IMPACT OF KAPTAI RESERVOIR DISCHARGE ON FRESH WATER FLOW AVAILABILITY IN HALDA RIVER

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ABSTRACT

The unique ecosystem of Halda river has been struggling for years due to anthropogenic influences like water withdrawals by constructing dams, weirs, regulators etc. Aid to that freshwater flow availability in the Halda river particularly during the dry season is also crucial for the sustainability of its biodiversity. Over the years, freshwater flow from the upstream of the river catchment has decreased significantly during the dry season and tidal flow intrusion from the Karnafuly river became the main source of fresh water in the lower 40 km reaches of the Halda river. This study was devised to assess how freshwater discharge from the Kaptai reservoir during the dry season influences significantly, the availability of freshwater in the Halda river and thereby its unique ecosystem.

A multi-disciplinary research method has been adopted including statistical analysis and mathematical modelling. Trend analysis of the annual peak discharge at different locations of Halda river revealed that over the years flow at the upper reaches of the Halda river has significantly decreased. However, this does not impact flow availability in the lower reaches of the river due to tidal flow from karnafuli river. Regression analysis of the historical discharge data from the Kaptai reservoir and salinity data from Mohara point of Halda river showed a moderate level of correlation which is statistically significant. To confirm this interdependency, mathematical model simulations were conducted. 1-D hydrodynamic and salinity model of the Karnafuli-Halda river system available at IWM was updated using latest data. The model was calibrated with measured discharge data and salinity data in selected points of the Halda and Karnafuly river systems. Several scenarios were simulated with variable freshwater discharge from the Kaptai reservoir as one of the upstream boundaries of the model.

Analysis of the model simulated data showed that maintaining sufficient discharge from the Kaptai reservoir is the main contributing factor towards ensuring sufficient freshwater flow in the Halda river during the dry season. At least 200 m^3/sec freshwater discharge from the Kaptai reservoir throughout the dry season would ensure salinity level in the Halda river within acceptable limit. The unique ecosystem of the Halda river will be exposed to the threat of salinity intrusion if this amount of freshwater discharge from the Kaptai reservoir is not maintained. Moreover, the state of water supply in Chattogram city will also become unsustainable.

Keywords: *Halda, Kaptai reservoir, Water Availability, Salinity, Ecosystem Preservation*

1. INTRODUCTION

The landscape and livelihood of people over centuries have become fundamentally shaped by dams and reservoirs (Collier et al., 1996). Over 50000 large dams built over the world (Berga et al., 2006) have played a crucial role in the overall development of the world economy by greatly assisting the growth of large cities, accelerating the development of agriculture, electrifying fast-developing industrial areas, and boosting urban economies (Richter et al., 2010). However, these dams often significantly alter the flow regime and morphology at downstream of the rivers and create a significant negative impact on the riverine ecosystem (Wolf et al., 2022; Zahar et al., 2008; Marcinkowski and Grygoruk, 2017). People who depend on rivers and live downstream of dams frequently face major changes to their way of life, including a loss of food security and other effects on their physical, cultural, and spiritual well-being. River flow disruptions and fragmentations by large dams often negatively impact downstream fish habitats, their population dynamics and demographic factors (like survival, growth and reproduction) as well as other riverine species (Arantes et al., 2019; Richter et al., 2010). In order to satisfy the increasing needs of the surrounding people, human interventions and infrastructure have increased the river ecosystem's influence in recent years (Ali et al., 2019).

The story also holds true for Halda river, one of Bangladesh's most significant natural carp spawning sites and has long been the main supply of naturally produced carp fry for pond culture throughout much of the nation (Tsai et al., 1981; Kibria et al., 2009; Saha et al., 2019; Azadi and Alam, 2013). Over the years a number of human activities like construction of dams, changing river alignment, pollution etc. have negatively impacted the environment of the Halda River. Between 1945 and 2008, the amount of spawning has consistently dropped, from 4000 kg of fry to roughly 70 kg (Kibria et al., 2009). It has long been known that the principal carp spawning grounds in the Halda River are found at several oxbow bends along the river. However, the straightening of the bends decreased the favourable places which has been considered as one of the main reasons for the reduction of spawning (Tsai et al., 1981; Kibria et al., 2009).

Along with the extinction of carp fisheries habitats, obstructing natural river flow by building rubber dams on the upstream of Halda river and sluice gates on the important tributaries of Halda river are governing factors for negatively impacting the riverine ecosystem in the area (Azadi and Alam, 2013). Pollution from anthropogenic activities like municipal wastewater discharge, industrial effluent discharge, and agricultural runoff is deteriorating the river water quality significantly, thereby intensifying the pressure on Halda river dependent ecosystem (Akter and Ali, 2012). This river receives the discharge of contaminants from tanneries and factories through about thirty-six channels (Kabir et al., 2013). The physiology, growth, and distribution of fish as well as other life in this special natural carp spawning ground in Bangladesh may be greatly impacted by this. Besides, the water in the Halda River is becoming dangerous to drink and use for household purposes, as evidenced by the high level of physicochemical pollution, the occurrence of pathogenic bacteria, and high microbial load (Rahman et al., 2022).

