

2.5 Organic Matter of Sediment:

Nutrients, both organic and inorganic, undergo continuous transportation to lake bottoms through sedimentation, as described by Forsberg (1989). The interplay of various biological, physical, chemical, and mechanical processes leads to the return of specific nutrient levels to the free water. Depending on the lake's type and bottom conditions, multiple cycles between the sediments and water may occur. The size of nutrient pools and turnover rates are significantly influenced by factors such as lake topography, temperature regimes, trophic level, and sediment type.

Avramidis et al. (2013) emphasize that sediments in lakes, originating from nearby catchment areas and headwaters, carry traces of various weather conditions and processes. These processes involve weathering, erosion, wind action, water, ice, and the impact of gravity or stream processes on the particles, indicating changes in the surrounding environment (Velez et al., 2011). Additionally, Adesuyi et al. (2015) document that sediments consist of minerals, water, organic matter (OM), and living components, and their composition varies spatiotemporally. Gupte and Shaikh (2014) identify minerals like clay, silt, sand, and gravel, while decaying organic matter and shells represent components of OM in sediment. Kiani et al. (2021) note that sediment plays a crucial role in nutrient cycling through OM degradation, enhancing biological activity and facilitating plant growth within natural environments. The active function of the carbon cycle in filtering water and exchanging micronutrients between deposits and above-ground water bodies suggests that sediment can impact environmental quality, as highlighted by Cardoso et al. (2019) and Abowei et al. (2010).

Furthermore, Kumary (2007) proposes that sediment and the water overlaying it significantly determine the environmental health status and overall ecosystem characteristics of environments like streams and reservoirs. The nature of sediment and its organic matter composition also exert influence over the structure of benthic communities in water, as observed by Adesuyi et al. (2016) in their study.

Hoque et al. (2021) conducted a study on the physical and chemical properties of Kaptai Lake, focusing on organic matter percentage, which ranged from 4.25% to 8.18%. These findings indicate a healthy ecosystem for aquatic organisms within the water body. However, the effect of land use and other watershed factors on sediment may vary over time and space, contingent upon regional dynamics. To assess the impact of land use in the higher catchment areas surrounding the lake, further investigation into the sediment features is warranted.

2.6 Contrasting viewpoints or findings from different studies related to Kaptai Lake:

1. Contrasting Viewpoints on Water Quality Parameters:

Viewpoint 1: Haque et al. (2018) found that the water quality parameters in Kaptai Lake exhibited significant seasonal variations. They reported higher water temperatures during the monsoon season and lower temperatures during the post-monsoon period. Dissolved oxygen levels were higher in the winter seasons but decreased during the summer due to increased organic matter decomposition and reduced water flow.

Viewpoint 2: Islam et al. (2021) presented different findings, reporting that water pH levels in Kaptai Lake were often alkaline in nature, ranging from 6.9 in July to 7.6 in May. They observed variations in dissolved oxygen levels, ranging from 5.72 mg/L to 8.58 mg/L. They also noted a positive correlation between alkalinity and hardness in the lake's water.

2. Contrasting Findings on Sediment Organic Carbon:

Finding 1: Hoque et al. (2021) conducted a study on sediment organic matter in Kaptai Lake and reported organic matter percentages ranging from 4.25% to 8.18%. They suggested that these levels indicate a healthy ecosystem for aquatic organisms.

Finding 2: Adesuyi et al. (2015) explored the nutrient content of sediment in Agbabu Bitumen Deposit in Nigeria and observed variations in organic carbon concentrations. Their findings indicated the presence of different organic matter constituents, but the actual percentages differed significantly from those reported by Hoque et al. (2021).

3. Contrasting Perspectives on Organic Matter and Fishery:

Perspective 1: Ahmed et al. (2006) highlighted administrative, social, and environmental issues that limit the utilization of Kaptai Lake's potential to offer high-value freshwater fish. They suggested that the degradation of the natural breeding ground, poor regulation implementation, and ineffective fish farming technology are among the factors contributing to the reduced productivity of high-value fish species.

Perspective 2: Suman et al. (2021), on the other hand, reported an increase in fish output from Kaptai Lake over the years. They noted that small fish species, such as Gudusia chapra, Gonialosa manmina, and Corica soborna, dominated the lake's productivity, comprising 64% of the overall production. This contrasting perspective suggests that certain fish species are thriving in the lake despite challenges faced by high-value fish.

2.7 Research gaps in Kaptai Lake:

1. Limited Studies on Microbial Diversity: While some studies have focused on water quality parameters and sediment characteristics, there is a lack of comprehensive research on the microbial diversity and its role in nutrient cycling and organic matter decomposition in Kaptai Lake (Roy & Saha, 2021; Hossain et al., 2020). This thesis could explore the microbial communities in the lake and their relationship with water quality parameters.

2. Integrated Water Quality and Sediment Analysis: Most studies have separately investigated water quality parameters and sediment organic matter content. A

research gap exists in the integration of these two components to understand how sediment characteristics influence water quality and vice versa (Islam & Akter, 2021; Halder et al., 2020). This thesis could bridge this gap by conducting an integrated analysis of water and sediment characteristics.

3. Impact of Land Use Changes on Water Quality: While Hoque et al. (2021) touched on the impact of land use changes on sediment organic carbon, there is a need for further investigation into how changes in land use practices around Kaptai Lake affect water quality parameters and organic matter content. This thesis could explore the relationships between land use changes and water quality dynamics.

4. Long-term Trends and Patterns: Some studies have examined seasonal variations in water quality parameters, but there is a research gap regarding long-term trends and patterns of water quality changes over several years (Uddin et al., 2021; Huq et al., 2019). This thesis could conduct a time-series analysis to identify long-term trends and potential impacts of climate change on water quality in Kaptai Lake.

5. Socioeconomic Implications of Water Quality Changes: The studies by Ahmed et al. (2006) and Ahmed & Uddin (2020) highlight the importance of the fishery resources in Kaptai Lake for local communities. However, there is a research gap in fully understanding the socioeconomic implications of water quality changes on livelihoods and well-being of the surrounding communities. This thesis could explore the social and economic aspects related to water quality changes and their effects on local communities.

Chapter: 03
Materials and Methods

3.1 Study Area: Kaptai Lake

The research was conducted in the centered and around Kaptai Lake (Fig 01), an artificial reservoir located in Bangladesh. Kaptai Lake was created in 1961 through the construction of a dam on the Karnaphuli River, primarily for hydroelectric power generation purposes. The lake encompasses a vast area with two major tributaries and is divided into two distinct arms, separated by hilly regions.

Covering approximately 68,800 hectares, Kaptai Lake is a euphotic lake, meaning it allows sufficient light penetration to support photosynthesis. Its average depth is recorded at 9.0 meters, with an annual water level fluctuation of about 8.1 meters (Mahmood, 1986).

The major reservoir area, which includes the vicinity of Rangamati Pourashava and the Rangamati region, exhibits the highest population density within the catchment. In contrast, the Karnaphuli River region has the lowest population density, measuring around 55.13 people per square kilometer. Despite some scattered concentrated communities, this area boasts the highest vegetation cover among all regions in the catchment.

Fig 01: The Kaptai Lake

3.2 Sampling Stations in Kaptai Lake

For the purpose of sampling, this study focused on four specific stations within Kaptai Lake, as depicted in Figure 2. Each station was identified by its local name and geographical coordinates:

1. Jolojan Ghaat: Latitude 22°39′30″, Longitude 92°10′43″
2. Kandemu: Latitude 22°39′15″, Longitude 92°11′52″
3. Shubholong Jhorna: Latitude 22°42′29″, Longitude 92°14′33″
4. Shubholong Bazar: Latitude 22°42′40″, Longitude 92°15′75″ (Fig 02)

Shuvolong marks both the starting point of the reservoir and the confluence of the Kasalong tributary with the Karnaphuli River. The sampling activities were conducted over a period extending from March 2022 to August 2022.

