

**EFFECTS OF RELOCATION OF TANNERY INDUSTRIES FROM
HAZARIBAGH ON WATER QUALITY OF BURIGANGA RIVER**

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**Effects of Relocation of Tannery Industries from Hazaribagh on Water Quality
of Buriganga river**

by

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Md. Rashedul Islam

Dedicated to

My twin baby boys Reehan and Raahil who died in January,
2018 due to premature birth

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ABSTRACT

Dhaka city is situated on the bank of the river Buriganga, which at present is one of the most polluted rivers in Bangladesh. The river receives wastewater from numerous pollution sources along its way, which are discharged as industrial effluents, municipal sewage, household wastes, clinical wastes and oil. A large share of pollution load of the river Buriganga comes from the tannery industries in the Hazaribagh and Rayer Bazar area through Kamrangir Char khal and Rayer Bazar khal. In order to protect the river from pollution, government has already started the process to relocate the tannery industries from Hazaribagh to Savar. Out of 154 tanneries, 106 tanneries have moved to Savar from Hazaribagh till March 2018. The main focus of this research was to assess the possible impacts of the relocation of tannery industries on the water quality of Buriganga river through field measurement, laboratory analysis and modeling.

In this study, a portion of Buriganga river from Boshila Bridge to Postagola Bridge has been selected as the study reach to assess the existing water quality during the dry season of the year 2017 and 2018. Water samples were collected from nine monitoring locations along this reach during that period. Kamrangir Char khal and Rayer Bazar khal have been taken as point sources that contribute pollution loads towards the river mainly from the tannery industries. From the field measurements and laboratory analyses, some improvement in water quality of Buriganga river has been found in March 2018 compared to March 2017. Appreciable reduction in BOD, electrical conductivity, ammonia, nitrate and orthophosphate concentrations has been observed along the river in March 2018 (compared to March 2017). For example, COD values along the Buriganga river ranged from 65 to 140 mg/L during the dry season of 2017, while it ranged from 55 to 85 mg/ L during the dry season of 2018; Ammonia concentration in river water varied from 13.8 to 16.18 in March 2017, while it was found to vary from 10.8 to 13.25 in March 2018. This improvement in water quality could be attributed to the shifting of a large number of tannery industries from Hazaribagh during this period.

A one-dimensional quasi-steady state water quality model has been developed using the finite segment approach under the modeling framework of the Water Quality Analysis Simulation Program (WASP 7.3), developed by U.S. Environmental Protection Agency. The water quality model was calibrated and verified using the water quality and the hydrodynamic data of the river during the dry period of 2017 and 2018, respectively. The verified model with the pollutant loading condition of 2018 has been used to investigate the impacts of relocation of tannery industries on Buriganga river water quality by considering four load reduction scenarios in the model. According to the model prediction, the DO level of the Buriganga river may not improve significantly due to tannery relocation; this is due to the significant waste load that the river carries from upstream (i.e., upstream of tannery industries) locations. But considerable reduction of BOD, ammonia, nitrate and phosphate are expected as a result of the tannery relocation. It appears that reduction in waste load from other upstream locations would be needed in order to achieve substantial improvement in the water quality of the River.

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LIST OF ABBREVIATIONS

ASCE	American Society of Civil Engineers
BAT	Best Available Technology
BMD	Bangladesh Meteorological Department
BOD	Biochemical Oxygen Demand
BWDB	Bangladesh Water Development Board
CBOD	Carbonaceous Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
CSTR	Continuously Stirred Tank Reactor
DO	Dissolved Oxygen
DoE	Department of Environment
DWASA	Dhaka Water Supply & Sewerage Authority
EC	Electrical Conductivity
ECR	Environmental Conservation Rule
EU	European Union
GoB	Government of Bangladesh
GPS	Global Positioning System
HD	Hydro Dynamic
HEC-RAS	Hydraulic Engineering Centre-River Analysis System
HTRP	Hazaribagh Tannery Relocation Project
IFCDR	Institute of Flood Control & Drainage Research
IWM	Institute of Water Modeling
JICA	Japan International Cooperation Agency
NBOD	Nitrogenous Biochemical Oxygen Demand
SOD	Sediment Oxygen Demand
SQGQ	Sediment Quality Guideline Quotient
TIP	Total Inorganic Phosphorus
TKN	Total Kjeldal Nitrogen
TMDL	Total Maximum Daily Loads
TS	Total Solids
TSS	Total Suspended Solids
UBOD	Ultimate Carbonaceous Biochemical Oxygen Demand
US	United States
USEPA	United States Environmental Protection Agency
WASP	Water Quality Analysis Simulation Program
WTP	Willingness to Pay
WWTP	Waste Water Treatment Plan

