WATER AVAILABILITY AND QUALITY IN MUSAPUR RESERVOIR: ANALYZING THE CURRENT SITUATION AND IDENTIFYING CHALLENGES

Md. Sohanur Rahman Prince [*1], Md Sadbir Rahman[2], Faruq Ahmed Mohiuddin[3], Tanmay Chaki[4] and Md. Sohel Masud[5]

[1] *Junior Engineer, Institute of Water Modelling (IWM), Bangladesh, e-mail: sri@iwmbd.org*
[2] *Associate Specialist, Institute of Water Modelling (IWM), Bangladesh, e-mail: srr@iwmbd.org*
[3] *Sr. Water Resources Specialist, Institute of Water Modelling (IWM), Bangladesh, e-mail: fam@iwmbd.org*
[4] *Senior Specialist, Institute of Water Modelling (IWM), Bangladesh, e-mail: tac@iwmbd.org*
[5] *Director, Institute of Water Modelling (IWM), Bangladesh, e-mail: msm@iwmbd.org*

***Corresponding Author**

ABSTRACT

The Musapur reservoir, located in southeastern Bangladesh on Little Feni River contributes significantly to mitigate salinity intrusion and water security in the region. It serves a multifaceted purpose, helping to alleviate the impact of floods and droughts, and ensuring a reliable water supply for local agriculture. A kilometer-long closure dam and a 23-vent regulator control the flow system of the Little Feni river and Musapur reservoir. For optimum utilization of the reservoir storage during the dry season, a detailed analysis of the water availability and water quality in the reservoir is essential.

This study conducts a thorough examination of historical hydrologic and meteorological data and primary water quality data to comprehensively analyze water availability and water quality in the reservoir. A hydrynamic model of the Little Feni river and Musapur reservoir was developed and duly calibrated to investigate the intricate interplay between precipitation patterns, streamflow variations and reservoir water levels. Several scenarios were simulated considering extreme, avegare and low flow events as well as different gate operation schedules. Using reservoir bathymetry data, an elevation-storage curve was developed. Utilizing the model simulated water levels in the Musapur reservoir and its elevation-storage curve, a detailed water availability analysis was conducted. Measurements of different water quality parameters were taken at different points of the reservoir both during the dry and wet seasons on 2023. Analysis of the measured water quality parameters enabled an understanding of the suitability of reservoir water for different uses.

Study findings indicate that the present state of reservoir operation is not efficient enough to meet the existing water demand. By optimizing the regulator operation and conducting capital dredging, it is possible to substantially enhance the water availability from the reservoir that can significantly contribute to growth in regional agriculture and water supply. However, optimization of the regulator operation may initiate flood risk in the upstream areas which need to be mitigated with continuous monitoring. Besides, there is a major concern regarding the water quality in the reservoir. High salinity and heavy metal concentration were observed in the reservoir during the dry season indicating deficiency in the regulator design, poorer maintenance and probable industrial pollution. These findings would facilitate the policy makers and govt. organisations for informed decision-making in reservoir management, and efficient utilization of this valuable water resource in the face of evolving global changes.

Keywords: *Reservoir, Hydrodynamic, Water Availability, Water Quality, Salinity*

1. INTRODUCTION

Water stands as a critical natural resource of immense importance in Bangladesh. The rivers, wetlands, and seasonal floods collectively form the essence of the nation. Despite their fundamental role, the availability of fresh water experiences a distinct seasonality owing to the predominant influence of the monsoon climate in the region (Chowdhury, 2010). Water is a limited and essential resource that is essential to maintaining ecosystems, enabling human activity, and maintaining the general health of the environment. To deal with water scarcity and variability, reservoirs have become a long-standing strategy for altering natural water flows, thereby securing the reliability of water sources that can facilitate human and environmental needs (Votruba & Broža, 1989, Asadieh et al., 2026). As essential parts of water management systems, reservoirs are essential to supplying the growing demands of irrigation and water supply. However, a thorough understanding of the processes behind spatiotemporal variations in surface water quantity and quality is necessary for sustainable water resource management (Liu et al., 2023).

This paper presents an in-depth assessment of water availability and water quality in Musapur reservoir. The Musapur Reservoir on Little Feni River in southeast Bangladesh, provides water for agriculture, aquaculture, and local transportation, making it a vital resource for the socioeconomic growth of the region (Moshfika & Rahman, 2018). This study aims to contribute valuable insights into the current state of Musapur reservoir, providing a foundation for informed water resource management decisions. The construction of the Musapur reservoir has already had a significant effect on local agriculture, as seen by the rise in crop output and the net primary production trend (Khan et al., 2022 and Neha et al., 2023). The assessment of water availability is essential for understanding the reservoir's capacity to meet current and future demands, especially in the face of changing environmental conditions. In addition, the predicted increase in the frequency and severity of extreme weather events as well as the change in streamflow patterns governed by climate change, underscores the need for modifications to the way the current water infrastructure is operated (Ehsani et al., 2017). In this respect, a critical review of the current operating rules of the Musapur regulator has been done to cope with future climate change and the growing need of water in the region.

Concurrently, the evaluation of water quality parameters is paramount for ensuring the health and sustainability of the aquatic environment and safeguarding public health. There has been insufficient research conducted to quantify the availability of Musapur reservoir water and assess the water quality across different months in a year. The primary objectives of this research are twofold: first, to quantify the current water availability in Musapur reservoir through a rigorous analysis of hydrological patterns, including inflows, outflows, and storage dynamics; and second, to assess the water quality by analysing key parameters. The integration of these assessments will offer a comprehensive understanding of the reservoir's overall health and resilience. In essence, this study aims to contribute valuable insights into the intricate relationship between water availability and quality in Musapur reservoir, offering a foundation for evidence-based decision-making and fostering the sustainable use of this vital water resource.