An increase in river water salinity is another driving factor that threatens the fisheries habitat in Halda river as well as the domestic water supply in Chittagong city (Akter and Ali, 2012). Salinity in the Halda river increases in dry season during the high tide though the salinity level plummets to normal during the wet season (Hasan et al., 2023). Since 1990's, there have been several events when chloride concentration at Mohora point of Halda river increased to more than 5000 mg/l (NJS, 2000). There are differing opinions in the scientific community regarding the governing reason behind the increase in Halda river salinity. Water blockage in the upstream as well as water abstraction by CWASA for public water supply in Chittagong city are being thought of as the governing reason for increase in Halda river salinity (BUET, BAU & CU, 2016). However, according to Ahmad (2009), another factor contributing to the Halda River basin's rising salinity is the insufficient freshwater flow in the Karnafuly river during the dry season resulting from flow regulation at the Kaptai Dam. Indeed, the Karnafuly and Halda rivers flow to the Bay of Bengal as one integrated system. During the dry season, tidal flow from Karnafuly to Halda is primarily responsible for the salinity issues in the Halda river (Akter and Ali, 2012). Even though a lot of studies have been conducted on the Halda river, its water resources and ecosystem, none of those have quantified the impact of Karnafuli river discharge governed by Kaptai dam flow regulation on the water resources of Halda river. Therefore, the present study was initiated to investigate the influence of freshwater discharge from the Kaptai reservoir to the Karnafuli river during the dry season on the salinity level and freshwater availability in the Halda river and its unique ecosystem.

2. STUDY AREA

The study area is the Karnafuli-Halda river system catchment within Bangladesh covering more than 10,000 km^2 spanning between longitudes 91°15' E to 92°40' E and latitudes 21°55' N to 23°44' N including areas of Rangamati, Khagrachari and Parts of Chattogram district (Fatikchari, Hathajari, Rangunia, Raozan, Boalkhali upazilla's and Chattogram city corporation areas). The topography of this area contains predominantly hilly terrain, foothills and a long strip of lowland coastal plains along the Bay of Bengal.

Karnafuli river originates from Lushai Hills in Mizoram State, India and flows through Rangamati and Chattogram district in Bangladesh and finally falls into the Bay of Bengal near Patenga, Chattogram. A hydroelectric power plant with an earthen dam was built in Kaptai, Rangamati during 1960s. The river plays a vital role in booming Bangladesh's economy by hosting the Chattogram seaport in the estuary. It is one of the major sources of freshwater in the region for drinking water supply, industrial supply, and irrigation.

Halda river originates from Halda chara in Ramgarh Upazila under Khagrachari District, Bangladesh. With a length of about 88 km, it flows through Fatikchhari Upazila, Hathazari Upazila, Raozan Upazila and Chittagong Chandgaon Thana before falling into the Karnafuli River at about 1 km upstream of the Kalurghat bridge. The river flows in a zigzag pattern with a width ranging from 75 meters on the upstream side to nearly 210 meters near the confluence with the Karnafuli river (Tsai et al., 1981). A reach of about 40 km from Nazirhat to Halda-Karnafuli confluence is tide affected. The tidal range varies from 2m (during neap tide) to 4m (during spring tide) in the tidal part of the river (BUET, BAU and CU, 2016). Like the Karnafuli, river, this is also a major source of water supply to the Chattogram city and a number of irrigation projects are dependent on the flow of this river.

Over the years a number of hydraulic structures like rubber dams, weirs, sluice gates, navigation locks etc. have been constructed on the Halda river and its major tributaries (Figure 1). The three rubber dams and weirs were constructed to facilitate irrigation in the winter season (December to March). In addition, 12 sluice gates and 4 navigation locks have been constructed on the mouth of different canals falling into the Halda river. The location of these sluice gates is within 20 km upstream of the Halda-Karnafuli confluence. These sluice gates were constructed to abstract water for irrigation during high tide, however, at present most of them are inactive.