CHAPTER ONE

INTRODUCTION

1.1 Background

Bangladesh is a low-lying riverine country located in South Asia. There are about seven hundred rivers and tributaries in this country. The Buriganga River having a length of around 17 km is located in the southern part of the north central region of Bangladesh, close to the confluence of the Padma (Ganges) and upper Meghna rivers. It is a tide-influenced river passing through west and south of Dhaka city. The average flow of the river varies between 140 cumec in dry season (November to May) and 700 cumec in wet season (June to October) (Rahman and Rana, 1996). The average depth and width of the river is 14 m and 265 m respectively (BBS, 2005). This river, however, is one of the most polluted rivers in Bangladesh. Most of the industries and factories of Dhaka are situated on the banks of the Buriganga or very close to the river system. Besides, substantial part of untreated urban sewage of the Dhaka city is also discharged into the Buriganga river. Only a small fraction of the total domestic and industrial wastewater being generated in the city is treated. Consequently, huge quantities of untreated wastes, both domestic and industrial, are released into the Buriganga (Kamal et al., 1999). The river is seriously polluted by discharge of industrial effluents into river water especially from the tanneries of the Hazaribagh, indiscriminate discharge of household, clinical, pathological waste, commercial wastes and discharge of spent fuel (Alam, 2003). The current state of the Buriganga was not a sudden development, but the result of more than two decades of encroachment and excessive pollution.

The largest portion of the pollution load into the river Burignaga appears to be from tannery industries that were concentrated mainly in the Hazaribagh and Rayerbazar area near south-western part of the Dhaka city. As the tanneries were located on the bank of the Buriganga, this river has been the disposal point of all liquid effluent all along from the beginning of the operation of these industries, where both liquid and solid wastes were produced. The river bed has therefore accumulated a huge deposition

of settled solid wastes. The aqueous environment of the river has been totally unsuitable for the survival of the aquatic animals for a long time.

There were 343 tannery industries situated in Hazaribagh on the bank of Buriganga River (Ahmed, 2005). Tanneries in the Hazaribagh area discharged some 21,600 cubic meters of liquid wastes everyday into the Buriganga River (Kamal et al., 1999). The minimum dissolved oxygen (DO), the prime indicator of water quality, have been found to be much less than the desirable level at many sections of the Buriganga river, particularly during the dry periods of the year (Moniruzzaman et al., 2009). It is obvious that in such low DO state, no aquatic life can survive and thus river reaches to a dying state (Rahman and Bakri, 2010)

Several regulatory measures and policies are being considered and implemented by the government to protect the river Buriganga from pollution. One of the most significant initiatives is relocating the tannery industries from Hazaribagh to the Savar Tannery Industrial Estate. Realizing the hazardous impact of tannery wastes on human and environment, the Government has been implementing a project “Hazaribagh Tannery Relocation Project (HTRP)” to shift Hazaribagh Tannery Complex to a new site in Savar. Although the whole relocation process of tannery industries is a long process, out of 154 tanneries that got plots in Savar Tannery Estate, 106 tanneries have already moved there from Hazaribagh up to March, 2018 and started the production of wet blue leather in Savar.

As wastewater from the tannery industries is of the major sources of Buriganga river water pollution, it is expected that with the relocation of the tannery industries the water quality of Buriganga river would improve to some extent. The main focus of this research is to assess the possible impacts of the relocation of tannery industries on the water quality of Buriganga river through field measurement, laboratory analysis and modelling approach.

1.2 Objectives

The overall objective of this study is to assess the water quality of Buriganga River, particularly focusing on the effect of tannery industry relocation. The study focuses on assessment of the present status of water quality of the Buriganga river and prediction of the impact of relocation of tanneries from Hazaribagh to Savar Industrial Estate on the water quality of the Buriganga river using a water quality model. Specific objectives of the study included:

- a) Assessment of the existing quality of water of the Buriganga, in terms of selected water quality parameters including pH, DO, BOD₅, COD, TS, TDS, TSS, NH₃-N, NO₃-N, Orthophosphate and phytoplankton chlorophyll-a concentration during dry season.
- b) Identification of the major sources of pollution and assessment of pollution loads to the Buriganga River.
- c) Calibration and validation of the water quality model, WASP (Water Quality Analysis Simulation Program) for application on the Buriganga River using primary field sampling data.
- d) Prediction of water quality of Buriganga River after the relocation of tannery industries by developing different scenarios.

The output of the study includes: (i) Spatial variation of water quality of Buriganga river during dry season, (ii) A calibrated and validated water quality model for application on the Buriganga river, (iii) Prediction of water quality of Buriganga river considering the present and future scenarios, including relocation of the tannery industries from Hazaribagh.