2. STUDY AREA

The study area, Musapur Reservoir, is situated in the lower reaches of the Little Feni River in the southeastern region of Bangladesh. The study area of this study has been shown in Figure 1. The river system, comprising Kakri and Little Feni Rivers, spans approximately 120 km across three districts: Cumilla, Noakhali, and Feni. At the reservoir's terminus, there exists a kilometer-long closure dam, and the total flow system of the Little Feni River and Musapur Reservoir is regulated by 23 vent regulators. The topography is predominantly flat, and the surrounding land use is characterized by agricultural areas and a rural landscape and with a water level above 2.5mPWD in the Musapur reservoir, there is a potential flood hazard at the upstream of the river.

Figure 1: Map of the study area

3. METHODOLOGY

In this study, a collaborative approach has been adopted to determine the existing state of the water availability and quality of the Musapur reservoir. In this regard, a hydrodynamic model has been developed and analysis of extensive primary water quality data has been done. Different scenarios and improvement measures have been proposed for enhancing water storage in the reservoir, thereby ensuring sufficient water supply both during the dry and wet seasons.

3.1 Data Collection

The development and calibration of a robust 1D hydrodynamic model necessitate a comprehensive and meticulous approach to data collection. The key components of data collection, emphasize the importance of accurate and representative input parameters for the successful simulation of river flow dynamics. The initial step involves obtaining precise bathymetric data through survey. Finer (100m interval) cross-sectional data has been surveyed and used in the model at the Musapur Reservoir than the rest of the network. Hydrological data, sourced from stream gauging stations, provides critical information on river discharge and water levels, essential for characterizing flow regimes. On the other hand, several water quality parameters have been obtained through in-situ water quality tests (pH, DO, Salinity, EC) and laboratory water quality tests of reservoir water.

3.2 Hydrodynamic Model Development

The development of a 1D hydrodynamic model using MIKE11 HD involves a comprehensive and structured process tailored to simulate the one-dimensional flow dynamics in rivers and channels. A hydrodynamic model is initialized with this data, incorporating information on boundary conditions and initial water levels. The hydrodynamic equations governing one-dimensional flow are discretized and solved using numerical methods within the MIKE11 HD framework. In this study around 160km river network (Kakri-Dakatia-Little Feni River) and three boundary conditions (two upstream and one downstream) have been considered. For the upstream boundary condition at Mia Bazar discharge data has been evaluated through generating a rating curve. Extensive historical discharge data from the past twenty years has been analysed to attain an appropriate rating curve to generate time series discharge data. Rainfall-runoff is a critical component in hydrodynamic models, playing a significant role in shaping the flow of water through a watershed or river system. In this study rainfall-runoff data has been acquired from South-eastern Regional Model. The time step of the model has been taken as five minutes, and the base model has been developed from March to September 2023, covering both dry and wet seasons using real-time monitored hydrological data.

3.2.1 Model Calibration

For the calibration process of the hydrodynamic model for Little Feni River, the simulated water level was fine-tuned by adjusting the Manning's roughness coefficient (n) to a calibrated value of 0.022 (Shown in Figure 2). This parameter adjustment significantly improves the accuracy of the model in depicting the river's flow dynamics. Various statistical indicators, including the Coefficient of Determination (R^2), Nash-Sutcliffe Efficiency (NSE), Mean Absolute Error (MAE), and Root Mean Squared Error (RMSE), were employed to assess the calibration of the model (Nash & Sutcliffe, 1970; Fox, 1981). Figure 3 presents a scatter plot depicting the relationship between observed water levels and those simulated by the calibrated model. The statistical evaluation yielded R^2, MAE, RMSE, and NSE values of 0.98, 0.14, 0.17, and 0.81, respectively. From a statistical standpoint, all indicators suggest favourable model performance.

The R^2 value of 0.98 in this hydrodynamic model signifies a robust correlation between observed and simulated data. The MAE value of 0.14 indicates a modest average deviation of the model's predictions from observed values, reflecting a commendable level of accuracy. A lower MAE is associated with enhanced accuracy. The RMSE of 0.17 implies a relatively minimal dispersion or variability in the model's predictions compared to observed values, indicating heightened precision. Smaller RMSE values are indicative of improved precision. According to the NSE value of 0.81, the performance of the model can be rated as "good" (Moriasi et al., 2007)