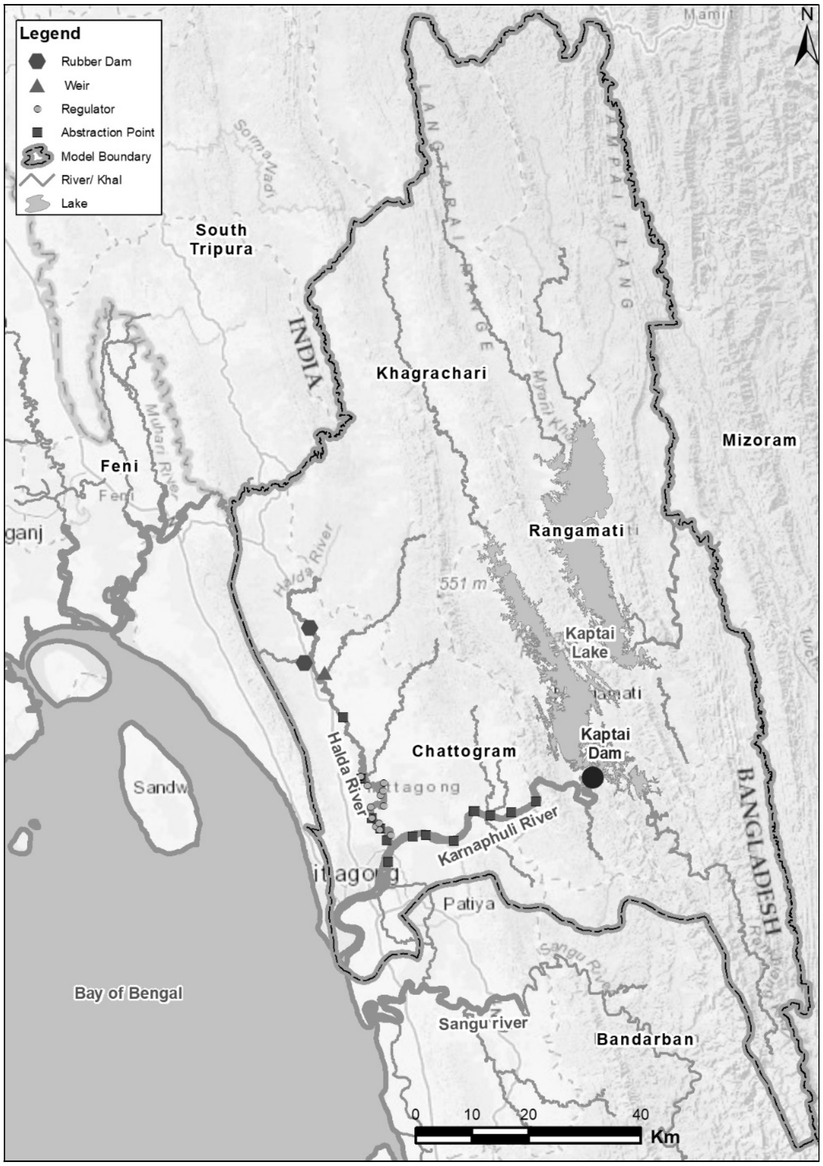

Figure 1: Study area map

3. METHODOLOGY

A multi-disciplinary research methodology was adopted in this study which includes different statistical analyses (like trend analysis, linear regression), hydrodynamic modelling and salinity intrusion modelling. All data required to apply these methods were collected from secondary sources.

3.1 Data Collection

Historical data on regional meteorology, river water level and discharge were collected from measuring stations of Bangladesh Water Development Board (BWDB), Bangladesh Inland Water Transport Authority (BIWTA) and Chattogram Port Authority (CPA) as shown in
Figure **2**. River cross-section data was available at the Institute of Water Modelling (IWM) from the 2019 survey. Observed discharge data from Kaptai Hydro-electric Power Plant (HEPP) were collected. Observed salinity and water level data (until 2019) at Mohara point of Halda river were collected from Chattogram Water Supply & Sewerage Authority (CWASA). Data regarding existing

water abstraction by different users like water supply, irrigation, industrial etc. were taken from a previous study (IWM, 2016) and further updated by consultation with the BWDB and CWASA officials.