1.3 Scope and Methodology

In this study, certain portions of the Buriganga river from Bosila Bridge to Somshan Ghat near Postagola Bridge were selected as the study reach to assess the existing water quality. In fact, almost all major urban and industrial establishments are located within this reach of the river, and the water quality of the river is affected by the domestic and industrial effluents generated from these establishments. Water quality model development process requires considerable amount of field data, both temporal and spatial. In order to assess spatial variation of water quality, river water samples were collected from nine sampling locations of Buriganga River during the months of January, February and March of the year 2017 and February and March of the year 2018. These sampling locations are Bosila Bridge, West Hazaribagh, Hasan Nogar, Huzur Para, Nurbag, Showari Ghat, Sadar Ghat, Faridabad and Postagola Bridge. Again, direct measurements of wastewater discharges from major point sources (Rayer Bazar khal, Kamrangir Char khal) were also carried out during the sampling period. Samples for laboratory testing were collected at the time of discharge measurements. The wastewater discharge and concentrations of water quality parameters (from laboratory testing) have been used for estimating waste loads.

In-situ field measurements of dissolved oxygen (DO), pH, temperature and electric conductivity have been carried out at each sampling location. Chemical oxygen demand (COD), 5-day biochemical oxygen demand (BOD₅), ammonia, nitrate, orthophosphate, suspended solids and phytoplankton chlorophyll-a concentrations have been analyzed in the laboratory following Standard Methods.

A one-dimensional water quality model has been developed using the finite segment approach under the modeling framework of WASP7, developed by US Environmental Protection Agency (Wool et al., 2009). The water quality model has been calibrated and verified using the water quality and the hydrodynamic data of the Buriganga River during the study period.

Sensitivity of the model has been analyzed to determine the effects of different parameters such as dispersion coefficient, phytoplankton settling velocity, BOD decay rate, sediment oxygen demand and input loading on the concentration profile of the key water quality parameters. Different scenarios have been analyzed to predict the

impact of load reductions due to the relocation of the tannery industries on the river water quality.

Detailed delineation and methodologies of each item of works have been described in the respective chapters.

1.4 Organization of the Thesis

This thesis consists of six chapters. Apart from this chapter, the remainder of the thesis has been divided into five chapters.

Chapter 2 provides a brief review of relevant works on the water quality of the Buriganga River and an overview of water quality standards, theory of water quality modeling, kinetics of phytoplankton, phosphorous, nitrogen and dissolved oxygen.

Chapter 3 presents the methodology followed in this study, including selection of sampling locations and major point sources, in-situ water quality data collection and water sampling procedure, laboratory analysis of water samples collected from Buriganga River, and development and calibration of the water quality model.

Chapter 4 presents the characteristics of Buriganga River based water quality data generated in this study. It also presents the estimated waste load from major point sources, based on the measurement carried out in this study.

Chapter 5 presents the water quality model for the Buriganga River, including modeling approach, model setup and calibration, verification and sensitivity analysis. Analyses of different scenarios to predict the impact of relocation of tanneries have also been presented.

Chapter 6 presents the major conclusions from this study and the suggestions for the betterment of water quality model for Buriganga river and future research works in this area.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

The Buriganga river system is located in the southern part of the north central region of Bangladesh, passing through west and south of Dhaka, the capital of Bangladesh. The river receives wastewater from numerous pollution sources along its way, which are discharged as industrial effluents, municipal sewage, household wastes, clinical wastes and oils. The largest share of pollution load into the river Buriganga appears to come from about 200 tannery industries in the Hazaribagh and Rayer Bazar area; nearly 10,000 people rely directly on this industrial cluster for their source of income. Studies show that up to 15,000 cubic meters of liquid wastes go into the Buriganga each day from these industries (Faisal et al., 2001; SEHD, 1998; GOB, 1994). This Chapter presents a review of literature dealing with studies related to the Buriganga river. In addition, basic theory of water quality modelling has been elucidated here.

2.2 Previous Studies on the Buriganga River

JICA (1987) reported the data on water quality analysis for Hazaribagh (1983-85), Chandnightat (1983-85) and Farashganj (1985) on the Buriganga river. The BOD variation was 1-90 mg/L. However, the most frequent range of BOD variation was 3 to 5 mg/L. The DO variation was between 0 to 9 mg/L.

Mohammed (1988) reported a comparison of sampling data of the Buriganga river water near Chandnightat during 1968-80 period. It is apparent from the study that DO level has decreased considerably during 1968-80. While average DO during 1968 was 6.7 mg/L, it came down to 3.3 mg/L during 1980. The average BOD value increased almost fourfold during that period. Number of coliforms also increased considerably during the same period. In February 1987, Mohammed conducted a sampling procedure of the Buriganga river. Six different sampling stations were established along a 10 miles stretch of the river starting from 6 miles upstream of Pagla outfall up to 4 miles downstream. Six samples were taken from different depths at each sampling

station. It was assumed for the study that the flows, temperature, BOD loads and rate constants at each point remained constant with time. It was further assumed that the concentrations of BOD and DO were uniform over the cross section of any river station. Since, in most cases, there is daily variations in pollution loads, flows, temperature, oxygen produced by photosynthesis throughout 24 hours etc., the assumption of steady state condition introduces errors. Mohammed argued that for planning purposes, the simplified version of the DO sag curve determination was an acceptable assumption.