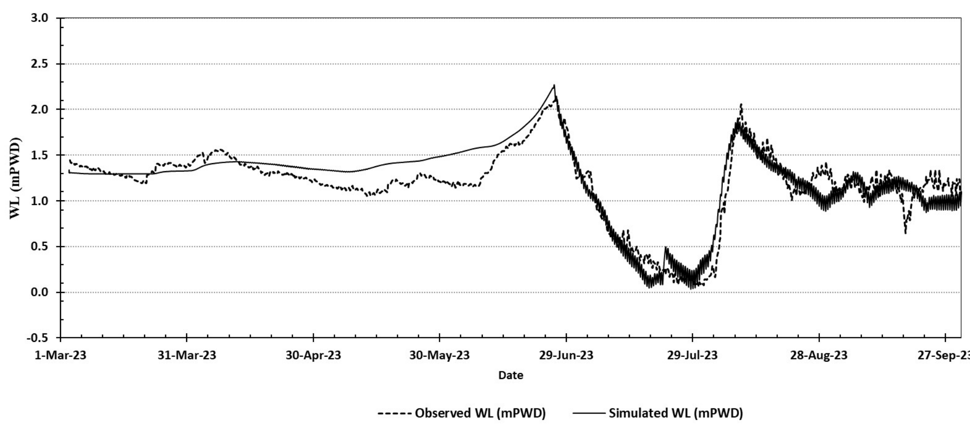

Figure 2: Water level calibration of hydrodynamic model for Musapur reservoir

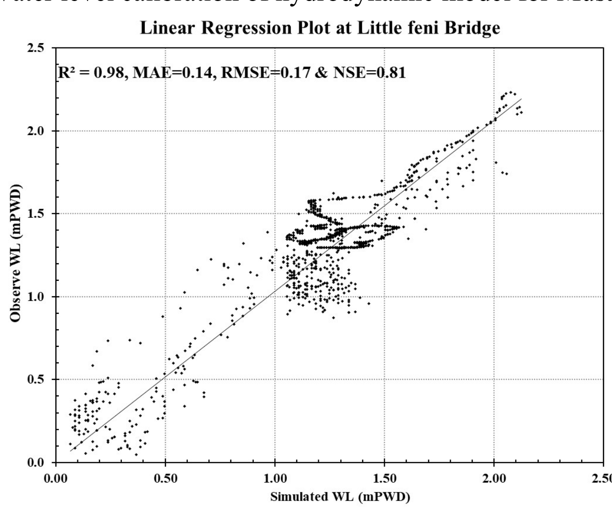

Figure 3: Regression analysis of observed and simulated water level

3.3 Water Quality Analysis

Throughout 2023, primary data collection on water quality in the Musapur Reservoir has been undertaken, followed by a comprehensive assessment of the gathered data. Thorough assessments were conducted, involving both on-site measurements and laboratory tests, spanning seven different locations of Musapur Reservoir.

3.4 Scenario Analysis

This study delves into the comprehensive investigation of the hydrodynamic behaviour of the Musapur Reservoir and conducts a thorough analysis of water availability. In pursuit of this objective, we explored five distinct scenarios, each characterized by variations in river flow and hydrologic patterns. To facilitate our study, we have developed five unique models corresponding to the scenarios. These scenarios encompass one extreme, two moderates, one low to moderate, and one low-flow condition (Table 1).

Table 1: List of scenarios

SL	Scenario Considered
Scenario-1	Existing reservoir condition with extreme hydrologic event and different gate opening schedule
Scenario-2,3	Existing reservoir condition with modarate hydrologic event and different gate opening schedule
Scenario-4	Existing reservoir condition with modarate to low hydrologic event and different gate opening schedule
Scenario-5	Existing reservoir condition with low hydrologic event and different gate opening schedule

3.5 Reservoir Storage Capacity Analysis

During the dry season, Musapur Reservoir accumulates water, primarily sourced from the Kakri and Little Feni Rivers, with the majority contributed by rainfall runoff from the adjacent catchment of the Little Feni River. In the wet season, all gates are opened to facilitate the discharge of water into the Bay of Bengal. An elevation-storage curve has been developed for Musapur Reservoir utilizing cross-sectional data obtained from the bathymetric survey conducted in 2023, as illustrated in Figure 4. In this study, the storage curve has been employed to ascertain the active storage corresponding to various water levels, with the dead storage level of the reservoir assumed at approximately 1 mPWD. In existing conditions, the active storage volume in the reservoir is about 7.4 Mm^3.

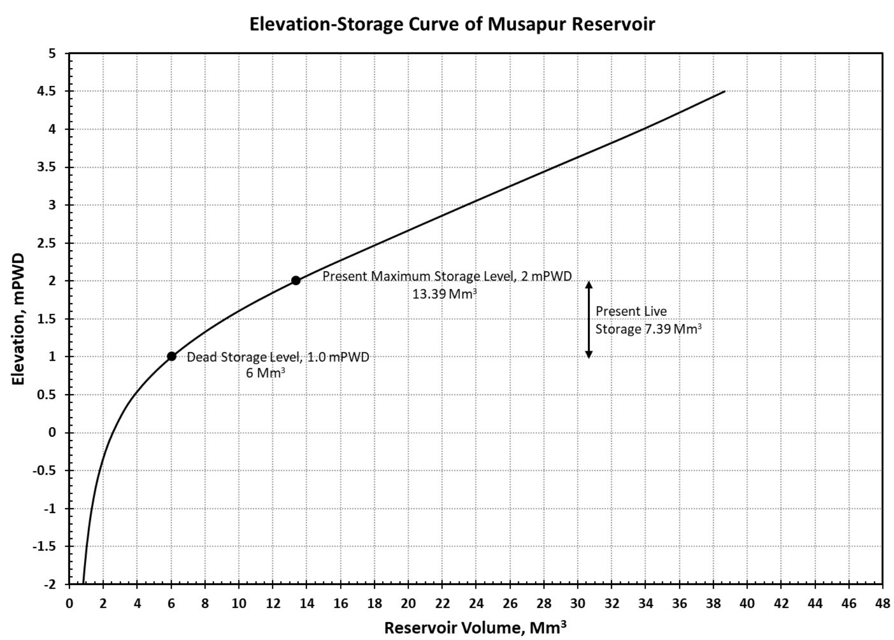

Figure 4: Elevation-storage curve of Musapur reservoir

4. RESULTS AND DISCUSSION

4.1 Water Availability Analysis

The model results incorporation of seasonal dynamics in reservoir conditions, particularly during the dry season and monsoon periods. In the dry season scenario, all gates of the regulator are kept closed. Conversely, during the monsoon, a subset of gates in the reservoir are opened to accommodate increased water inflow. Within each scenario, we have developed specific models tailored for a 14-month duration, spanning various years. Different scenarios encompass the implementation of seven distinct gate closing and opening combinations to optimize water storage within the reservoir across varying water levels. This approach enables a comprehensive evaluation of the reservoir's response to different hydrologic conditions.

Simulated water level hydrograph of the extreme scenario has been shown in Figure 5. It has been observed that in the case of an extreme event, closing the regulator gate during October 1 to 10 results in a significant rise in water level, reaching up to 5 meters PWD, exceeding the reservoir's capacity. This has the potential to lead to severe flooding in the upstream region of the river. Figure 6 and 7 illustrate the simulated water level hydrograph for a moderate event. In this scenario, if the gates are closed during October 1 to 10, there is a possibility that water levels could surpass 3mPWD, leading to a potential flood upstream of the reservoir. Figure 8 illustrates the simulated water level for a moderate to low event. In this scenario, during the gate opening period, the reservoir's water level is approximately 1.45mPWD which is lower than in other scenarios. Water levels for various gate closure instances under this scenario were found to be similar to those in the moderate scenario. The simulated water levels for the low scenario are presented in Figure 9. It was observed that, for different gate closing times, the reservoir water levels are lower than in all other scenarios. Analysis of various scenarios indicates that delaying the closing date of the regulator gate results in a lower reservoir water level, thereby reducing the stored water volume. Conversely, for low hydrologic events, closing the gate earlier allows for the storage of a substantial amount of water without posing a risk of flooding in the upstream area. Under the current circumstances, the Musapur regulator gates are closed in late November, leading to a reduced reservoir level during the dry season. Implementing an optimal gate operation rule, tailored to the hydrologic conditions of the region, emerges as a viable solution to achieve a significant reservoir water level. This strategy has the potential to fulfill the local demand for freshwater, support irrigation needs, and industrial water supply.