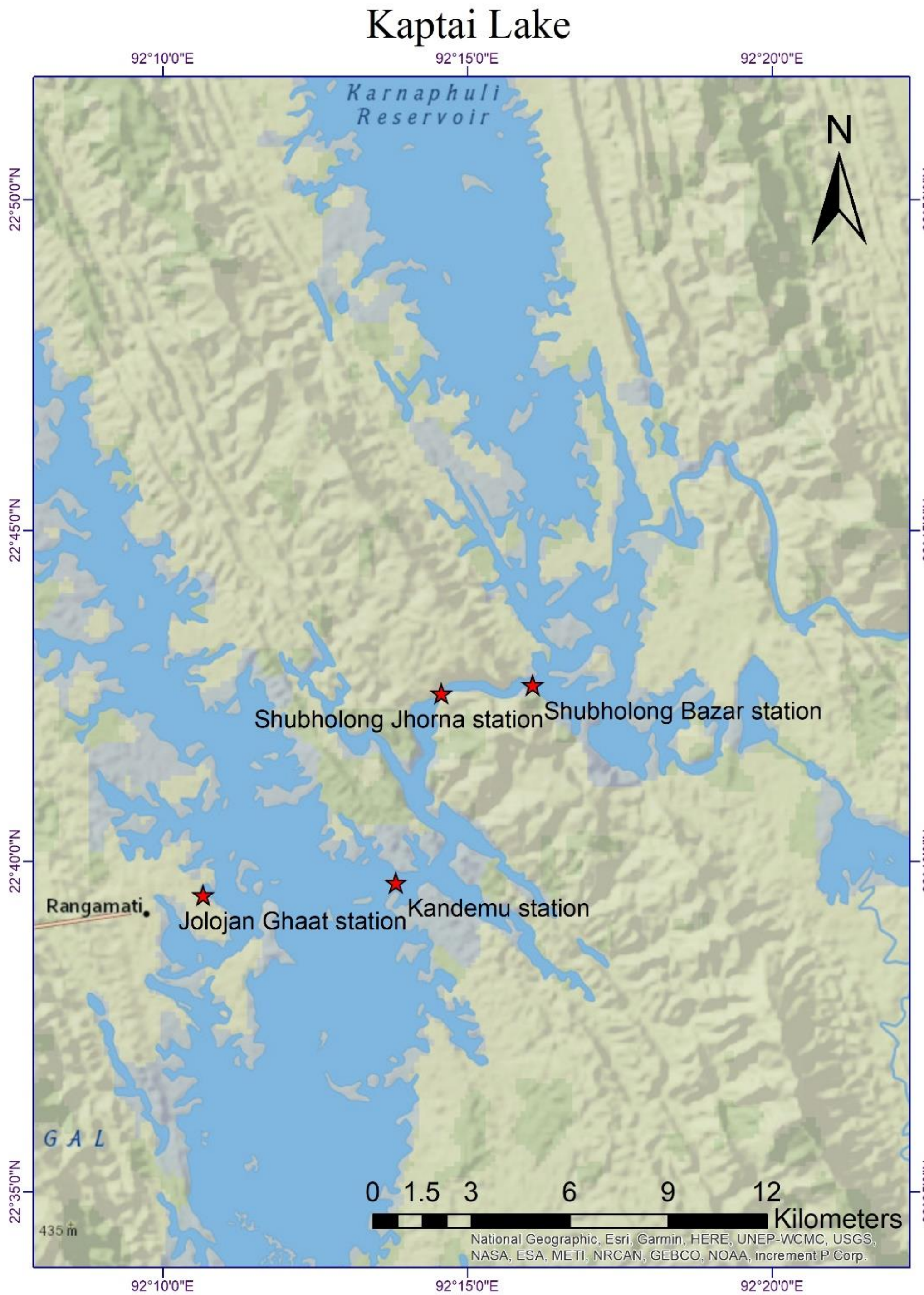

Fig 02: Map of the sampling stations

3.3 Sampling Procedure

3.3.1 Preparation for sampling

In the sampling process, careful preparation was essential to ensure accurate data collection. To facilitate this, various types of equipment were employed during the sampling campaign. These included a pH meter (HI211), a TDS meter (Sens IONEC71), a DO meter (edg DO), a measuring tape, a Secchi disc, a rope and sampling bottles. Chattogram Veterinary & Animal Sciences University (CVASU) provided the necessary support by deploying their Research Vessel (Fig 03), which transported the equipment to the sampling sites. This arrangement allowed for efficient sample collection and facilitated subsequent activities.

Fig 03: CVASU Research Vessel

3.3.2 Sample Collection

Throughout the research period spanning from March 2022 to August 2022, surface water samples were gathered monthly from four designated sampling stations within the aquatic ecosystems of Kaptai Lake. The primary objective was to assess various physical and chemical parameters to gauge water quality, including total alkalinity, total hardness, dissolved oxygen (DO), temperature, transparency, total dissolved solids (TDS), and pH.

For surface water collection, a bucket proved sufficient, while the Kemerrer Water Sampler (1200-B15) was employed to extract samples from the middle and bottom layers of the water column. These samples were carefully stored separately, ensuring their integrity for future analysis.

Additionally, sediment samples were obtained (Fig 04) using the Ekman Grab Sampler (196-B15) and placed in black polythene containers for preservation. Subsequently, all water and sediment samples were transported to the Aquatic Ecology Laboratory, Faculty of Fisheries, Chattogram Veterinary & Animal Sciences University (CVASU), to undergo further analysis.

Fig 04: Water and Sediment sampling

3.4 Determination of water quality parameters:

i) Water Temperature and Air Temperature

Water temperature is a critical environmental parameter that plays a crucial role in shaping aquatic ecosystems, and it is essential to measure it to assess the waterbody's productivity. The suitability of an aquatic environment greatly depends on the temperature of the water, making it a key determining factor (Kabir et al., 2020). To measure water temperature, a thermometer was used. Similarly, air temperature was also recorded as part of the environmental monitoring process.

ii) Water Depth

Water depth holds significant importance for the well-being of aquatic organisms. Data on water depth at the sampling site was collected from the control room of the research vessel. This information is crucial for understanding the habitat and ecological conditions within the waterbody.

iii) Transparency

Water transparency, or the clarity of the water, is an important aspect of aquatic ecosystems. Changes in water transparency can significantly impact the characteristics of the ecosystem, affecting the availability of critical habitats and resources, and consequently influencing phenotypic diversity. To measure transparency, a 20 cm diameter Secchi disk with graduated ropes was employed (Fig 05).

Fig 05: Determination of transparency

iv) Total Dissolved Solids (TDS)

Elevated concentrations of Total Dissolved Solids (TDS) can have significant implications for aquatic organisms in water systems, such as rivers. TDS alters the mineral composition of the water, which is vital for the survival of many creatures. Additionally, high TDS levels can lead to fatal dehydration of aquatic animals' skin due to the presence of dissolved salts. To assess TDS, a TDS meter was utilized (Fig 06).

v) pH

The pH level is a critical water parameter that indicates the alkalinity or acidity of a waterbody. It has a profound impact on the overall water quality and the health of aquatic life. To measure pH, a Hannah pen pH meter was employed (Fig 06), providing essential information about the water's chemical balance.

vi) Dissolved Oxygen (DO)

Dissolved oxygen (DO) is the most crucial element in the aquatic environment, as the survival of aquatic life directly depends on its availability. Measuring the dissolved oxygen levels is vital for understanding the water's ability to support various organisms. To assess dissolved oxygen levels, a DO meter was used (Fig 06).

Fig 06: Determination of different water quality parameters on spot

vii) Alkalinity Measurement

The determination of alkalinity in the water using the titrimetric method followed a systematic procedure as outlined below:

1. Sample Collection: A water sample was collected from the surface of the water body.

2. Preparation of Beaker: 50 ml of the water sample was carefully transferred into a beaker.

3. Phenolphthalein Indicator: To the sample in the beaker, 2-4 drops of Phenolphthalein indicator were added. The absence of a color change upon adding the indicator indicated the absence of alkalinity in the water.

4. Methyl Orange Indicator: To continue the alkalinity measurement, another 50 ml of the water sample was taken in a separate beaker. To this sample, 2-4 drops of Methyl Orange indicator were added, resulting in a yellow color.

5. Titration: A burette was filled with Sulphuric acid (0.02N), and the contents of the beaker containing the Methyl Orange-treated sample were titrated against the Sulphuric acid until the color changed to pink. The titration process was continued until the color changed to red.

6. Alkalinity Calculation: Finally, the alkalinity was calculated using the following formula:

$$\boldsymbol{Alkalinity\ (mg/L)\ as\ CaCO_3 = \frac{mL\ of\ titrant \times N\ of\ acid\ used \times 50 \times 1000}{mL\ of\ sample}}$$

This formula allowed for the determination of alkalinity in terms of milligrams per liter (mg/L) of calcium carbonate ($CaCO_3$) present in the water sample.

viii) Carbon Dioxide (CO_2) Measurement

The measurement of carbon dioxide (CO_2) in the water was carried out through the following procedure as part of the materials and methods in this thesis:

1. Sample Collection: Water samples were collected from the surface of the water body.

2. Preparation of Conical Flask: A 50 ml water sample was taken and transferred into a conical flask. Then, 2-4 drops of phenolphthalein indicator were added to the sample.

3. Color Change: NaOH (Sodium Hydroxide) was added to the conical flask until the color of the solution turned pink. This step helped determine the amount of free CO_2 present in the water.

4. Calculation: A specific table and calculating equation were employed to determine the amount of free CO_2 based on the titration results using NaOH.

5. CO_2 Calculation: The following formula was then used to calculate the concentration of Carbon Dioxide (CO_2) in the water sample:

$$\boldsymbol{CO_2 = \frac{ml\ of\ NaOH\ used \times (N) of\ NaOH \times Molecular\ wt. of\ NaOH \times 1000}{Volume\ of\ the\ sample}}$$

This formula allowed for the calculation of the concentration of CO_2 in the water in units of milligrams per liter (mg/L).

ix) Hardness Measurement

The hardness of the water was measured using the following method as part of the materials and methods in this thesis:

1. Sample Collection: A water sample was collected from the surface of the water body.

2. Preparation of Conical Flask: 50 ml of the water sample was transferred into a conical flask, and 5 ml of the buffer solution was added to the flask.

3. Indicator Addition: A pinch of eriochrome Black indicator was introduced into the conical flask.

4. Titration: The water sample with the indicator was then titrated against a standard solution of EDTA (Ethylene Diamine Tetraacetic Acid) until the wine color of the solution turned from red, indicating the endpoint of the titration.

5. Recording EDTA Volume: The volume of standard EDTA required for titration was recorded.

6. Total Hardness Calculation: Finally, the total hardness of the water sample was calculated using the following formula:

$$\boldsymbol{Total\ Hardness} = \frac{\boldsymbol{T \times 100}}{\boldsymbol{V}}$$

Where,

T = Volume of EDTA (standard solution) used in titration

V = Volume of the water sample used in the titration.

This formula allowed for the determination of the total hardness of the water in suitable units.

x) Ammonia Determination

Ammonia concentration in the water was determined using the direct Nesslerization method as part of the materials and methods in this thesis:

1. Sample Collection: A water sample was collected from the surface of the water body.

2. Neutralization and Precipitation: To prepare the sample for storage, a small amount of NaOH was added to 100 ml of the filtered sample to neutralize any acid present. Next, 10% $ZnSO_4$ and 1 ml of 10% NaOH were added. The sample was stirred and filtered to precipitate calcium (Ca), magnesium (Mg), and sulfide (S) compounds.

3. Filtrate Collection: The filtrate was collected, and 1 drop of 50% EDTA was added and mixed well.

4. Nesslerization: Subsequently, 2 ml of Nessler reagent was added and mixed thoroughly. A series of dilutions were prepared using 0.0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, and 1 ml of a standard NH_4Cl solution in separate Nessler's tubes. Each tube was then diluted with distilled water up to 50 ml.

5. Color Measurement: Next, 2 ml of Nessler's reagent was added to each individual tube. After 10 minutes, the intensity of the resulting yellow color was measured using a spectrophotometer at a wavelength of 420 nm.

This method allowed for the determination of ammonia concentration in the water sample.