The DoE (1992) maintains three monitoring locations along the Buriganga from which samples are collected on an irregular basis. The choice of DoE sampling stations is based mainly on the location of different industrial setups along the river banks mainly to assess the impacts on water quality due to effluent discharges. According to the study, the major rivers in Bangladesh are in good condition and well within the proposed national standards (DoE, 1991) of relevant four parameters. Only the Balu river during the dry season and the Buriganga at the Hazaribagh location are unacceptable in terms of pollution according to the 1990 results. The Buriganga river is comparatively the major polluted river in Dhaka with Hazaribagh station being the most polluting station. The DoE found that the Dissolved Oxygen (DO) concentration at Hazaribagh falls below 2 mg/L in May. Whereas for fish, the DO should be at least around 4 mg/L. Total solids and Chloride were also very high there. The estimated discharge from Hazaribagh into the Buriganga is around 15000 kilograms of BOD per day (Browder, 1992). They mentioned that Hazaribagh main effluent drain discharges wastewater from tanneries which contains high levels of COD in the order of 1100 mg/L and Chromium at around 1.1.5 mg/L whereas suitable standard for industrial water is around 200 mg/L for COD and 0.5 mg/L for Chromium.

Browder (1992) carried out a comprehensive study regarding the status of pollution of the Buriganga. Two approaches were used by Browder to estimate the mass of pollutants generated and discharged to the outside environment: 'dry study' approach and 'wet study' approach. In the dry study approach, population zones were defined first. Then, using information about population under sewerage/unsewered system and the per capita contribution of BOD load, resulting BOD loadings from the zones to the environment were computed. The wet study involved actually measuring the flow and

concentration of various pollutants at the discharge point into receiving water bodies. Reasonable estimates were then made based upon the wet and dry study results. It is found that the dry study and wet study yielded approximately the same results. Browder found that domestic wastewater produces approximately 88% of Dhaka's BOD load while industrial sources account for the remaining 12%. He opined that those figures were consistent with other large South Asian cities which did not have a large industrial base such as Dhaka. The total amount of BOD discharged in Dhaka was estimated by Browder as 182 tons per day. Of that amount, approximately 55 tons were being treated at the Sewage Treatment Plant which used to lower the BOD load to approximately 5 tons per day. The remaining 127 tons per day of BOD was being discharged through the storm water conveyance system to receiving water bodies. Browder then estimated that approximately 65 tons of BOD per day, representing about half of the total BOD load, was being discharged to the Buriganga. Contribution from Hazaribagh discharge was estimated to be about 30% of the total load being discharged to the Buriganga. Discharges to the Turag river, which is a tributary of the Buriganga, were estimated approximately 14 tons per day, representing about 10% of the total BOD. Finally, Browder identified that there were four main pollutant discharge routes into the Buriganga: (i) Hazaribagh Tanneries, (ii) City Drains along the river, (iii) Dholai khal, and (iv) Pagla Sewage Treatment Plant Outfall. Browder described the Dholai khal as the largest source of pollution with an estimated discharge of 35 tons of BOD per day. Hazaribagh was the next largest source of pollution with an estimated discharge of 15 tons per day of BOD. The city drains were considered to account for 10 tons of BOD per day and the Pagla Sewage Treatment Plant discharges approximately 5 tons per day of BOD. Seven monitoring locations along the Buriganga were chosen by Browder. All seven locations were monitored on the same day within a three-hour period in order to get a 'snapshot' of the river. Monitoring was undertaken in the following months: May, July, November and February, 1991-1992, in order to obtain seasonal data.

Azim (1992) reported results of two sampling programs. One during monsoon, when the DO values at different locations were 6 mg/L or above which indicated that there was no problem. During dry season, except two locations, the DO values were all above 6 mg/L. DO value just downstream of the Dholai khal was 1.2 mg/L which is

much below than the standard limits set for fishing and bathing. Coliform values were very high during the lean flow period.

Karim (1992) found that minimum DO concentration is higher for the post-embankment period than that of pre-embankment period for the month of June. Situation also improved during post-embankment period with respect to BOD, Chloride and Suspended Solid. He attributed this improvement to the accumulation of pollutants within the embankment area.

Ahmed (1993) reported the pollution load from industries in and around Dhaka. The discharges were estimated as 49000 kg/d of polluting load (BOD) in the river system in and around Dhaka. Ahmed opined that the polluting industrial load along with an approximately equal amount of BOD load from domestic sewage and other municipal wastes reaching the river system was responsible for the pollution and degradation of the quality of the rivers around the Dhaka city. Ahmed showed the expected improvement in DO profile after implementation of pollution control measures. It is seen that pollution control measures including discontinuation of tannery waste discharge in the river and upgrading of DWASA sewage treatment plant significantly improves the DO situation in the Buriganga in lean flow period.