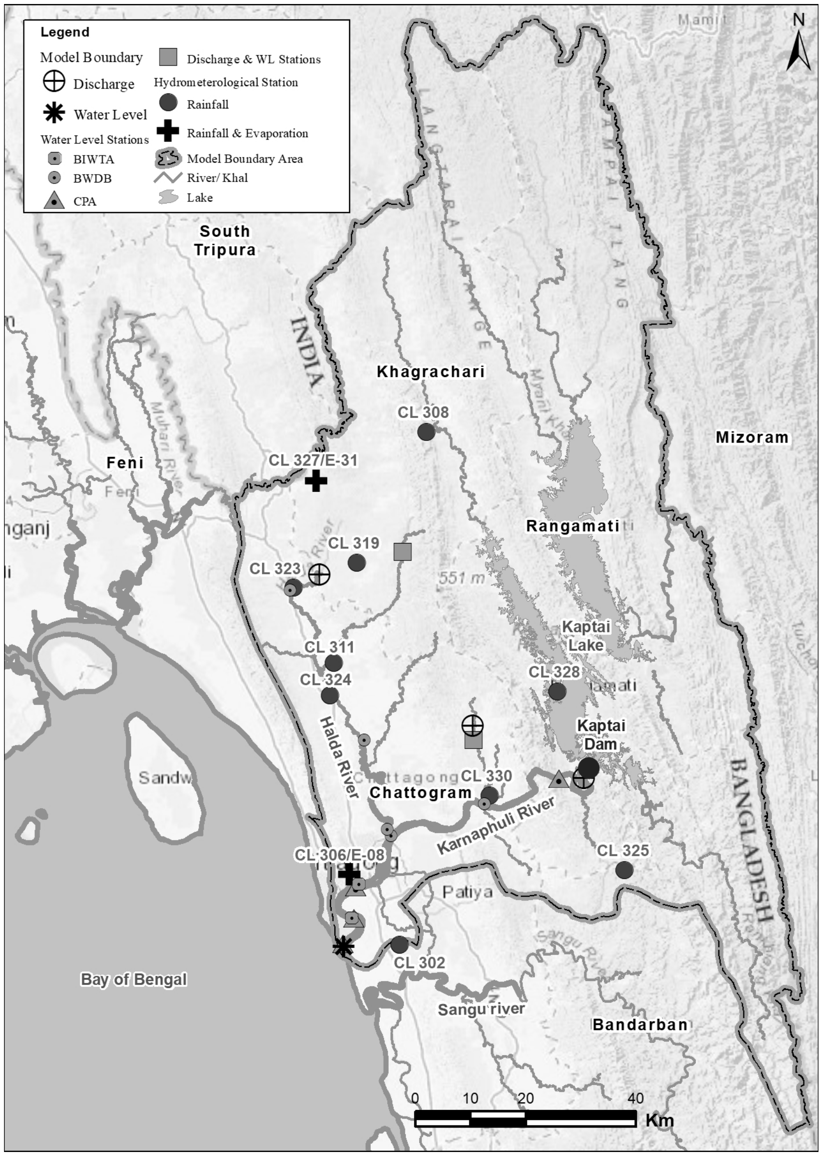

Figure 2: Hydrometric and meteorologic stations in the study area

3.2 Trend Analysis

Trend analysis of the annual peak discharge data (1965-2020) at Panchapukuria station was conducted by measuring the slope of the linear best-fit regression line. This station is located about 48 km upstream of the Halda river confluence with Karnafuli river. A similar exercise was done using model simulated discharge data at Mohara point of Halda river located just about 1.3 km upstream of the Halda-Karnafuli confluence. The statistical significance of the identified trends was tested using Mann-Kendall test (Mann, 1945). Numerous statistical tests are commonly used to determine the significance of a trend, including the t-test, Mann-Kendall test, and bootstrap-based slope tests (Neha et al., 2023). A t-test's power can match or surpass that of a rank-based test, such as the Mann-Kendall test, for data that is normally distributed; but, when dealing with non-normal data, a t-test's accuracy is significantly lower than that of the Mann-Kendall test (Yue et al., 2004). While computing the skewness of the discharge data at Panchapukuria, non-linearity was observed. Therefore, the Mann-Kendall test was preferred for analysing the significance of the linear trend analysis.

3.3 Regression Analysis

Regression analysis was done using observed flow release data from Kaptai dam and observed salinity data at Mohara point of Halda river to gather an understanding if there is any relation between these two data sets. Regression analysis is a widely acknowledged statistical method for examining correlations between variables (Sykes, 1993). While conducting the analysis, flow discharge data at Kaptai dam was taken as the predictor variable and observed salinity data at Mohara point of Halda river was taken as the response variable. The goodness-of-fit of the regression was tested with co-efficient of determination R2 which is the most informative metric to evaluate a regression mode (Chicco et al., 2021). The statistical significance of the regression was tested using the F-test at a 5% significance level.

3.4 Application Hydrodynamic Model and Salinity Model

A 1-D hydrodynamic model and salinity model of the eastern hilly region of Bangladesh available at IWM were updated for this study. The model was updated with relevant data on the Karnafuli-Halda river system until August 2020. The hydrodynamic model of the river system was calibrated by comparing simulated discharge with measured discharge for the dry season of 2013-2014 at Kalurghat point of Karnafuli river and Modunaghat point of Halda river (Figure 3 and Figure 4). The salinity model of the river system was calibrated by comparing simulated salinity and observed salinity levels at Kalurghat point of Karnafuli river (Figure 5). The dry season of 2013-2014 was selected for the model calibration period as an exceptionally high salinity was observed in the river system during that time. From the comparison between observed and model simulated discharge data (Figure 3 to Figure 5), a reasonable calibration of both the hydrodynamic model and salinity model is evident.