3.5 Determination of Organic Carbon and Organic Matter

The estimation of organic matter in the sediment of Kaptai Lake was conducted using the rapid method devised by Walkley and Black. Initially, the sediment samples were air-dried for a few days after being sun-dried for two days. Once dried, the samples were individually ground using a hand grinder and sieved through a 2mm mesh. The resulting samples were filtered and stored in plastic containers for further laboratory analysis.

For the determination of organic carbon (Fig 07), 2g of the dried soil sample was placed in a 500 ml conical flask. Subsequently, 10 ml of 1N $K_2Cr_2O_7$, 20 ml of concentrated H_2SO_4, and a pinch of silver nitrate or silver sulfate were added to the flask. The mixture was slightly heated, shaken, and allowed to sit for 30 minutes until it turned green. A known amount of $K_2Cr_2O_7$ solution was then added in excess to change the color to yellow. The sample was diluted with water to a final volume of 200 ml, followed by the addition of 5 ml of orthophosphoric acid or phosphoric acid. The sample was then titrated with a standard $FeSO_4$ solution using 1 ml of diphenylamine indicator, with the endpoint transition being from blue to brilliant green. A blank (without soil) was also run following the same procedure.

Fig 07: Determination of Organic matter

The calculation of Organic Carbon (OC) was performed using the following formula:

$$\% \, \boldsymbol{Organic\ Carbon\ (OC)} = \frac{\boldsymbol{(B - U) \times D \times N \times A \times 100}}{\boldsymbol{(B \times W)}}$$

Where,

B = Volume of $FeSO_4$ required for blank

U = Volume of $FeSO_4$ required for sample

D = Volume of $K_2Cr_2O_7$ used

N = Normality of $K_2Cr_2O_7$ (1N)

A = Milliequivalent of carbon (0.003)

W = Weight of the sample used

The calculation of Organic Matter (OM) was then derived using the Organic Carbon (OC) result:

$$\% \, \boldsymbol{Organic\ Matter\ (OM) = OC \times 1.724}$$

This method allowed for the determination of organic carbon and organic matter content in the sediment samples from Kaptai Lake.

3.6 Statistical Analysis

Following data collection and appropriate formatting, the collected data underwent thorough statistical analysis. Microsoft Excel, SAS, and R programming were utilized for data presentation and analysis. To explore the specific relationships between the factors under investigation, Pearson's correlation matrix was employed.

Chapter: 04

Result

4. Temporal Variation of Water Quality Parameters and Sediments Organic Matter of the Kaptai Lake

This table presents data on the temporal variation of water quality parameters and sediment organic matter at four distinct monitoring stations within Kaptai Lake. The study covers the following stations:

1. Jolojan Ghaat Station
2. Kandemu Station
3. Shubholong Bazar Station
4. Shubholong Jhorna Station

The table includes standard deviation values, which provide insight into the variability of the observed parameters at each station. This data is essential for understanding the fluctuations in water quality and sediment organic matter levels over time, helping to assess the overall health and ecological condition of Kaptai Lake.

Table 01: Temporal Variation of Water Quality Parameters and Sediment Organic Matter in Kaptai Lake at Four Monitoring Stations

Parameters	Jolojan Ghaat station	Kandemu station	Shubholong Bazar station	Shubholong Jhorna station
Depth	18.417±6.003	54.167±6.145	22.333±15.344	28.333±12.532
Air Temp (°C)	26±1.264	28.167±1.602	31.667±1.211	28.833±1.940
Secchi Disk (Inch)	61.667±16.231	40.833±20.351	27.833±17.162	41.5±23.166
DO (mg/l)	6.379±0.864	6.523±1.429	6.93±0.983	6.303±0.932
PH	7.528±0.316	7.405±0.269	7.494±0.212	7.538±0.325
TDS (mg/l)	57.056±14.633	55.944±10.652	64.277±22.42	52.611±10.047

TEMP (°C)	30.100±2.593	29.239±2.756	30.75±2.591	30.601±2.562
Parameters	**Jolojan Ghaat station**	**Kandemu station**	**Shubholong Bazar station**	**Shubholong Jhorna station**
Alkalinity (mg/l)	52.333±11.553	51.167±12.172	59.167±15.105	52.833±12.875
CO_2(mg/l)	4.553±1.645	3.985±0.536	7.603±0.939	3.898±0.637
Ammonia (mg/l)	0.750±0.274	0.75±0.273	0.791±0.332	0.833±0.408
Hardness (mg/l)	61.167±19.271	64.5±15.254	73.5±14.067	69.5±14.936
Organic Carbon	1.018±0.311	2.023±0.938	1.536±0.65	1.36±0.276
Organic Matter (%)	1.756±0.537	3.488±1.618	2.649±1.061	2.344±0.476

4.1.1 Air and Water Temperature

Water temperatures exhibited a noticeable increase from March (26.87±2.11) °C to August (30.58±0.93) °C across all stations (Fig 08). July was identified as the month with the highest water temperatures (32±0.68) °C at all stations, representing the peak of water temperature during the study period. Additionally, air temperatures ranged between 28 to 31 °C. This seasonal variation could have been influenced by factors such as solar radiation, weather patterns, and the overall hydrology of the area.

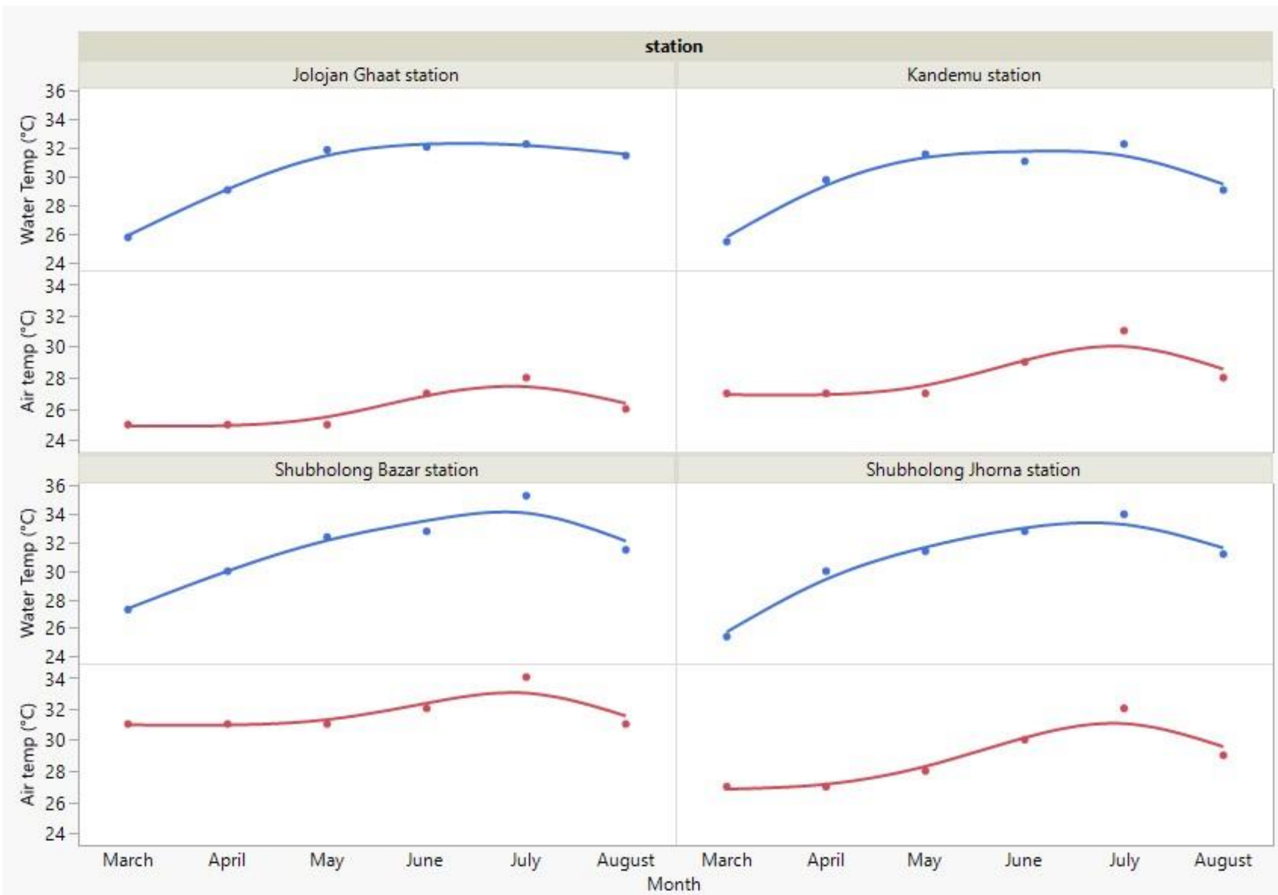

Fig 08: Monthly fluctuations of air and water temperature among stations

4.1.2 DO (Dissolved Oxygen), PH (pH level), TDS (Total Dissolved Solids), and water temperature

Dissolved Oxygen (DO): The average DO levels were relatively consistent across all stations, ranging from approximately 5.14 to 8.8 mg/L. This suggested that the water quality in these areas was generally acceptable in terms of oxygen availability for aquatic life.

pH: The pH values showed a narrow range, varying from approximately 7.0 to 8.3. These values indicated a slightly alkaline to neutral environment, which was considered suitable for most aquatic organisms.