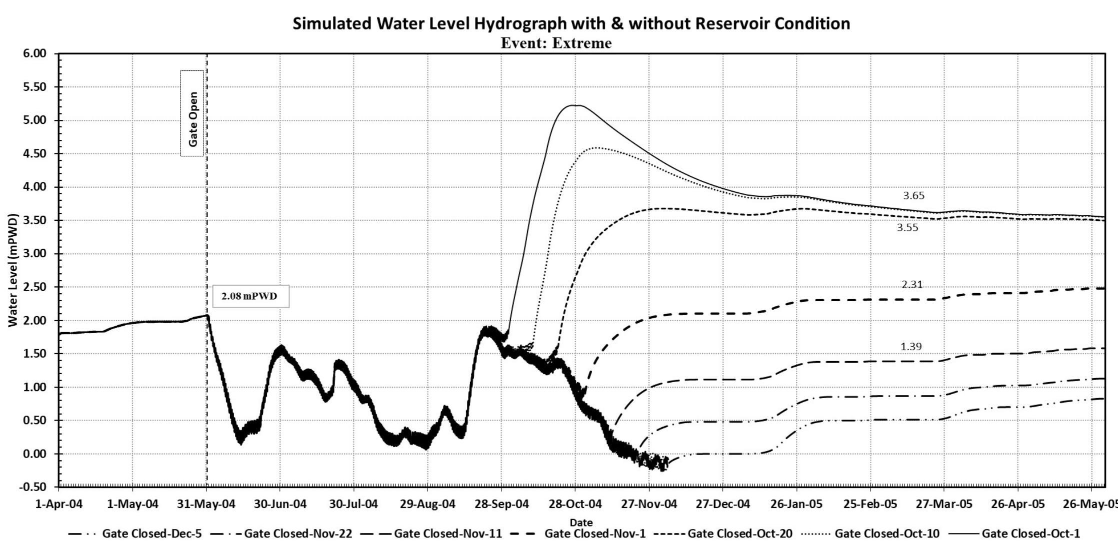

Figure 5: Simulated water level hydrograph of Musapur reservoir under extreme scenario

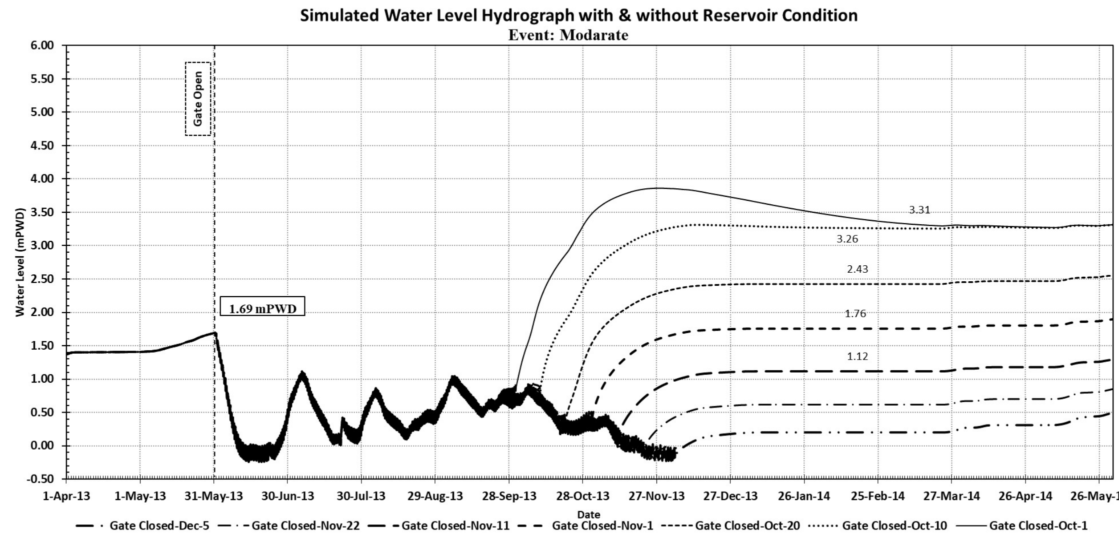

Figure 6: Simulated water level hydrograph of Musapur reservoir under moderate scenario

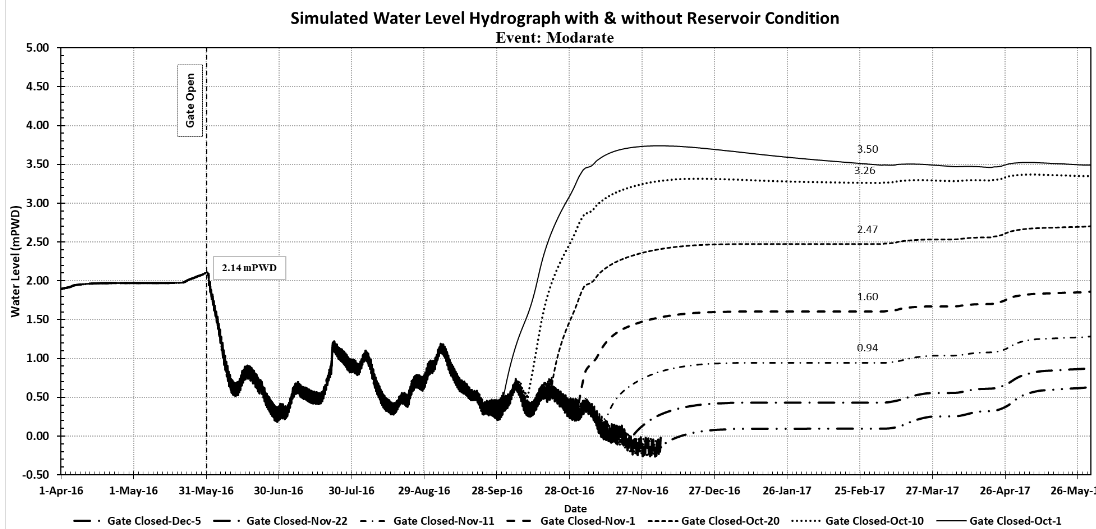

Figure 7: Simulated water level hydrograph of Musapur reservoir under moderate scenario