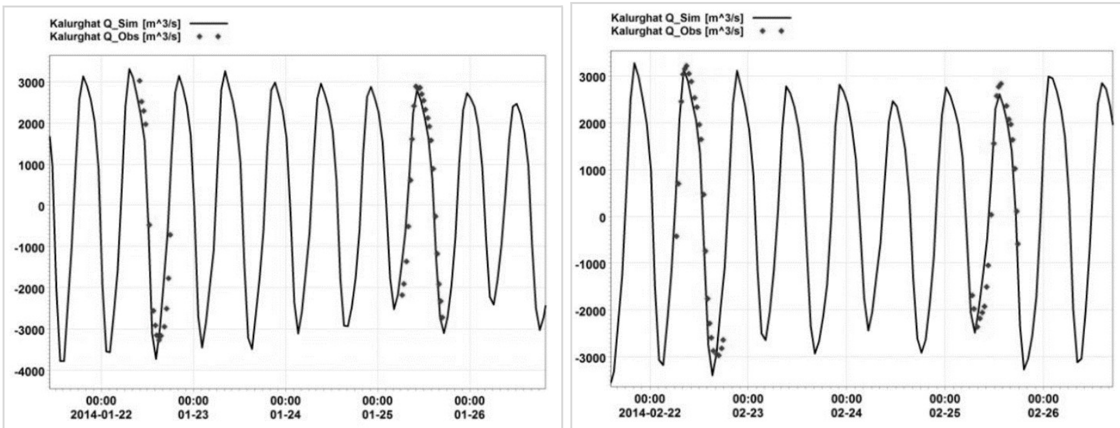

Figure 3: Model calibration at Kalurghat point of Karnafuli River

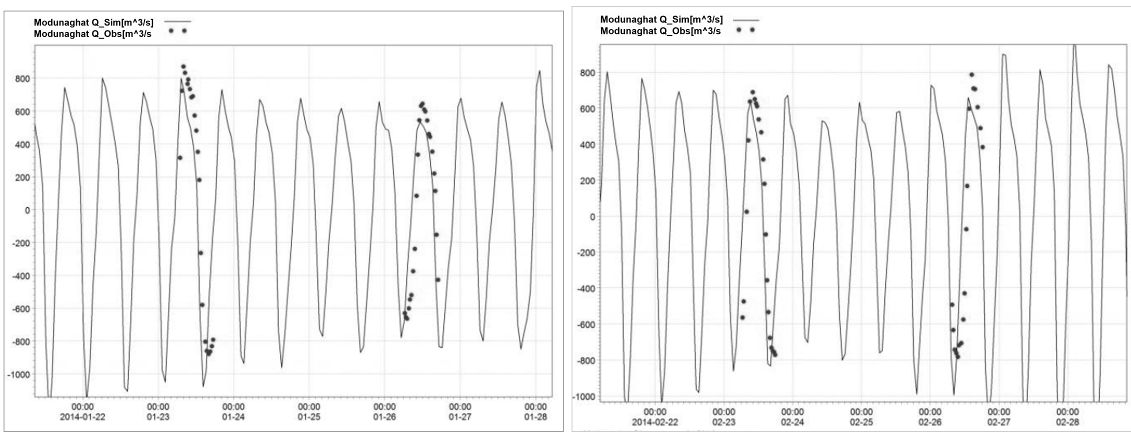

Figure 4: Model calibration at Modunaghat point of Halda River

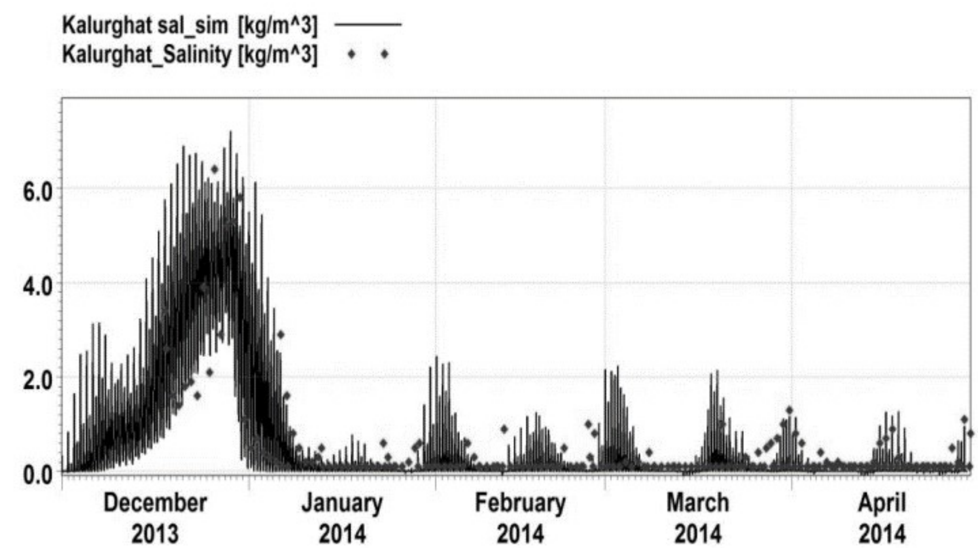

Figure 5: Salinity Model calibration at Kalurghat Point of Karnafuli River

The updated hydrodynamic model and salinity model of the Karnafuli-Halda river system were applied to generate long-term discharge data at different points of the Halda river for conducting trend analysis. Besides, the salinity level in the river system with respect to varying levels of freshwater release from the Kaptai dam was simulated to analyse it’s impact on the salinity level of Halda river.

4. RESULTS AND DICUSSION

4.1 Trends in Halda River Flow

Trend analysis of the observed peak discharge at Panchapukuria station shows a decreasing trend over the years (
Figure 6). The Probability value of the linear trend is less than 0.05 derived from the Mann-Kendall test which indicates that the decreasing trend in river flow is statistically significant. In the contrary, trend analysis of the model simulated discharge data at Mohara point shows a slightly increasing trend over the years (
Figure 7). However, the probability value of the trend is higher than the significance level of 5% which indicates the increasing trend is not statistically significant. Still, river discharge at Mohara point is consistently much higher than river discharge at Panchpukuria.

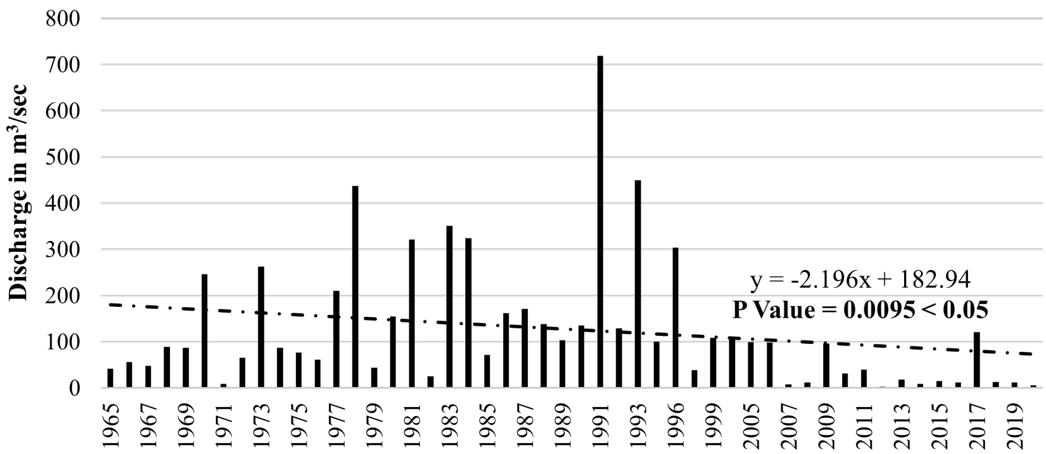

Figure 6: Peak flow trend during Nov to May at Panchapukuria point of Halda river