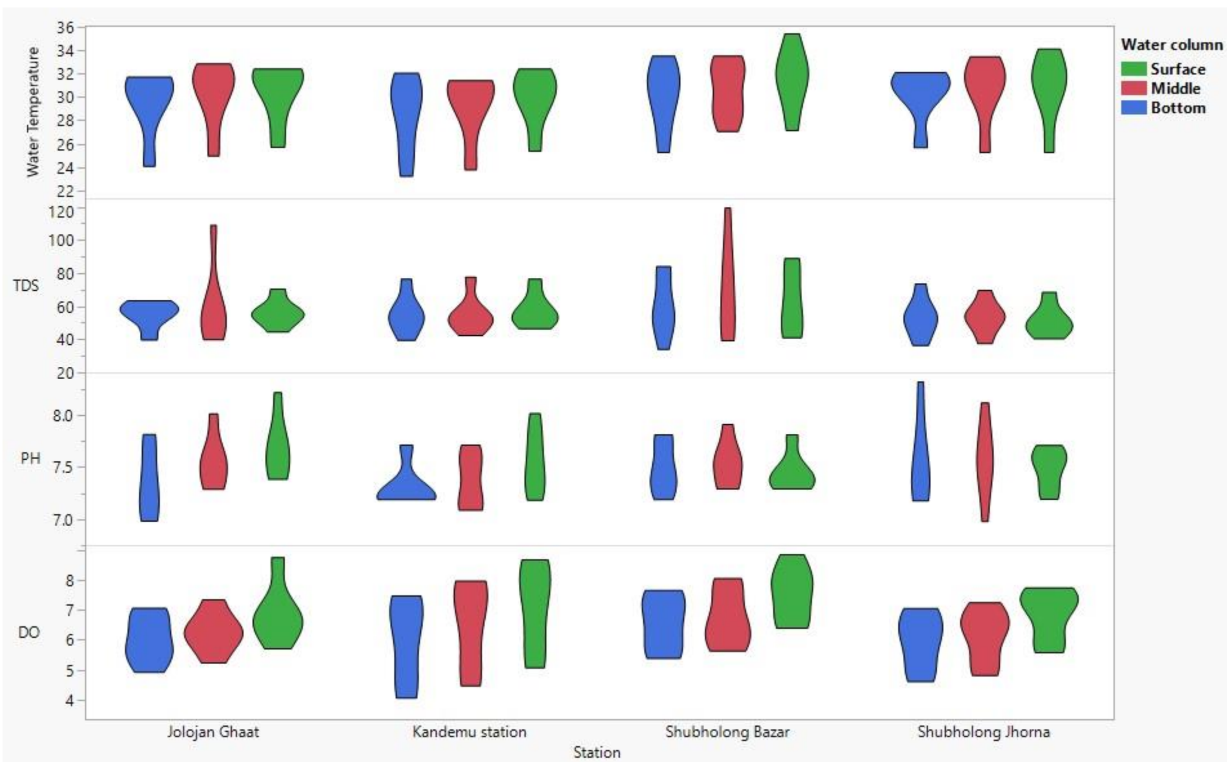

Fig 09: Fluctuations of DO, PH, TDS and Water temperature among stations at different Water column

Total Dissolved Solids (TDS): TDS levels differed among the stations, with values ranging from around 37 mg/L to 118 mg/L. Higher TDS values may have indicated a higher concentration of dissolved minerals or pollutants in the water.

Water Temperature: Water temperature remained relatively constant across the stations, with values ranging from approximately 23.4°C to 35.3°C. These temperatures fell within the range that is typical for most freshwater ecosystems.

4.1.3 Ammonia

The mean ammonia levels ranged from 0.63 mg/l in May to 1.19 mg/l in March. The values exhibited a decreasing trend from March to July (1.19 mg/l to 0.63 mg/l) and a slight increase in August (0.88 mg/l). The standard deviation remained relatively consistent, ranging from 0.25 to 0.29 mg/l, indicating consistent dispersion of data points around the mean. The minimum and maximum values remained constant at 0.50 mg/l and 1.00 mg/l, respectively, throughout the months.

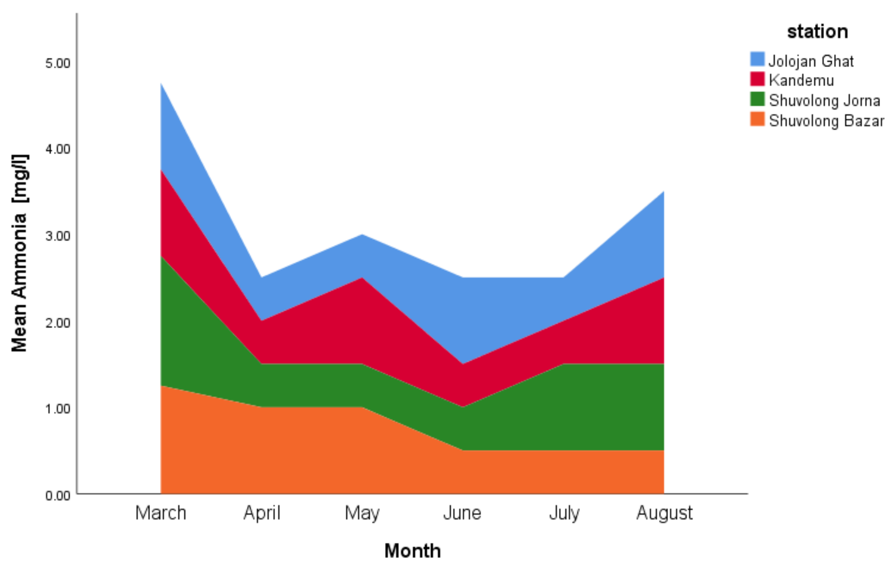

Fig 10: Monthly variation of ammonia (mg/l) of Kaptai Lake water

4.1.4 Transparency, Hardness, Alkalinity, and CO_2

Secchi disk (Transparency): The mean transparency values varied throughout the monitoring period. In March, the water exhibited the highest mean transparency of 68±6 inches, suggesting consistent clarity. However, the transparency significantly decreased in April to a mean value of 53±18 inches, indicating increased variability in water clarity.

As the months progressed, the trend of decreasing transparency continued. In May, the mean transparency dropped to 42±10 inches, suggesting a moderate decline in water clarity. June experienced a notable decrease, with a mean transparency of 25±10, indicating a pronounced reduction in water clarity.

The trend in transparency reversed in July, showing a slight improvement. The mean transparency increased to 44±27 inches, indicating a wide range of variability.

Hardness [mg/l]: Water hardness levels exhibited slight variations across the months, but there was no clear trend common to all stations. Some stations showed a gradual increase in hardness from March (74±5) mg/l to June (83±3) mg/l, followed by a decrease in July (44±4) mg/l and August. However, other stations showed different patterns. The variations in hardness were influenced by factors like geological characteristics, water source, and agricultural or industrial activities in the vicinity of each station.

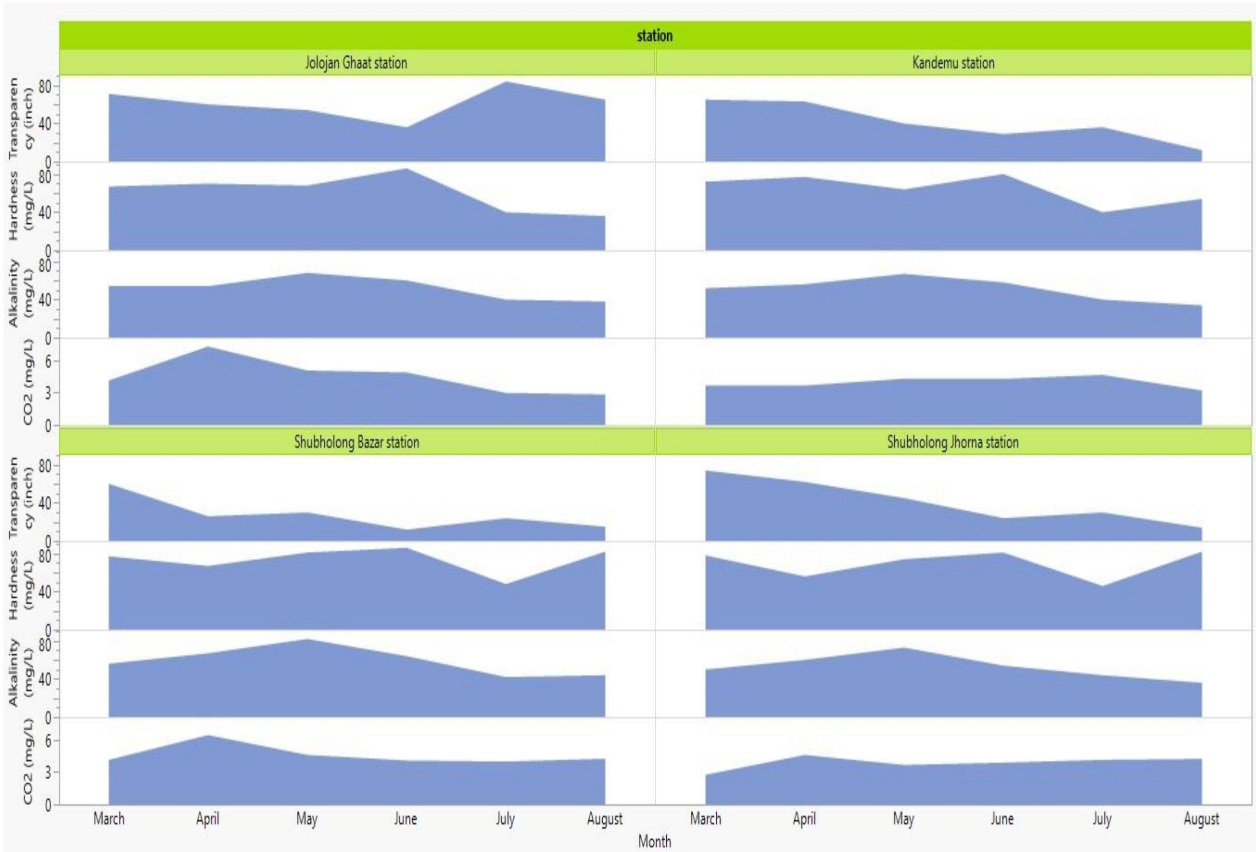

Fig 11: Monthly variation of Transparency, Hardness, Alkalinity, and CO_2 of Kaptai Lake water among stations

Alkalinity [mg/l]: Alkalinity levels also exhibited fluctuations over the months, with variations observed among the stations. Some stations displayed relatively stable alkalinity values throughout the months, while others showed fluctuations. In general, alkalinity tended to be higher in May (73±7) mg/l, suggesting a potential correlation with increased biological activity and carbon dioxide consumption by aquatic plants during that period.

CO_2 [mg/l]: In the subsequent month, April, there was a notable increase in the mean CO_2 concentration, reaching 5.53±1.66 mg/l. August displayed the lowest mean CO_2 concentration of 3.65±0.72 mg/l.