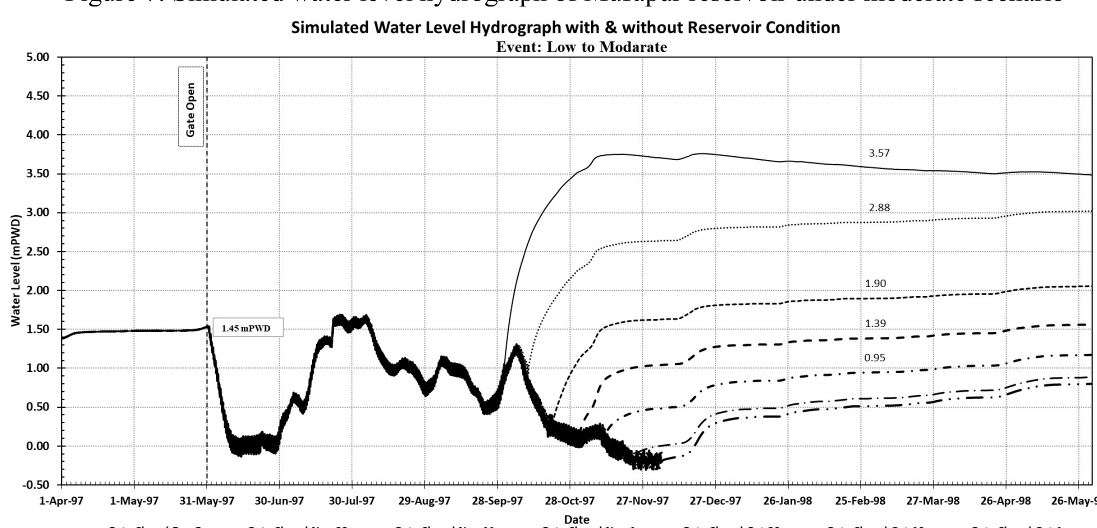

Figure 8: Simulated water level hydrograph of Musapur reservoir under low to moderate scenario

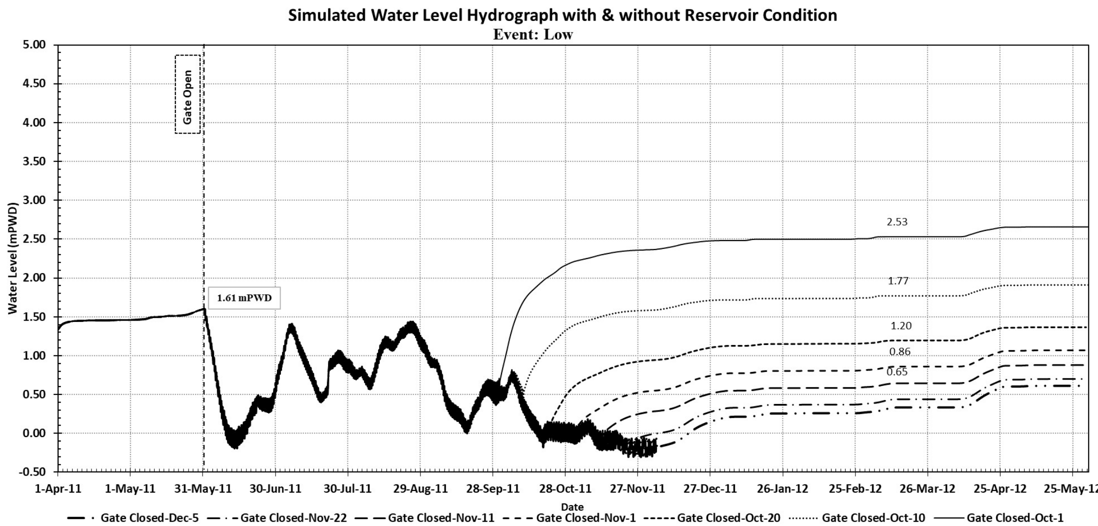

Figure 9: simulated water level hydrograph of Musapur reservoir under low scenario

At present condition, the active storage volume of the reservoir (7.4 Mm^3) is not sufficient to meet the irrigation demand after accommodating for evaporation and other losses. If the reservoir water level is kept around 2.5mPWD with an updated gate operation, an additional 21.44 MLD water could be stored after excluding the evaporation loss and present irrigation demand (Table 2). Moreover, by increasing the reservoir capacity by 1.5m dredging depth across a 945-acre area of the reservoir, around 53.26 MLD additional water could be stored (Table 3).

Table 2: Available water at +2.5 mPWD reservoir level in present condition

Reservoir Level, +2.5 mPWD	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**
Active Storage (Mm^3)	12.33	11.26	9.83	7.86	5.45	4.23
Irrigation Demand (Mm^3)	0.74	1.1	1.68	2.03	0.84	
Evaporation Loss (Mm^3)	0.33	0.33	0.29	0.38	0.38	0.37
Available Water (Mm^3)	11.26	9.83	7.86	5.45	4.23	3.86
Available Water **(MLD)** after maintaining dry season requirements	**21.44**					

Table 3: Available water at +2.5 mPWD reservoir level after dredging

Reservoir Level, +2.5 mPWD	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**
Active Storage (Mm^3)	18.06	16.99	15.56	13.59	11.18	9.96
Irrigation Demand (Mm^3)	0.74	1.10	1.68	2.03	0.84	
Evaporation Loss (Mm^3)	0.33	0.33	0.29	0.38	0.38	0.37
Available Water (Mm^3)	16.99	15.56	13.59	11.18	9.96	9.59
Available Water (MLD) after maintaining dry season requirements	**53.26**					

4.2 Water Quality Analysis

The results of these water assessments revealed a concerning trend, with various water quality parameters consistently surpassing established Environmental Quality Standards. Notably, the prolonged elevation of salinity levels was observed, persistently exceeding prescribed standards over a significant timeframe mostly in the dry season when hardly any rainfall occurs. This manuscript provides an in-depth analysis of the water quality findings, elucidating the implications of these exceedances on the ecological integrity of Musapur Reservoir and the broader environmental context.