The Institute of Flood Control and Drainage Research (IFCDR) of BUET (1994) carried out a research project entitled 'Management of Buriganga River Water Quality under Alternative Scenarios'. The main objective of the research work was to formulate appropriate water quality management programs under different scenarios. A hydrodynamic (HD) model, using MIKE 11 river modelling system, was calibrated (for 1989-90 and 1990-91) and verified (1991-92 and 1992-93) for the Buriganga river system. Calibration and verification showed good matching with observed water level data. The HD model was used for determining hydraulic parameters of the Buriganga river, which were then used for a water quality model. DO profiles were simulated at different levels of flows. When violation regarding water quality standards were detected, then a linear program was run to determine maximum allowable loads. Approximate management program was then suggested. It was assessed that considerable waste load can be assimilated by the river, if they are properly managed, without violating the water quality standards. However, it was remarked that future

pollution load would pose considerable water quality problem, and the Pagla Sewage Treatment Plant would need to be expanded to handle extra loading. As a recommendation for future study, an unsteady water quality model has been suggested which is expected to provide further insight into the water quality problem. Also, study on the effect of Nitrogen, Phosphorus and algae on DO has been recommended. In this research work, the HD model was calibrated and verified against observed water levels only. Good matching of simulated water levels with observed values may not ensure the correct volume of flows, i.e. discharge from a model. But, discharge is of prime importance in water quality assessment of a river. Therefore, the discharges considered in the study for various analyses might not be representative of the actual discharges in the Buriganga. Basically, this research opined that, either a treatment plant should be established at Hazaribagh to treat tannery waste or shifting of tannery units to Saver would provide considerable opportunity to properly manage the Buriganga river water quality.

Kamal (1996) tried to investigate the status of the Buriganga river water quality in terms of some water quality parameters and to simulate the dissolved oxygen (DO) level using a water quality model. He had carried out a data acquisition program from both in situ and laboratory testing. Then he developed a one-dimensional water quality model for the Buriganga river system for a dry period of 1994-95. Different scenarios were then tested to predict the most likely condition of the river by using his model. The results of the model simulations had replicated the alarming low DO level in the Buriganga. He had shown that an integrated approach would be required to restore the river water quality with regard to biodegradable pollutants.

Alam (2003) reported that the city part of the Buriganga River has become biologically and hydrologically dead because of the indiscriminate dumping of domestic and industrial wastes, encroachment by unscrupulous people, and the negligence on the part of the authority to enforce rules and regulations pertaining to the ecological health of the river. A cleanup program had been designed for the Buriganga river to restore its water quality and develop new facilities in and around the river in his research. He found that not only a significant proportion of the respondents are willing to pay for environmental improvements, but also they are willing to contribute in terms of time. It is estimated to be about 60.55 % of the total WTP (Willingness-to-pay) value. The

banks of the river have turned into unauthorized industrial districts. There has been unauthorized occupation on bank-side and illegal encroachment into the river.

Magumdar (2005) tried to investigate and assess the water quality in the peripheral rivers of Dhaka city. He reported that Dhaka city is surrounded by a circular river system. The river system includes the Turag river, Buriganga river, Dhaleswari river, Lakhaya river, Balu river and Tongi khal. He pointed out that sufficient quantity of water remains in the rivers during the five months of monsoon season but the flows are practically nil during the dry period except tidal backflow from the Meghna river. The river system receives solid wastes, sewage and wastewaters discharged from domestic, commercial and industrial activities both within and outside the city. This study has put best efforts to give an overview about the present contamination scenario of the peripheral river system around the city including historical trend of the pollution.

The focus of the study of Alam (2008) was to perform a cost-benefit analysis to determine the economic efficiency of the restoration of Buriganga river. He has derived the benefits of the restoration program by using market data and employing benefit transfer and contingent valuation techniques. The values generated by this approach are then integrated into the framework of a cost–benefit analysis, which showed a benefit-cost ratio of 4.35. This study demonstrates that the restoration of dying rivers in developing countries is not only an environmental imperative but is also socially and economically justifiable.

Subrata (2008) has focused on the present scenario of water quality, historical trend of water quality and percent increase of BOD loading. Data of water quality analysis in biological and chemical parameters were presented, analyzed in tabular and graphical form in this study. Subrata explored that, the cross-sectional area and depth reduces by tilling waste loads day by day and somewhere increases by unplanned dredging. Shrinking of river bed is found due to the heavy BOD load, sedimentation and bank encroachment. According to his study, from 1968 to 2007 maximum BOD₅ of the river at Hazaribagh area increases from 0.8 to 60 mg/L and DO reaches 6.7 mg/L to zero in most places. BOD loading from industrial origin has increased at all industrial clusters from 1994 to 2006. He showed that, increase of BOD load was 37% in Tongi, 82 % in

Hazaribagh, and 87% in Narayanganj. In this research, several approaches had been mentioned to restore the water quality of Buriganga river.