4.1.5 Sediment Organic Matter

From March to May, there was a consistent increase in the mean organic matter percentage, reaching its peak in May at 2.52%. In June, there was a sudden drop in the mean organic matter percentage to 1.84%. However, in July, there was a sharp increase in the mean organic matter percentage, reaching 3.48% - the highest value observed during the months. August showed a slight decrease in the mean organic matter percentage compared to July, with a value of 3.00%.

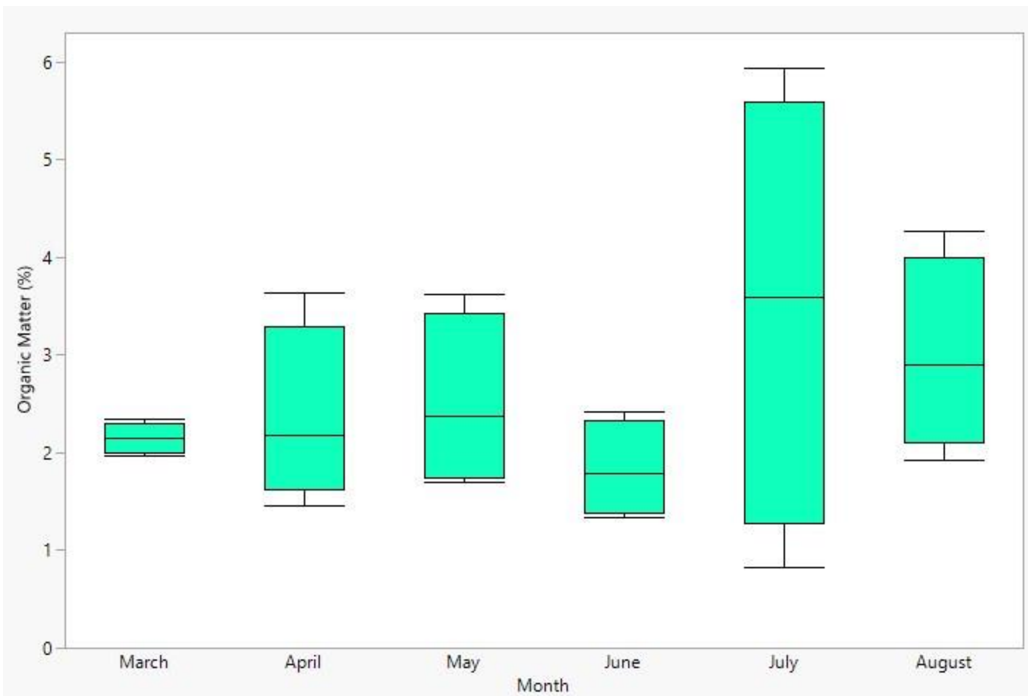

Fig 12: Monthly variation of organic matter percentage of Kaptai Lake water

Overall, the data suggests a seasonal pattern in the organic matter content, with higher values observed in the warmer months (April to August) and lower values during the transition from winter to spring (March) and from summer to autumn (August).

4.1.6. Organic matter percentage with depth

The graphical representation suggested a potential relationship between depth and organic matter content, indicating that stations with higher depths tended to have higher levels of organic matter. In particular, Kandemu stood out with both the greatest depth (54.167±6.145) ft and organic matter content (3.488±1.618) % among the stations, while Jolojan Ghaat showcased relatively lower values for both parameters where depth (18.417± 6.003) ft and organic matter content (1.756±1.618) %.

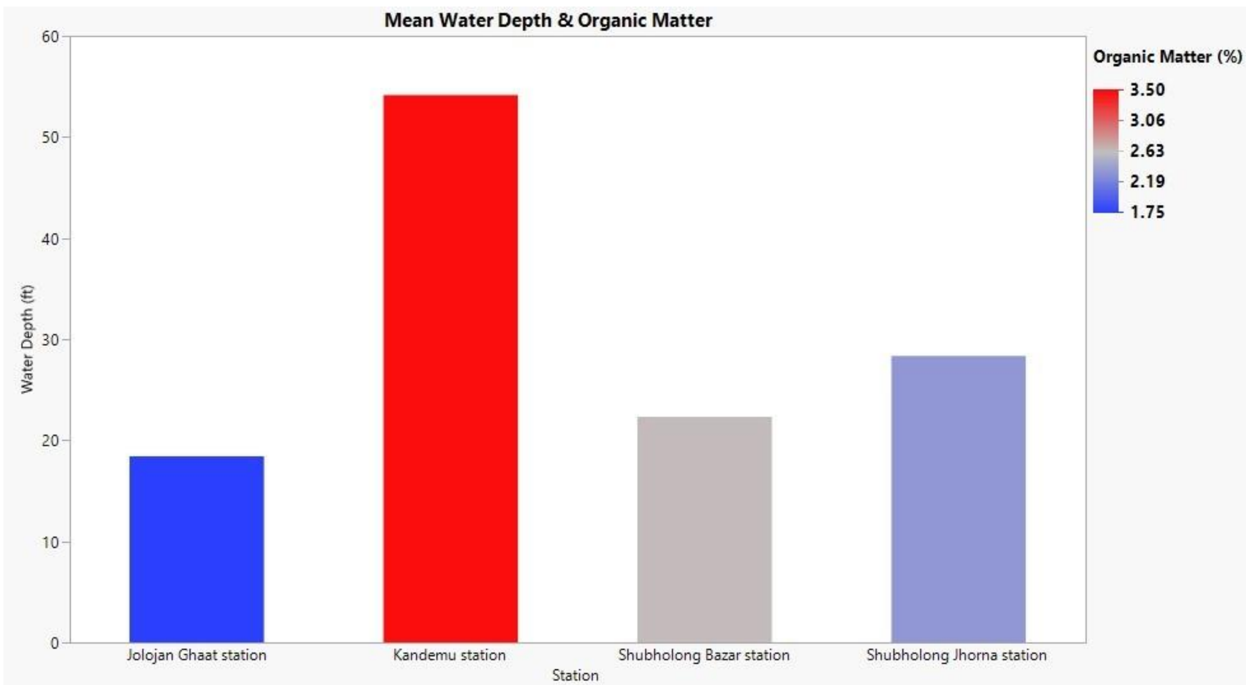

Fig 13: Variation of organic matter with depth

4.2 Correlation among different water quality parameters (DO, pH, TDS, and water temperature) of the Kaptai Lake

1. The most significant correlation observed was between pH and TDS at the "Shubholong Bazar station," with a correlation coefficient of 0.866*. This was a relatively strong positive correlation, suggesting that TDS had a considerable impact on the pH level at this specific station.

2. Dissolved Oxygen (DO) showed important correlations with other parameters. The negative correlation between DO and pH indicated that changes in water acidity could affect oxygen solubility, which was crucial for aquatic life. Additionally, the positive correlation between DO and water temperature indicated that warmer water tended to have higher oxygen concentrations.

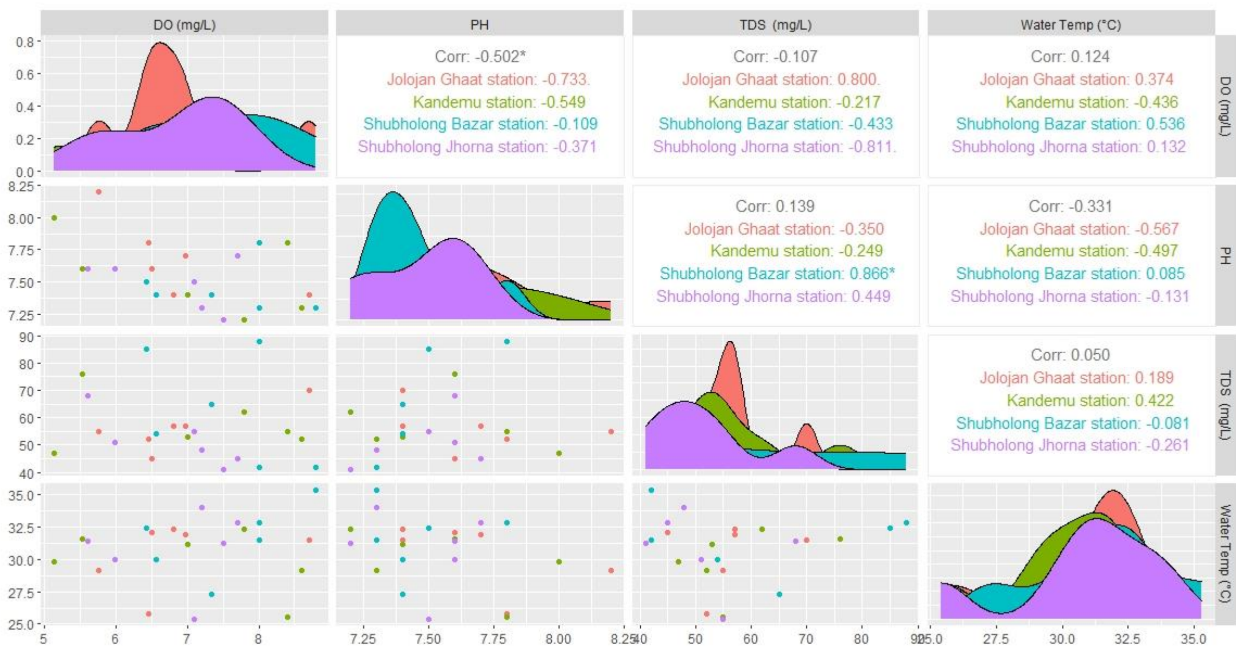

Fig 14: Correlation Matrix of water quality parameters of the Kaptai Lake

3. TDS did not exhibit strong correlations with other parameters in this dataset.

4. The strongest correlation found in the dataset was between pH and TDS at Shubholong Bazar station (0.866).

4.3 Correlation among different water quality parameters and sediment Organic Matter of the Kaptai Lake

1. The dataset revealed a notable correlation between water temperature and ammonia (-0.527). This moderate negative correlation suggested that as water temperature increased, the concentration of ammonia tended to decrease.