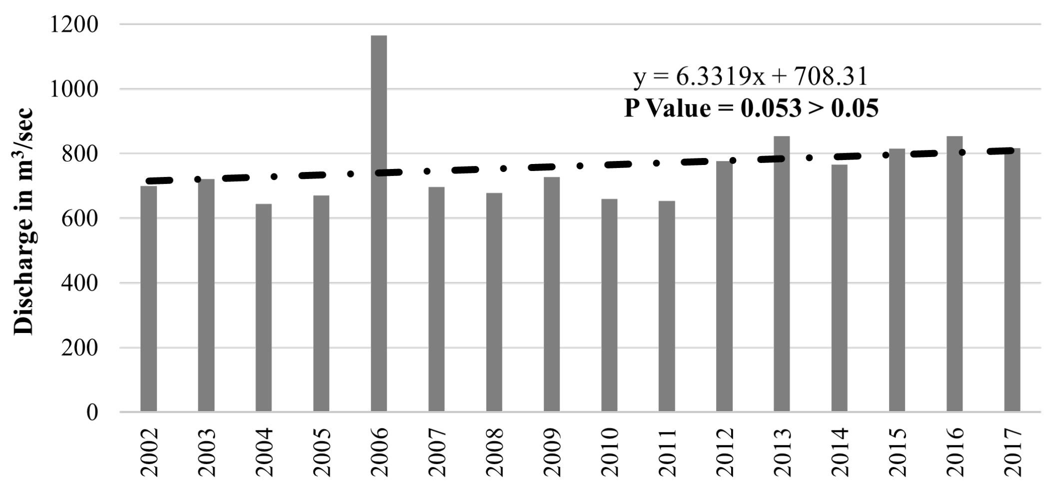

Figure 7: Peak Flow during Nov to May at Mohara point of Halda River

This implies that dry season flow at the upper 40 km reach of the Halda river (from its origin to Panchapukuria) has been decreasing over the years which obviously signifies the impacts of upstream flow withdrawal by the irrigation projects. However, those upstream withdrawals are not impacting the flow availability in the downstream part of the Halda river which seems rational given that the lower 40 km reach of the Halda river is subjected to tidal flow intrusion from the Karanafuli river (Tsai et al.,1981 and BUET, BAU and CU, 2016).

4.2 Relation Between Kaptai Dam Discharge and Halda River Salinity

The occurrence of high to very high salinity in the lower reaches of Halda river has direct relevance to the freshwater discharge from the Kaptai dam. This phenomenon was first reported in a study conducted by JICA in 2000 and later Ahmad (2009) argued about the same. In the dry season of 1995, chloride concentration at Mohara exceeded 6000 mg/L when the freshwater release from the Kaptai dam was very low (NJS CONSULTANTS CO. LTD, 2000). A similar phenomenon occurred in January-February of 2007 when only one unit of the Kaptai dam was in operation and the freshwater release was as low as 70 m^3/s, which remarkably increased the salinity level at Mohara and Modunaghat points even during the low tide. The same situation occurred in December 2013 when freshwater release from Kaptai HEPP was as low as 50 m^3/s (IWM, 2016).

The strong relationship between low freshwater release from Kaptai dam and high salinity in the Halda river is also evident from
Figure **8** which plots the monthly average discharge from Kaptai dam during the years 2012-2018 and recorded monthly maximum chloride concentration at Mohara point at that time. There have been 10 months over this period when the average freshwater discharge from Kaptai dam was less than 200 m^3/sec. During those months, chloride concentration at Mohara point increased more than 1000 mg/l and in some cases reached up to 5000 mg/l.

Regression analysis of the Kaptai dam discharge data and salinity level in the Halda river also proves a strong relationship between them. A power trend was observed between the variables while conducting the regression analysis. Coefficient of determination (R^2) for the power regression was computed as 0.69 which again stipulates that a moderately strong relationship with salinity in Halda river can be explained by the freshwater discharge from the Kaptai dam. The probability value of the power regression was computed much less than 0.05. It confirmed that the power regression is statistically significant at a 5% significance level.

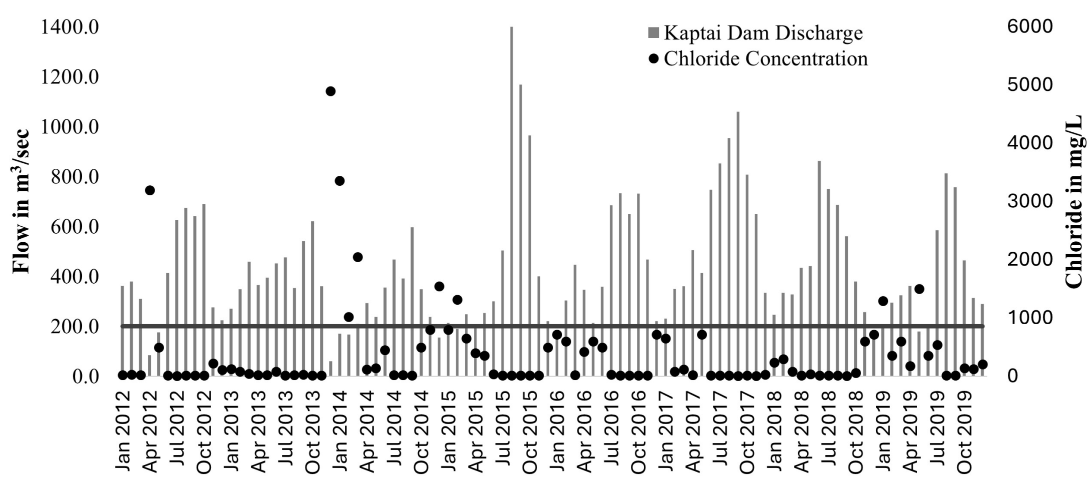

Figure 8: Monthly average discharge from Kaptai dam during the period 2012-2018 and maximum Chloride Concentration observed at Mohara point of Halda River