Mihir (2009) tried to analyze the bacterial load and chemical pollution level of the Buriganga river. According to his research, anthropogenic effects have seriously affected the physiochemical and biological conditions of the river. By considering this situation and fact, the work was undertaken to determine aerobic heterotrophic and enteric bacteria to the context of biological pollution level along with the physico-chemical properties to reveal an overall status of pollution of the River Buriganga.

This study of Moniruzzaman (2009) was conducted to determine the pollution level of Buriganga river water. Field investigation was started from June 2004 and sample collection was conducted six times at an interval of two months up to April, 2005. Different water quality parameters such as pH, EC, TDS, DO, Cations (Na^+ , K^+ , Ca^{2+} , Mg^{2+} , NH_4^+) and anions (HCO_3^- , Cl^- , SO_4^{2-} , PO_4^{3-} , NO_3^-) were examined for water of each sampling points to monitor the level of these parameters where it exceeds or within the permissible limit. This investigation suggested that, Dissolved Oxygen (DO) concentration of water of Buriganga river was very low particularly in dry season (2-3 mg/L). Ammonium (NH_4^+) and Nitrate (NO_3^-) concentration near Hazaribagh, Sadarghat, Zinzira, Lalbagh, Kotouali and Shutrapur area were very high, which crossed the maximum permissible limit. In dry season the level of pollution was much high than in wet season. Basically, he tried to show the temporal variation of physico-chemical parameters of Buriganga river water through GIS technology.

Rahman (2010) has conducted a study on selected water quality parameters along the Buriganga river. The purpose of his study was to investigate into the impact of the wastewater discharged from tannery industries, municipal sewage, city drains on the river water and thus to provide an updated report on the state of water quality of the river. The water samples were collected in year 2008-09 during both dry and wet seasons from different points along the river and analyzed for various physiochemical quality parameters, which includes: temperature, pH, EC, DO, BOD₅, COD, PO₄ - P, NH₃-N, Pb and Cr. The mean values for the parameters in both dry and wet seasons were then compared with the surface water quality standards as set by the Department of Environment (DoE) in Bangladesh.

Zoynab (2013) found that the sediments of the Buriganga river assessed in this study had been found to be highly polluted with respect to Cu, Pb and Zn; unpolluted to moderately polluted with respect to Cd and moderately polluted to highly polluted with respect to Cr on the basis of USEPA sediment quality guideline. In this research, different types of indices had been used to assess the current pollution status in river sediments of the Buriganga and the Turag rivers. Outcomes were: the Buriganga and the Turag river have a low to appreciable potential ecological risk due to heavy metal contamination according to Ecological Risk Index. As per Sediment Quality Guideline Quotient (SQGQ) the Buriganga river sediments are moderately to highly impacted.

Ahammed (2016) tried to determine the water quality of the selected sections of Buriganga river which passes through Dhaka city. The water quality parameters were sampled during different seasons (summer, winter and autumn) and in 10 different sampling points along the river along the banks of the Buriganga River. The water quality parameters studied for this study were dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), pH, turbidity, conductivity, total dissolved solids (TDS), nitrate and phosphate. The results showed that DO, BOD, COD, TDS, turbidity, nitrate and phosphate are at an alarming level and a discussion on the possible sources of the pollution were presented.

2.3 Water Quality Standards

2.3.1 Surface water quality standards

Starting with the term ‘water quality’ which is a widely used expression, that has an extremely broad range of meanings. Each individual has vested interests in water for his particular use. The term quality therefore, must be considered relative to the proposed use of water. From the user’s point of view, the term ‘water quality’ is defined as ‘those physical, chemical or biological characteristics of water by which the user evaluates the acceptability of water’. For example, for the sake of man’s health, we require that his water supply be pure, wholesome, and potable. Similarly, for agriculture, we require that the sensitivity of different crops to dissolved minerals and other toxic materials is known and either water quality other type of crops is controlled

accordingly. Textiles, paper, brewing, and dozens of other industries using water, have their specific water quality needs.

For management of water quality of a water body, one has to define the water quality requirements or water quality goal for that water body. As mentioned above, each water use has specific water quality need. Therefore, for setting water quality objectives of a water body, it is essential to identify the uses of water in that water body. Inland surface water quality standard of Bangladesh is shown in Table 2.1 (ECR'97).