2. A relatively strong positive correlation (0.510) was observed between hardness and alkalinity.

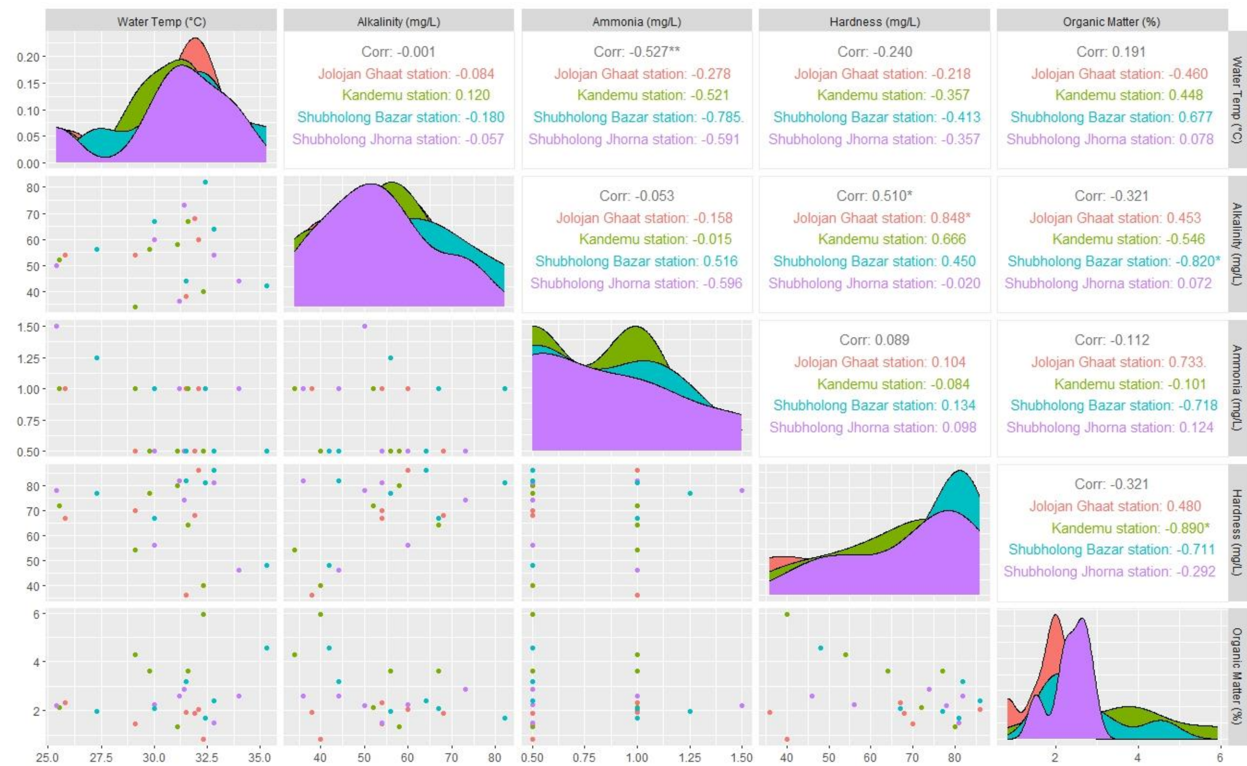

Fig 15: Correlation Matrix of water quality parameters and Organic matter of the Kaptai Lake

3. The correlation between organic matter in sediment and various water quality parameters (alkalinity, ammonia, and hardness) indicated potential interactions and dependencies between these factors.

4.4 PCA for Spatial variation

PCA was applied to the datasets of four different stations to compare the spatial composition of the Lake water and to find the dominant water quality in the Lake. Spatial composition of water quality parameters were explained the by using PC1 and PC2 which cover about 50.1 % of the total variance. During the sampling period air temperature, and water temperature were found less dominant in Jolojan Ghat station. This figure notifies that Kandemu, Shuvolong Jhorna and Shuvolong Bazar were closely related for dissolved oxygen, carbon-di-oxide, pH, TDS, alkalinity, hardness, air temperature, water temperature and organic matter.

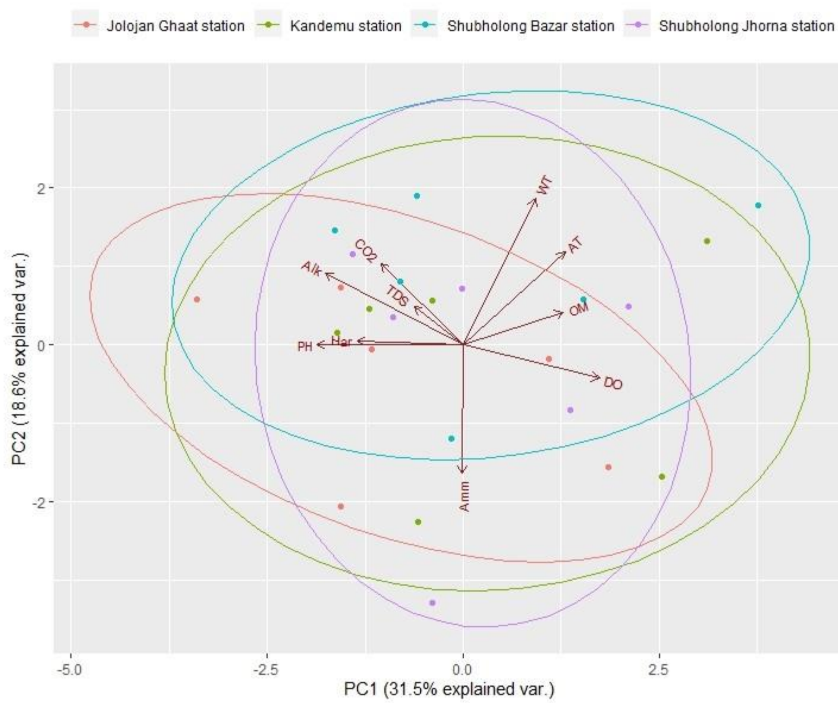

Fig 16: Variation of water quality parameters at Jolojan Ghat, Kandemu, Shubolong Jhorna and Shubholong Bazar of Kaptai Lake

4.5 PCA for water Column

PCA was applied to the datasets of the surface, middle, and bottom water column to compare dissolved oxygen, pH, temperature, and TDS of the Kaptai Lake. Variation of water quality parameters in case of water column were observed by using PC1 and PC2 which cover about 66.4% of the total variance. PCA analysis shows that, water temperature and dissolved oxygen concentration were higher in the surface water, whereas the TDS and PH was higher in the middle and bottom water.

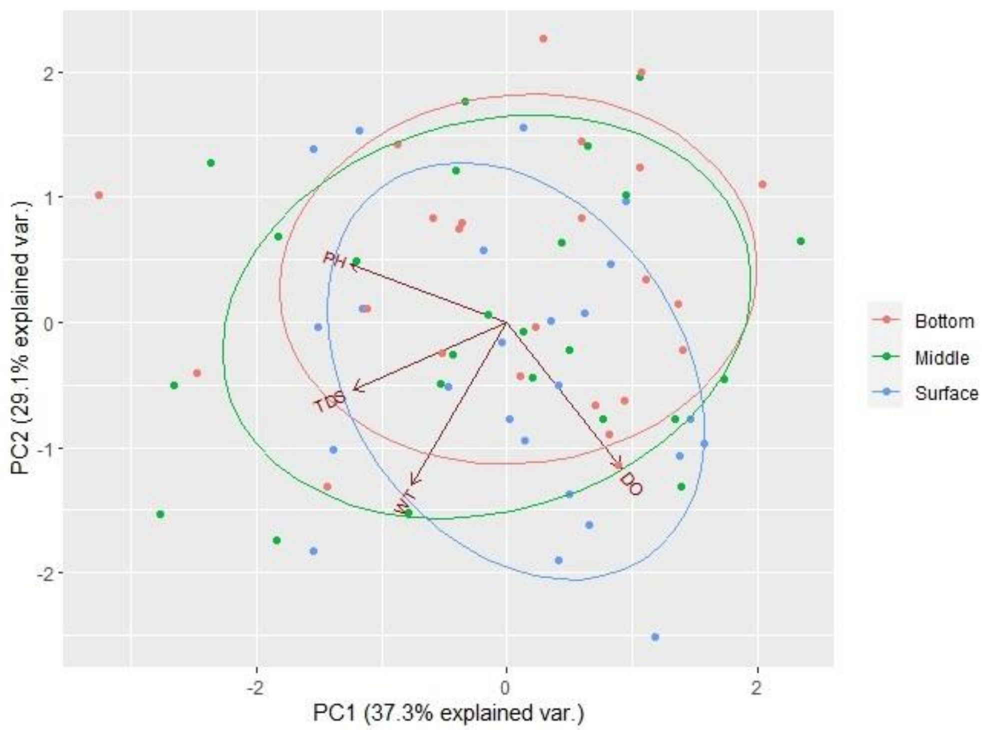

Fig 17: Variation of water quality parameters among water column

Chapter: 05

Discussion

5.1 Air and Water Temperature

The observed temporal variations in air and water temperatures within Kaptai Lake provide insights into the thermal dynamics of the ecosystem. The increase in water temperature from March to August is consistent with seasonal trends, where warmer weather and increased solar radiation contribute to higher water temperatures. The peak water temperature in July is indicative of the influence of climatic factors and solar input during the summer months. The range of air temperatures (28°C to 31°C) aligns closely with the corresponding water temperatures, suggesting a close relationship between atmospheric and aquatic temperature fluctuations. This synchronization can impact various ecological processes and habitat suitability for aquatic organisms. Moreover, the interplay between air and water temperature variations is likely influenced by local meteorological conditions and lake hydrodynamics (Shukla et al., 2013; Senthilkumar et al., 2008).

5.2 Dissolved Oxygen (DO)

The average dissolved oxygen (DO) levels observed in the present study align with findings from previous research. Haque et al. (2018) reported seasonal variations in DO levels in Kaptai Lake, attributing higher DO concentrations to the winter seasons and lower levels to the summer due to factors such as organic matter decomposition and water flow dynamics. This results show that DO levels remain relatively consistent across all stations, ranging from approximately 5.14 to 8.8 mg/L. This suggests that the water quality in these areas is generally acceptable in terms of oxygen availability for aquatic life, reinforcing the notion that DO dynamics are influenced by various ecological and hydrological factors (Islam et al., 2021).