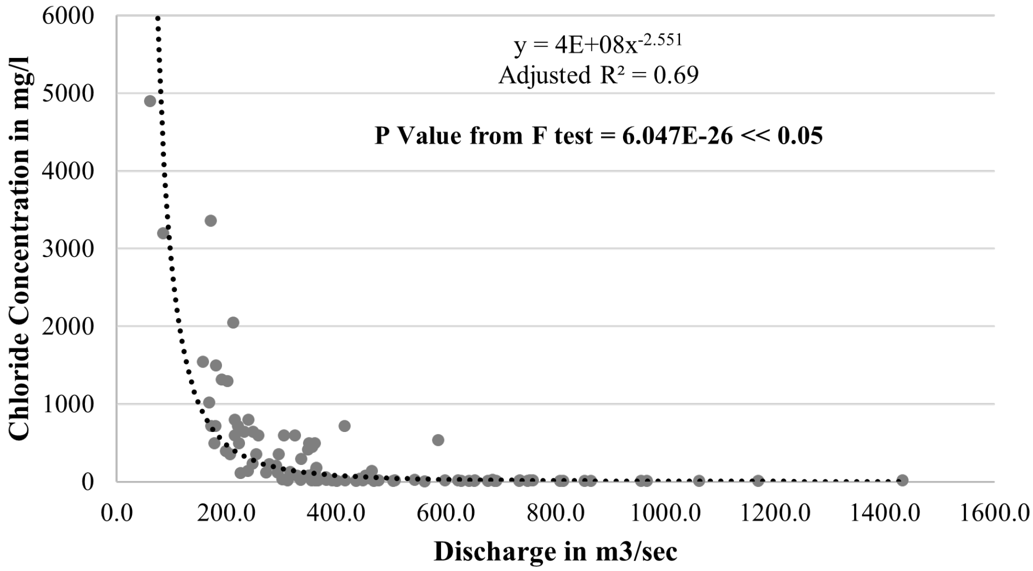

Figure 9: Regression between Kaptai dam discharge and chloride concentration at Mohara point of Halda River

From the simulated salinity model, it was found that with actual discharge from the Kaptai dam, the salinity level at the Mohara point of Halda river in December 2013 went up to 10 ppt or 5500 mg/l of chloride (
Figure **10**). This complies with the observed maximum chloride concentration at Mohara point during that period presented in
Figure **8**. It was found from the model simulation that the salinity level at Mohara point in December 2013 would have remained below 1 ppt with a minimum discharge of 200 m^3/sec from the Kaptai dam (
Figure **11**).

It signifies that maintaining a considerable amount (at least 200 m^3/sec) of freshwater discharge from Kaptai dam during the dry season is highly important to keep salinity in the Halda river within an acceptable limit (less than 1 ppt). It is not only necessary for ensuring favourable conditions for the spawning of carps and the protection of biodiversity in the Halda river but also to furnish raw water of suitable quality to the water treatment plants dependent on Halda river which serves a large part of Chittagong city with potable water supply.

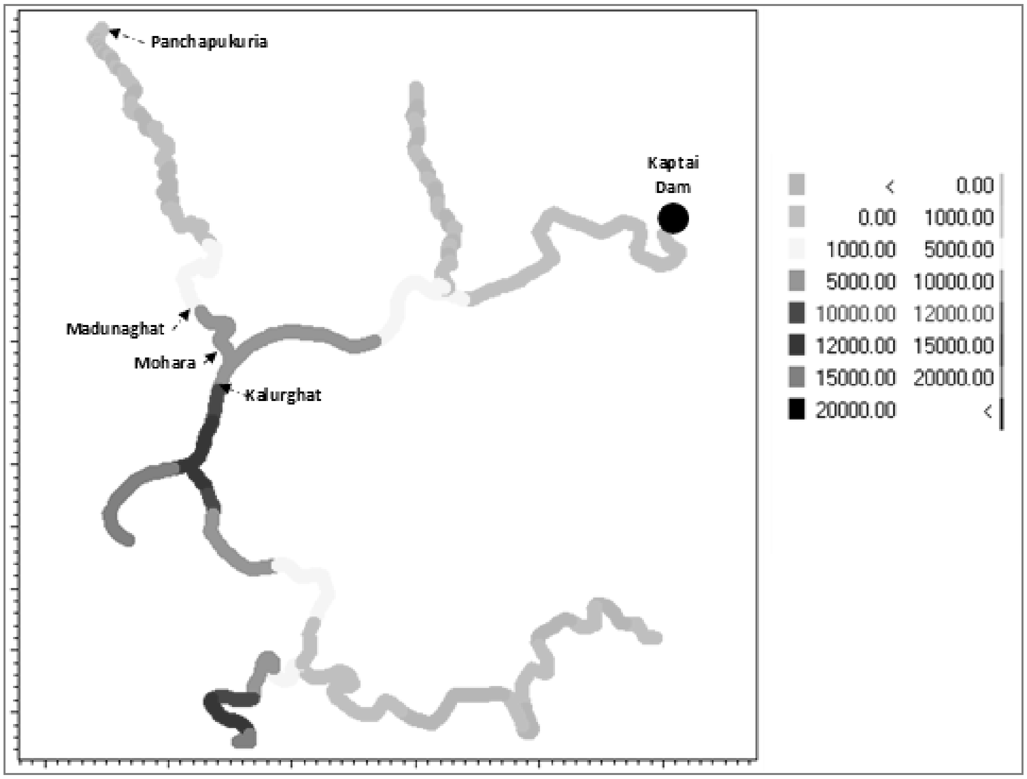

Figure 10: Salinity level in Halda-Karnafuli river system in december 2013 with actual discharge from the Kaptai dam