Figures 10, Figure 11, and Figure 12 illustrate observed salinity, electrical conductivity, and chloride ion concentration respectively. These quality data were acquired through multiparameter testing carried out at different locations on the site over the year 2023. Under reservoir conditions in the dry season, high values of salinity concentration, chloride ion concentration, and electrical conductivity were observed, attributed to minimal precipitation and nearly non-existent upstream flow. The highest values were recorded during the month of May. In contrast, with the regulator open under non-reservoir conditions, the lowest concentration values were identified. Throughout the year and at various locations within the Musapur Reservoir, Dissolved Oxygen (DO) and pH values were within the normal range as per the ECR (2023) guidelines (Figure 13 and Figure 14). However, in some instances, the pH of water exceeded the Environmental Quality Standard (EQS) which is probably attributed to measurement error. DO of water was found less than the acceptable minimum level in some locations during the wet season which is probably attributed to the flushing of pollutants from the upstream catchments.

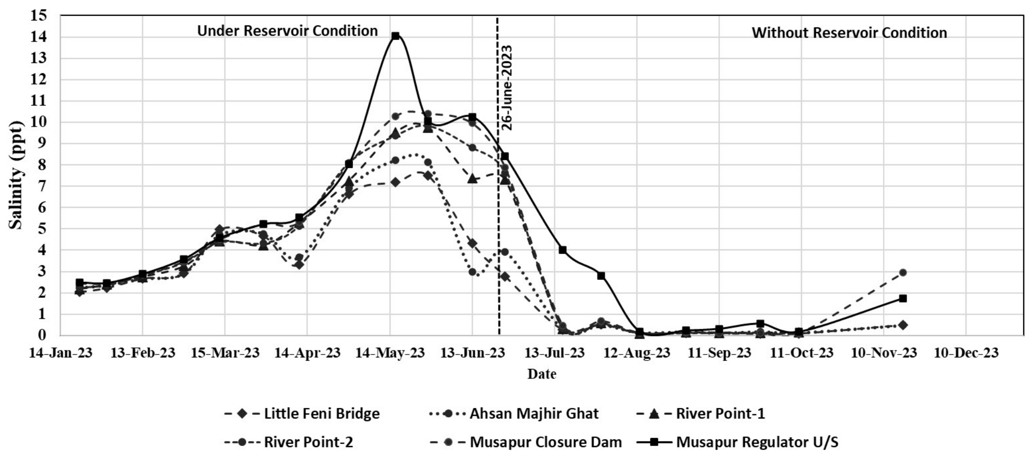

Figure 10: Salinity concentration at different places of Musapur reservoir

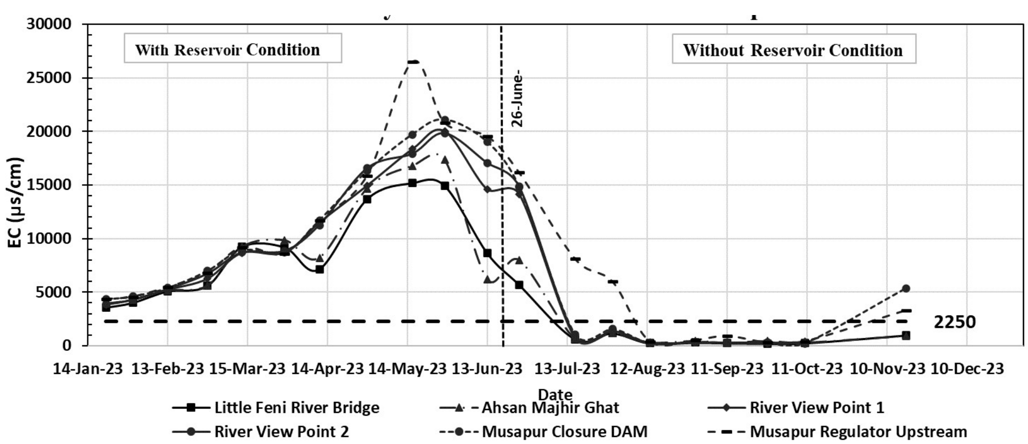

Figure 11: Electrical conductivity at different places of Musapur reservoir

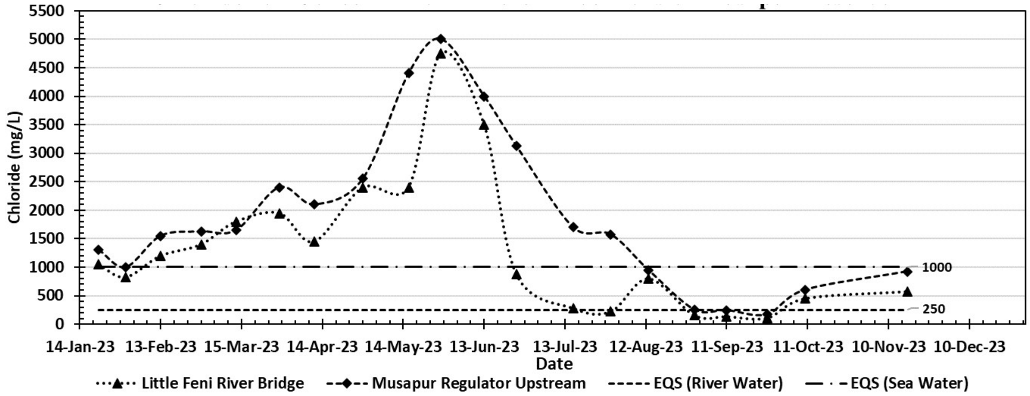