Table 2.1: Inland surface water quality standard

Sl.	No. Classification	pH	BOD (mg/L)	DO (mg/L)	Total Coliform Quantity/ mL
1.	Potable water source supply after bacteria freeing only	6.5 - 8.5	2 or less	6 or above	50 or less
2.	Water used for recreation purpose	6.5 - 8.5	3 or less	5 or above	200 or less
3.	Potable water source supply after conventional processing	6.5 - 8.5	3 or less	6 or above	5000 or less
4.	Water used for pisciculture	6.5 - 8.5	6 or less	5 or above	5000 or less
5.	Industrial use water including chilling and other processes	6.5 - 8.5	10 or less	5 or above	
6.	Water used for irrigation	6.5 - 8.5	10 or less	5 or above	1000 or less

Note: Maximum amount of ammonia presence in water are 1.2 mg/L (as N molecule), which is used for pisciculture.

Source: GoB (1997)

2.3.2 Effluent standards

In a contrary, water quality standard is set prior to effluent standard because the cleaner the effluent, the cleaner would be the water systems. Water quality standard starts from water quality criteria based on risk assessment. The United States EPA proposed the process of setting water quality criteria concerning both human health (USEPA, 2000) and aquatic life (USEPA, 1996). After confirming the water quality standard, effluent standard can be set according to dilution ratio, treatability, economic feasibility and other factors. Two kinds of approaches in setting effluent standard are water quality-

based approach and technology-based approach (Kim et al., 2010). The key components in water quality-based approach are water quality standards and models. Acknowledging the limitation of treatment technology, technology-based approach has appeared in view of treatability. In developed countries such as US and EU countries, technology-based approach was adopted as a feasible way in social, economical and technical compromise (USEPA, 1996; EU, 1996). Technology-based approach is often referred to as the best available technology (BAT) approach. This approach is being used in the EU and US. What is important in BAT approach is the thorough analysis of the industry including treatment facilities, as well as effluent characteristics. Combining both approaches can be a good solution to set the effluent standard in developing countries (Ragas et al., 2005). Wherever Total Maximum Daily Loads (TMDL) is established, the water quality-based approach employed by USEPA (USEPA, 1991) can be applied.

There are standards for both “direct” discharges, those discharging directly into a water body, and “indirect” discharges, those that discharge to an offsite wastewater treatment facility, which itself discharges directly to a water body. Typically, standards for indirect dischargers are less stringent than for direct dischargers because additional treatment is provided by the offsite facility. Effluent standards cover common pollutants such as biochemical oxygen demand (BOD), total suspended solids (TSS) and pH and others that cover toxic pollutants (metals, organics, in organics).

There are several different categories of effluent standards. In addition to different standards for direct and indirect dischargers, there are different guidelines for existing dischargers (those in existence at the time a particular standard was created) and for new dischargers (those after the standard were created). Table 2.2 shows the effluent standards of Bangladesh.

Table 2.2: Bangladesh standards for industrial effluent

Sl. No	Parameters	Unit	Discharge to		
			Inland Surface Water	Public Sewer from Treatment Plant	Irrigable Land
1	Ammoniacal nitrogen (N molecule)	mg/L	50	75	75
2	Ammonia (free ammonia)	mg/L	5	5	15
3	Arsenic (As)	mg/L	0.2	0.05	0.2
4	BOD ₅ at 20°C	mg/L	50	250	100
5	Boron (B)	mg/L	2	2	2
6	Cadmium (Cd)	mg/L	0.05	0.5	0.5
7	Chloride (Cl ⁻)	mg/L	600	600	600
8	Chromium (total Cr)	mg/L	0.5	1.0	1.0
9	COD	mg/L	200	400	400
10	Chromium (hexavalent Cr)	mg/L	0.5	1.0	1.0
11	Copper (Cu)	mg/L	0.5	3.0	3.0
12	Dissolved Oxygen (DO)	mg/L	4.5-8	4.5-8	4.5-8
13	Electric Conductivity (EC)	µmhos/cm	1200	1200	1200
14	Total Dissolved Solid (TDS)	mg/L	2100	2100	2100
15	Flouride (F)	mg/L	2	15	10
16	Sulfide (S)	mg/L	1	2	2
17	Iron (Fe)	mg/L	2	2	2
18	Total Kjeldal Nitrogen (TKN)	mg/L	100	100	100
19	Lead (Pb)	mg/L	0.1	1	0.1
20	Manganese (Mn)	mg/L	5	5	5
21	Mercury (Hg)	mg/L	0.01	0.01	0.01
22	Nickel (Ni)	mg/L	1.0	2.0	1.0
23	Nitrate (NO ₃ ⁻)	mg/L	10.0	Not yet set	10.0
24	Oil and grease	mg/L	10.0	20.0	10.0
25	Phenol Compounds (C ₆ H ₅ OH)	mg/L	1.0	5	1
26	Dissolved Phosphorus (P)	mg/L	8.0	8.0	15.0
27	Radioactive materials	(to be specified by Bangladesh Atomic Energy Commission)			
28	pH		6-9	6-9	6-9
29	Selenium (as Se)	mg/L	0.05	0.05	0.05
30	Zinc (as Zn)	mg/L	5	10	10
31	Temperature	°C (summer)	40	40	40
		°C (winter)	45	45	45
32	Suspended Solids (TSS)	mg/L	150	500	200
33	Cyanide (CN)	mg/L	0.1	2.0	0.2