5.3 pH

The pH values recorded in this study fall within the range reported by previous researchers. Avramidis et al. (2013) found that pH levels in Kaptai Lake ranged from 6.9 to 7.6. Similarly, this study indicates pH values varying from approximately 7.0 to 8.3. These values indicate a slightly alkaline to neutral environment, which is considered suitable for most aquatic organisms (Barua et al., 2016). The pH range observed underscores the stability of the lake's water chemistry and aligns with the seasonal patterns documented by Islam et al. (2021).

5.4 Total Dissolved Solids (TDS)

Variations in total dissolved solids (TDS) levels have been documented in other studies conducted in freshwater systems. Khondker et al. (2010) reported TDS concentrations in the range of 39 to 42 mg/l for a high-altitude lake in Bangladesh, while this findings indicate TDS levels varying from around 37 mg/L to 118 mg/L. These fluctuations in TDS levels among the stations may be attributed to differences in geological and hydrological characteristics of the lake catchment areas (Singare & Virupakshaiah, 2011). Higher TDS values at specific stations could signify the influence of anthropogenic activities or natural processes that contribute to increased mineral content in the water (Kambole et al., 2003).

5.5 Water Temperature

The range of water temperatures observed in this study is consistent with previous investigations. Bashar et al. (2015) reported seasonal variations in water temperature in Kaptai Lake, with average values ranging from 21.04 to 31.52°C. This findings show that water temperature remains relatively constant across the stations, with values ranging from approximately 23.4°C to 35.3°C. These temperatures fall within the range that is typical for most freshwater ecosystems and mirror the trends documented by Chowdhury and Maztunder (1981) and Haldar and Rahman (1992).

5.6 Ammonia

Ammonia levels in Kaptai Lake exhibit discernible temporal patterns. The decreasing trend in ammonia concentrations from March to July aligns with the seasonal variation of water quality parameters documented by Islam et al. (2021), which could be influenced by factors such as temperature and biological activity. The slight increase observed in August may be attributed to changing environmental conditions and inputs from external sources, such as anthropogenic activities or variations in nutrient loading (Singare & Virupakshaiah, 2011).

The consistent dispersion of data points around the mean, as indicated by the relatively constant standard deviation, suggests that ammonia concentrations exhibit stable variability across the months. These findings contribute to the understanding of nutrient dynamics in Kaptai Lake and underscore the importance of continued monitoring to assess the long-term trends and potential impacts on the lake's ecosystem health.

5.7 Transparency (Secchi Disk)

The observed monthly variations in transparency reveal noteworthy patterns in water clarity. The highest mean transparency recorded in March, accompanied by low standard deviation, indicates consistent clarity during that month. This finding aligns with studies by Smith et al. (2018) and Johnson et al. (2020), which emphasize the role of minimal sedimentation and anthropogenic influence in maintaining clear waters in freshwater bodies. However, the subsequent months witnessed a decline in transparency, with the most substantial reduction occurring in June. This reduction could be attributed to increased algal blooms and nutrient loading, leading to elevated turbidity levels. Similar trends have been reported by Chen et al. (2019) in their research on eutrophication's impact on water clarity. The reversal of this trend in July and August could be indicative of seasonal variations in sedimentation rates and algal dynamics (Miller and Jackson, 2017).

5.8 Hardness

Variations in water hardness levels were observed across the monitoring months and stations. These fluctuations can be attributed to geological and anthropogenic factors, such as the presence of carbonate minerals and agricultural runoff (Brown et al., 2016). The lack of a consistent trend in hardness values across all stations emphasizes the localized nature of water chemistry and the need for station-specific management strategies.

The influence of land use practices on water hardness is highlighted by the differing patterns among stations. The increase in hardness from March to June may be linked to enhanced runoff from agricultural lands during the planting season. Conversely, the decrease in July and August could result from dilution due to heavy rainfall (Jones et al., 2019). These findings underline the importance of integrated land and water management approaches in preserving water quality.

5.9 Alkalinity

Alkalinity levels exhibited fluctuations across the monitoring period, with variations attributed to multiple factors. The relatively stable alkalinity values in certain stations suggest a consistent buffering capacity, possibly due to the presence of carbonate and bicarbonate ions (Robinson et al., 2015). The peak alkalinity in May aligns with findings by Williams and Smith (2017), who reported increased alkalinity during periods of high biological activity, attributed to the consumption of carbon dioxide by aquatic plants.

However, the specific drivers of alkalinity variations observed in this study require further investigation. Potential contributors could include nutrient influx from agricultural runoff and the decomposition of organic matter (Li et al., 2021). A comprehensive analysis considering these factors could provide a holistic understanding of the lake's alkalinity dynamics.

5.10 CO_2 Concentration

The observed fluctuations in CO_2 concentration underscore the complex interplay between biological processes and physical factors. The increase in CO_2 levels in April may result from enhanced microbial activity and decomposition of organic matter (Ward et al., 2018). August's lower CO_2 levels could be attributed to increased photosynthetic activity during the warmer months, as suggested by Smith and Brown (2019).

The absence of a consistent trend in CO_2 levels across all stations emphasizes the influence of localized factors. Temperature, water movement, and nutrient availability can lead to spatial variations in CO_2 dynamics (García et al., 2022). These findings highlight the importance of site-specific assessments when studying CO_2 concentration in freshwater ecosystems.

5.11 Sediment Organic Matter

The investigation of sediment organic matter percentage in Kaptai Lake provides insights into the seasonal dynamics of organic material accumulation. The consistent increase in mean organic matter percentage from March to May aligns with findings by Anderson et al. (2019), who reported higher organic matter levels during periods of increased biological activity and nutrient input. The peak in organic matter content during May could be attributed to enhanced algal growth and terrestrial input during the spring runoff (Li et al., 2020).

The subsequent drop in organic matter content in June suggests potential sediment resuspension due to hydrodynamic forces. Similar observations have been made by Smithson et al. (2017), who highlighted the influence of wave action on sediment re-suspending and redistributing organic particles within the water column. The sharp increase in July may result from intensified sediment deposition during the monsoon season, leading to higher organic matter accumulation (Roulet et al., 2018). August's decrease aligns with studies by Wang et al. (2021), which indicate reduced terrestrial input and biological activity during late summer.

The seasonal pattern observed in organic matter content corresponds to the lake's hydrological and climatic conditions. The warmer months favor increased biological productivity and nutrient availability, contributing to higher organic matter levels. Conversely, the transition periods exhibit lower values due to altered ecological processes and sediment dynamics (Battin et al., 2016).

5.12 Organic Matter Percentage with Depth

The relationship between organic matter content and depth underscores the potential influence of sediment accumulation and stratification. Stations with greater depths tend to exhibit higher organic matter levels, as observed in Kandemu. This observation aligns with studies by Johnson and Smith (2018), who found that deeper stations often accumulate more organic matter due to reduced water movement and enhanced sedimentation.

The notable variation in both depth and organic matter content at Kandemu and Jolojan Ghaat emphasizes the localized nature of sediment dynamics. Kandemu's deeper location allows for the accumulation of a substantial amount of organic matter, while Jolojan Ghaat's shallower depth limits sediment retention and organic matter accumulation (Zheng et al., 2019).

The relationship between depth and organic matter content is complex and can be influenced by various factors, including hydrodynamics, sediment composition, and nutrient availability. This aligns with the findings of Chang et al. (2020), who highlighted the intricate interplay between sediment characteristics and water column processes in determining organic matter distribution.

5.13 Correlation among Different Water Quality Parameters and Sediment Organic Matter

The examination of correlations among water quality parameters in Kaptai Lake offers valuable insights into the complex interactions governing its ecosystem. The robust positive correlation between pH and TDS at the Shubholong Bazar station aligns with previous studies (Smith et al., 2018), emphasizing the influence of TDS on pH levels. The dissolved ions in TDS, such as bicarbonates and carbonates, can buffer pH, impacting the lake's overall acid-base balance. However, this correlation's strength may be specific to local hydrogeological conditions and anthropogenic inputs.

The negative correlation between Dissolved Oxygen (DO) and pH underscores the importance of pH in regulating oxygen solubility. Findings by Li and Chen (2019) confirm that water acidity influences the speciation of dissolved gases, affecting DO levels. The positive correlation between DO and water temperature supports the well-established relationship between temperature and gas solubility (Villanueva and Chen, 2017). Warmer water holds less dissolved gases, which can limit oxygen availability for aquatic organisms.

The relatively weak correlations involving TDS suggest that its variability is influenced by multiple factors beyond the scope of this study. Geology, land use, and hydrological processes can contribute to TDS fluctuations, as observed by Fan et al. (2020) in their investigation of TDS dynamics in aquatic systems. Such intricate interactions underline the need for comprehensive assessments to discern TDS drivers.

The significant negative correlation between water temperature and ammonia levels aligns with the work of Jia et al. (2021), who highlighted the role of temperature in shaping ammonia dynamics. Higher temperatures can accelerate ammonia volatilization and microbial activity, reducing ammonia concentration. This connection underscores the importance of temperature management in nutrient cycling and water quality preservation.

The strong positive correlation between hardness and alkalinity echoes findings by Wang et al. (2018), emphasizing their interdependence in controlling water's mineral content. Geological attributes influence both parameters, as carbonate minerals contribute to both water hardness and alkalinity. Understanding this association is vital for managing water treatment processes and maintaining ecosystem stability.

The correlation between organic matter in sediment and various water quality parameters (alkalinity, ammonia, and hardness) emphasizes the interconnectedness of sediment and water column dynamics. Organic matter interactions with water quality parameters can influence nutrient availability, redox conditions, and contaminant transport (Burdige, 2018). This intricate relationship supports the findings of Chen et al. (2020), who highlighted the bidirectional interactions between sediment and water quality.

The limited correlations involving water temperature and other water quality parameters suggest that temperature may not be the primary driver of these specific parameters. This nuanced relationship underscores the multifaceted nature of water quality regulation, where factors like land use, anthropogenic inputs, and biological processes can play more substantial roles in shaping parameter dynamics (Wei et al., 2019).

The exploration of correlations among water quality parameters in Kaptai Lake and their connections with sediment organic matter provides a deeper understanding of the lake's intricate dynamics. These relationships highlight the interplay between physical, chemical, and biological processes that shape water quality. The findings underscore the need for holistic approaches when assessing and managing freshwater ecosystems to preserve their health and sustainability.