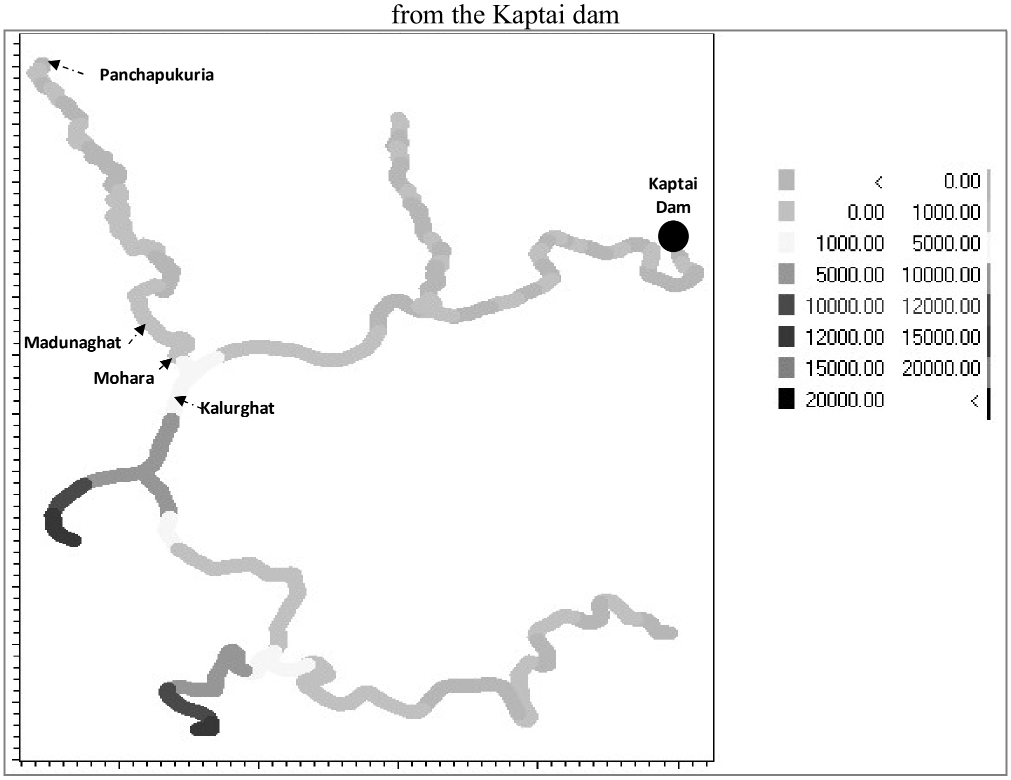

Figure 11: Salinity level in Halda-Karnafuli river system in december 2013 with minimum 200 m^3/sec discharge from the Kaptai dam

5. CONCLUSIONS

Altering river flows by constructing large dams can have a negative impact on fish habitats downstream, population dynamics, and demographic considerations. Over the years, the construction of dams and weirs at upstream of the Halda river has disrupted flows during the dry season which created a significant negative impact on its valuable fisheries resources and unique ecosystem. Besides, it is threatening the potable water supply for the inhabitants of Chittagong city. Nevertheless, this study has proved that anthropogenic activities in the catchment of the Halda river are not the sole reason for disrupting the unique ecosystem of the Halda river. Rather freshwater release from the Kaptai dam during the dry season plays a vital role in controlling salinity levels in the lower reaches of the Halda river, thereby securing the riverine ecosystem and public water supply.

The result of the study shows that the upper 40 km reach of the Halda River is facing a substantial declining trend in river discharge, which is indicative of a negative impact due to upstream withdrawals. That being said, this has an insignificant impact on the freshwater flow availability in the downstream reaches of the Halda river, where the Karanafuli River's tidal flow intrusion is quite important. High salinity in the Halda River and freshwater discharge from the Kaptai Dam have been found to be strongly correlated, with regression analysis supporting this finding. The Kaptai dam's low discharge during the dry season leads to high levels of chloride in the Halda river, which affects biodiversity and water quality.

The importance of releasing enough freshwater from the Kaptai Dam to maintain the salinity level in the Halda River within acceptable limit is further highlighted by model simulations. To keep the salinity of the Halda River below 1 ppt during the dry season, the Kaptai Dam must maintain a minimum discharge of 200 m^3/sec. This will ensure favourable environment for carp spawning in the Halda river and biodiversity preservation. In addition, it will guarantee the availability of raw water for the Halda River-dependent water treatment plants, which will secure a sustainable water supply in Chittagong city in the long term. Maintaining the natural balance, biodiversity, and water quality of the Halda River in the future essentially depends on the Kaptai Dam continuing to provide a minimum of 200 m^3/sec freshwater flow. Nevertheless, maintaining such an ideal flow from the Kaptai dam may not be possible all through the dry season in years subjected to draught considering the multipurpose use of the Kaptai reservoir. Therefore, a critical review of the existing operation rules of the Kaptai dam is necessary.

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