Figure 12: Chloride ion concentration at different places of Musapur reservoir

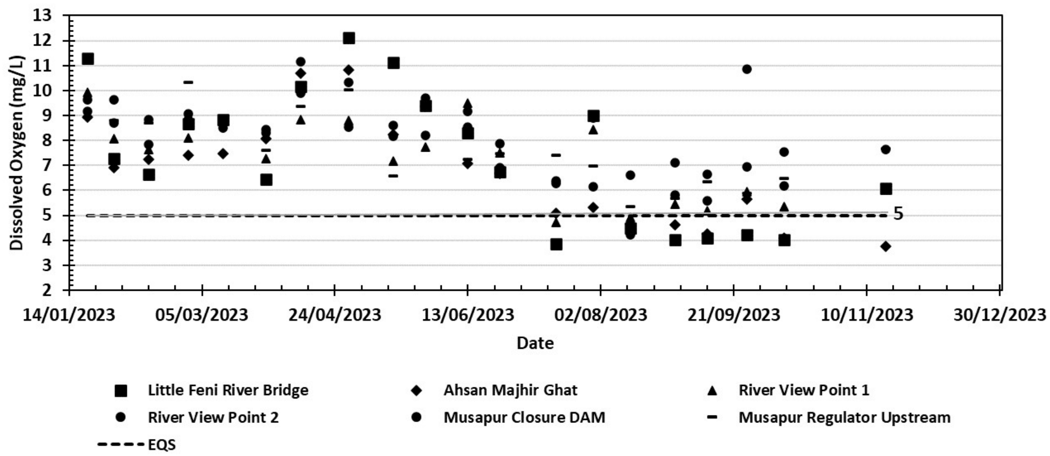

Figure 13: Dissolved Oxygen at different places of Musapur reservoir

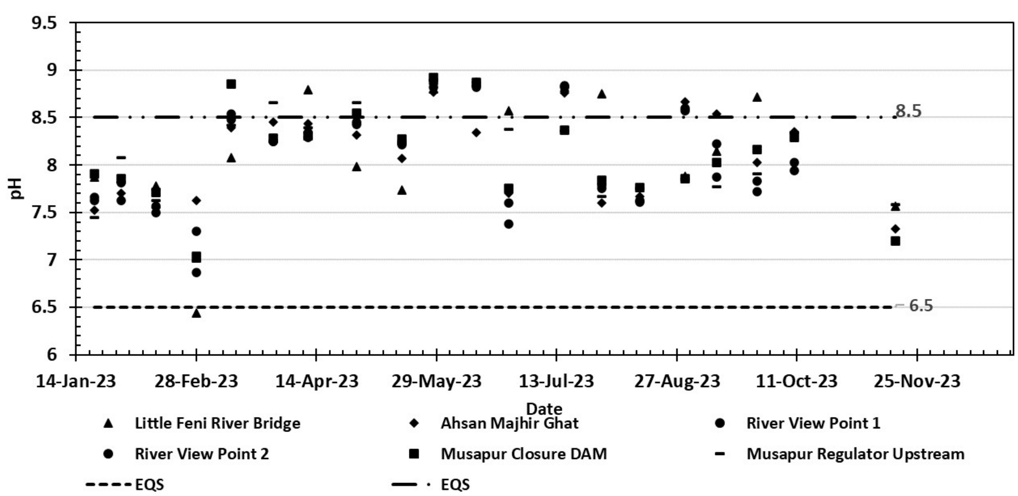

Figure 14: pH at different places of Musapur reservoir

As depicted in Figure 15, the Total Dissolved Solids (TDS) values surpassed the Environmental Quality Standard (EQS) limit stipulated by ECR 2023 during the dry season. However, during the wet season, TDS concentrations remained within the specified limit. Turbidity values adhered to the limit in the dry season but exceeded during the monsoon, attributed to sediment carried by flowing water from upstream. Total Coliform levels remained below permissible limits, except for a few times in the wet season. Ammonium-Nitrogen concentration consistently registered high values throughout the year. Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) values exhibited fluctuating patterns, predominantly on the higher side. Furthermore, heavy metals, including Lead, Cadmium, and Chromium, were identified (above the exceeding limit) in the Musapur reservoir during the dry season (Table 4). Upon comprehensive analysis of all water quality parameters, it is evident that most of the water quality parameters of Musapur reservoir surpass the EQS limits established by ECR 2023. Other than agricultural use, to render the reservoir water suitable for local consumption or industrial applications, appropriate treatment measures are imperative.