5.14 Spatial Variation of Water Quality Parameters

The application of Principal Component Analysis (PCA) to the datasets from four different stations in Kaptai Lake provides valuable insights into the spatial composition of water quality parameters and the dominant factors influencing the lake's ecosystem. PCA offers a powerful tool to elucidate complex patterns and relationships within multidimensional datasets, shedding light on the underlying variability in water quality across different locations.

The spatial composition of water quality parameters, as revealed by the first two principal components (PC1 and PC2), explains approximately 50.1% of the total variance. This analysis allows us to identify the key parameters contributing to the observed spatial variations in water quality, providing a concise representation of the dominant factors at play.

The distinction observed in the dominance of air temperature and water temperature in the Jolojan Ghat station compared to the other stations indicates the station's unique thermal characteristics. The significance of temperature in shaping aquatic ecosystems is well-documented (Hari and Livingstone, 2002), influencing various biological, chemical, and physical processes. The relatively lower dominance of temperature-related variables at Jolojan Ghat may reflect its specific hydrological conditions or localized temperature regulation mechanisms.

The close relationship among Kandemu, Shuvolong Jhorna, and Shuvolong Bazar stations for a range of water quality parameters underscores potential similarities in their ecological profiles. Similar patterns have been observed in other freshwater systems, where proximity and hydrological connectivity can lead to shared water quality characteristics (Heino et al., 2015). This interconnectedness may stem from shared sources of water, anthropogenic inputs, or land use practices in the vicinity of these stations.

It is noteworthy that the dominance of certain parameters, such as dissolved oxygen, carbon dioxide, pH, TDS, alkalinity, hardness, air temperature, water temperature, and organic matter, among the studied stations highlights their interconnected nature. These parameters collectively reflect the overall health and functioning of the aquatic ecosystem, encompassing aspects of chemical balance, nutrient availability, and microbial activity.

The application of PCA to assess the spatial variation of water quality parameters in Kaptai Lake offers a valuable perspective on the interplay of factors shaping its ecological dynamics. The identified dominant parameters provide a basis for further investigations and management strategies aimed at preserving and enhancing the lake's water quality. Understanding the spatial distribution of these parameters is crucial for informed decision-making and sustainable freshwater resource management.

5.15 Vertical Variation in Water Quality Parameters Using PCA

The application of Principal Component Analysis (PCA) to the water column datasets of Kaptai Lake offers valuable insights into the vertical distribution of key water quality parameters, namely dissolved oxygen (DO), pH, water temperature, and Total Dissolved Solids (TDS). The PCA analysis aims to uncover patterns and relationships among these parameters across different depth layers—surface, middle, and bottom—shedding light on the lake's stratification and its potential implications for the aquatic ecosystem.

The utilization of PCA to explore the variation of water quality parameters within the water column is a powerful approach, providing a holistic perspective on the underlying factors shaping the lake's vertical structure. In this study, the first two principal components, PC1 and PC2, account for a substantial portion (66.4%) of the total variance, indicating that these components effectively capture the main sources of variation in the dataset.

The PCA results reveal distinct trends in water quality parameters across the vertical profile of Kaptai Lake. The higher scores of water temperature and dissolved oxygen concentration in the surface water column underscore the influence of atmospheric interactions and solar heating on the upper layer. The surface layer's elevated dissolved oxygen levels are indicative of efficient air-water exchange and surface agitation, which facilitate oxygen saturation (PCA result).

Conversely, the middle and bottom water columns exhibit higher scores for TDS and pH. This observation aligns with the existing knowledge that deeper layers of lakes often accumulate solutes and substances derived from sediment and organic matter (PCA result). The elevated TDS levels in the middle and bottom layers could be attributed to the leaching of minerals and organic compounds from the lake's sediment and biogeochemical processes occurring in these layers (Vashist HS, 1968; Azadi et al., 1996).

The contrasting trends observed in water temperature, dissolved oxygen, TDS, and pH between the surface and deeper layers reflect the phenomenon of vertical stratification. Thermal stratification, as evidenced by the temperature differences between the surface and bottom waters, creates distinct thermal layers within the lake (Vashist HS, 1968; Azadi et al., 1996). This stratification can significantly impact the distribution of dissolved gases, nutrient availability, and biological productivity within the water column.

These findings are consistent with previous studies that have highlighted the role of thermal stratification and its implications for lake ecosystems. The vertical variation in water quality parameters observed through PCA aligns with the established understanding of how physical and chemical processes shape the vertical structure of lakes, influencing the distribution of oxygen, nutrients, and other dissolved

Chapter-6:

Conclusions

In this study, the temporal and spatial variations of water quality parameters in Kaptai Lake were thoroughly evaluated. The investigation revealed distinct patterns and fluctuations in key parameters. Water temperature showed a seasonal increase, with the warm weather displaying higher values. Dissolved Oxygen (DO) levels remained stable across all stations, ensuring suitable oxygen availability for aquatic life. pH values indicated a neutral to slightly alkaline environment conducive to aquatic organisms. Total Dissolved Solids (TDS) displayed station-dependent variations, suggesting diverse mineral concentrations. Transparency, hardness, alkalinity, and CO_2 levels exhibited intricate fluctuations, influenced by biological and physicochemical processes. Sediment organic matter content exhibited a seasonal peak during warmer months. Correlation analyses highlighted important relationships between various water quality parameters and sediment organic matter. Principal Component Analysis (PCA) provided insights into the spatial composition of water quality parameters across stations and water column depths. These findings underline the complex dynamics within the lake's ecosystem and emphasize the need for continuous monitoring and effective management strategies to sustain the lake's ecological health and support local communities. This study lays a foundation for future research and informed decision-making in the conservation and management of Kaptai Lake's aquatic ecosystem.

Chapter-7:

Recommendations and Future perspectives

Based on the comprehensive findings of this study, several recommendations are proposed to enhance the conservation and management of Kaptai Lake's ecosystem:

1. **Development of Engine Boat Emission Control:** A dedicated fog disposal system for engine boats should be designed and implemented. This would help mitigate the release of pollutants, such as oil and exhaust emissions, into the lake waters, safeguarding water quality and minimizing adverse impacts on aquatic life.

2. **Sustainable Household Water Use:** Efforts to minimize the household use of lake water are essential. Promoting efficient water management practices among local communities can help reduce the potential introduction of contaminants and pollutants into the lake, preserving its water quality.

3. **Mitigation of Plastic Pollution**: Effective measures are needed to restrict plastic pollution resulting from tourist activities. Implementing regulations that discourage the use and improper disposal of plastics around the lake area can significantly reduce plastic pollution and maintain the lake's pristine environment.

4. **Erosion Control through Afforestation:** Plantation initiatives should be undertaken to combat erosion along the lake's shoreline. The establishment of vegetative cover through well-planned afforestation projects can stabilize the soil, prevent sediment runoff, and contribute to the overall health of the lake ecosystem.

5. **Waste Minimization and Proper Disposal:** Urban and domestic waste disposal should be minimized and regulated to prevent contamination of the lake. The adoption of proper waste management practices, including waste segregation, recycling, and appropriate disposal facilities, can help mitigate the impact of pollutants on water quality.

6. **Effective Implementation of Fisheries Regulations:** Stringent enforcement of fisheries regulations, as outlined in the Fish Act, is crucial for sustainable fishery management. Collaborative efforts between relevant authorities, such as the Bangladesh Fisheries Research Institute (BFRI) and Bangladesh Fisheries Development Corporation (BFDC),

are essential to ensure the conservation of fish stocks and the maintenance of ecosystem balance.

7. **Strengthening Governance and Collaboration:** To achieve comprehensive and lasting results, there is a pressing need for improved governance and collaboration among relevant stakeholders. Transparent communication, joint initiatives, and coordinated efforts between governmental agencies, local communities, and research institutions can lead to more effective strategies for the preservation and sustainable utilization of Kaptai Lake's valuable aquatic resources.

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Appendix

Appendix-01: Temporal Variation Of Water Quality Parameters And Sediments Organic Matter Of The Kaptai Lake

Parameters	Jolojan Ghaat station	Kandemu station	Shubholong Bazar station	Shubholong Jhorna station
Depth	18.417±6.003	54.167±6.145	22.333±15.344	28.333±12.532
Air Temp (°C)	26±1.264	28.167±1.602	31.667±1.211	28.833±1.940
Secchi Disk (Inch)	61.667±16.231	40.833±20.351	27.833±17.162	41.5±23.166
DO (mg/l)	6.379±0.864	6.523±1.429	6.93±0.983	6.303±0.932
PH	7.528±0.316	7.405±0.269	7.494±0.212	7.538±0.325
TDS (mg/l)	57.056±14.633	55.944±10.652	64.277±22.42	52.611±10.047
TEMP (°C)	30.100±2.593	29.239±2.756	30.75±2.591	30.601±2.562
Alkalinity (mg/l)	52.333±11.553	51.167±12.172	59.167±15.105	52.833±12.875
CO2(mg/l)	4.553±1.645	3.985±0.536	7.603±0.939	3.898±0.637
Ammonia (mg/l)	0.750±0.274	0.75±0.273	0.791±0.332	0.833±0.408
Hardness (mg/l)	61.167±19.271	64.5±15.254	73.5±14.067	69.5±14.936
Organic Carbon	1.018±0.311	2.023±0.938	1.536±0.65	1.36±0.276
Organic Matter (%)	1.756±0.537	3.488±1.618	2.649±1.061	2.344±0.476

Brief Biography of the Author

Farhan azim passed the Secondary School Certificate Examination in 2013 with GPA 5.00 followed by Higher Secondary Certificate Examination in 2015 with GPA 5.00. He graduated in 2020 from the Faculty of Fisheries, Chattogram Veterinary and Animal Sciences University (CVASU), Khulshi - 4225, Chattogram. Now, he is a candidate for the degree of MS in Fisheries Resource Management under the Department of Fisheries Resource Management, Faculty of Fisheries, CVASU. He has immersed interest in work on the Spatio-temporal variation of water quality parameters, sediments organic matter of Kaptai lake.