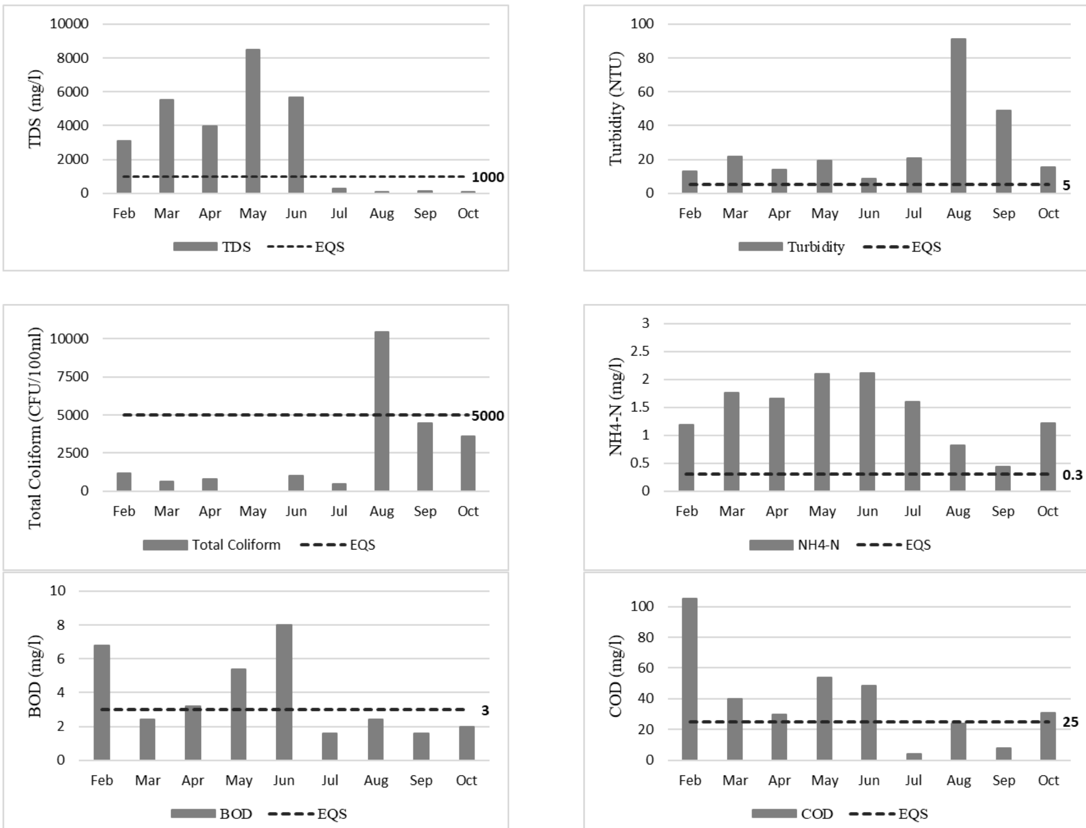

Figure 15: Water quality results of different parameters in Musapur reservoir

Table 4: Concentration of heavy metals in Musapur reservoir

Heavy Metal	**Concentration (mg/l) at Musapur Reservoir, Little Feni River**								
	Feb	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**
Lead (Pb)	0.031	0.04	0.058	0.08	0.06	Not Found	Not Found	Not Found	Not Found
Cadmium (Cd)	0.04	0.04	0.06	0.07	0.05	0.01	Not Found	Not Found	Not Found
Chromium (Cr)	0.003	Not Found	Not Found	Not Found	Not Found	0.01	Not Found	Not Found	Not Found
Zinc (Zn)	0.05	0.41	0.09	0.06	0.084	0.13	0.02	0.07	Not Found
Mercury (Hg)	Not Found	Not Found	Not Found	Not Found	Not Found	Not Found	0.0002	Not Found	0.0005

5. CONCLUSIONS

The construction of the Musapur reservoir was guided by a specific objective of limiting saline water intrusion and enabling the conservation and storage of freshwater in the Little Feni River during the dry season to facilitate irrigation and drinking water supply. This study offers a thorough examination of water availability and quality analyses in the Musapur Reservoir. The current active storage volume of the reservoir, standing at 7.4 Mm^3, falls short of meeting the local irrigation demand. However, with strategic gate operation adjustments, an additional 21.44 MLD of water could be stored, effectively addressing the water demand during the dry season. A more substantial solution involves increasing the reservoir's capacity by implementing a 1.5m dredging of the reservoir. This measure would result in an impressive additional storage capacity of approximately 53.26 MLD.

Overall, the study suggests potential enhancement of the Musapur reservoir storage during the dry season through optimized regulator operations and capital dredging, which can offer surface water based drinking water supply after treatment and growth in local agriculture. Nonetheless, a concerning aspect arises regarding flood risk in the upstream part of the catchment during the wet season. To mitigate this risk, monitoring and proper operation of the Musapur regulator gates need to be ensured. Besides, in the dry season, there is a concern regarding the reservoir water quality particularly salinity and heavy metals. A thorough investigation in tracing the origin of these pollutants is recommended to ensure acceptable water quality in the reservoir.

REFERENCES

Asadieh, B., Krakauer, N. Y., & Fekete, B. M. (2016). Historical trends in mean and extreme runoff and streamflow based on observations and climate models. Water, 8(5), 189.

Chowdhury, N. T. (2010). Water management in Bangladesh: an analytical review. Water policy, 12(1), 32-51.

Ehsani, N., Vörösmarty, C. J., Fekete, B. M., & Stakhiv, E. Z. (2017). Reservoir operations under climate change: Storage capacity options to mitigate risk. Journal of Hydrology, 555, 435-446

Fox, D. G. (1981). Judging air quality model performance. Bulletin of the American Meteorological Society,62(5),599-609.DOI:https://doi.org/10.1175/1520-0477(1981)062<0599:JAQMP>2.0.CO;2

Liu, Y., Xie, X., Tursun, A., Wang, Y., Jiang, F., & Zheng, B. (2023). Surface water expansion due to increasing water demand on the Loess Plateau. Journal of Hydrology: Regional Studies, 49, 101485.

Moshfika, M., & Rahman, A. (2018). Hydrological and hydraulic consideration for design and construction of closure dam on Little Feni River. In Civil and Water Resources Engineering Conference. ISBN: 978-1-925488- 52-4

Moriasi, D. N., Arnold, J. G., Van Liew, M. W., Bingner, R. L., Harmel, R. D., & Veith, T. L. (2007). Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. Transactions of the ASABE, 50(3), 885-900.

Nash, J. E., & Sutcliffe, J. V. (1970). River flow forecasting through conceptual models part I - A discussion of principles. Journal of Hydrology, 10(3), 282-290. DOI: https://doi.org/10.1016/0022-1694(70)90255-6

Neha, M. I., Rahman, M. S., & Islam, M. F (2023). Application of Remote Sensing to Investigate the Impact of Musapur Reservoir on the Morphology of Little Feni River and Local Agricultural Production. International Conference on Planning, Architecture and Civil Engineering, Rajshahi University of Engineering & Technology (RUET), Rajshahi, Bangladesh, 12-14 October, 2023, pp 1270 – 1275

Votruba, L., & Broža, V. (1989). Water management in reservoirs. Elsevier.