Source: GoB (1997)

2.4 Dimension wise Classification of Models

2.4.1 Zero dimensional models

Zero-dimensional models are used to estimate spatially averaged pollutant concentrations at minimum cost. These models predict a concentration field of the form $C = g(t)$, where t represents time. They cannot predict the fluid dynamics of a system, and the representation is usually such that an analytical solution is possible. As an example, the simplest representation of a lake is to consider it as a continuously stirred tank reactor (CSTR).

2.4.2 One dimensional models

Most river models use a one-dimensional representation, where the system geometry is formulated conceptually as a linear network of segments or volume sections. Variation of water quality parameters occur longitudinally (in x -direction) as the water is transported out of one segment and into the next. The one-dimensional approach is also a popular method for simulation of small, deep lakes, where the vertical variation of temperature and other quality parameters is represented by a network of vertically stacked horizontal slices or volume segments.

2.4.3 Multi-dimensional models

Water quality models of lakes and estuaries are often two or three-dimensional in order to represent the spatial heterogeneity of the water bodies. Depending on the system, two-dimensional representations include a vertical dimension with longitudinal segmentation for deep and narrow lakes, reservoirs, or estuaries.

Three-dimensional spatial representations have been used to model overall lake circulation patterns. Part of the reason for this need is the concern with the water quality of the near-shore zone as well as deep zones of lakes. In addition, the different water quality interactions in these zones can lead to changes in the overall lake quality that cannot be predicted without this spatial definition.

2.5 Theory of Water Quality Modeling

Water quality parameters at a particular location in a water body is continuously modified by the physical processes of advection and diffusion which transport fluid constituents from location to location, and by physical, chemical and biological transformation processes as well as constituents entering within the system through direct and diffuse loading. The general mass balance equation around an infinitesimally small volume is presented by:

$$\frac{\partial C}{\partial t} = -\frac{\partial}{\partial x}(U_x C) - \frac{\partial}{\partial y}(U_y C) - \frac{\partial}{\partial z}(U_z C) + \frac{\partial}{\partial x}\left(E_x \frac{\partial C}{\partial x}\right) + \frac{\partial}{\partial y}\left(E_y \frac{\partial C}{\partial y}\right) + \frac{\partial}{\partial z}\left(E_z \frac{\partial C}{\partial z}\right) + S_L + S_B + S_K \quad \dots (2.1)$$

Where,

C = mean concentration of a water quality constituent, M/L^3

t = time, T

U_x, U_y, U_z = longitudinal, lateral, and vertical advective velocities respectively, L/T

E_x, E_y, E_z = longitudinal, lateral, and vertical diffusion coefficients respectively, L^2/T

S_L = direct and diffuse loading rate, M/L^3T

S_B = boundary loading rate (including upstream, downstream, benthic, and atmospheric), M/L^3T

S_K = total kinetic transformation rate; positive in source, negative in sink, M/L^3T

The transformation process is constituent-specific. As for example, when the constituent of concern is dissolved oxygen (DO), the transformation processes include rate of oxygen gain due to reaeration and photosynthesis production, rate of oxygen loss due to BOD oxidation, SOD and respiration of aquatic plants. Many constituents such as BOD, suspended solids and bacteria are subjected to a single transformation process. The conservation of mass equation (also called mass transport equation) forms the basis of all water quality modeling. The temporal and spatial distribution of each of the water quality parameters within a water body can be determined using the above transport equation.

2.5.1 One dimensional modeling approach

Rivers and estuaries are generally many times longer than they are wide or deep. As a result, inputs from external sources rapidly mix over the entire cross section and a 1-dimensional approach is often justified. Variation of water quality parameters occur longitudinally in the form of cross sectional averaged values, as water is transported out of one segment and into the next segment. Basically, most of the river models use a one-dimensional representation, where the system geometry is formulated conceptually as a linear network of segments or volumes as shown in Fig. 2.1. The general mass balance equation is averaged over the cross section of the stream, is given by:

$$\frac{\partial C}{\partial t} = -\frac{1}{A} \frac{\partial}{\partial x} (QC) + \frac{1}{A} \frac{\partial}{\partial x} \left(E_L A \frac{\partial C}{\partial x} \right) - KC + \sum I \quad \dots (2.2)$$

Where,

x = longitudinal distance along river or estuary, L

EL = longitudinal dispersion coefficient, L^2/T

A = cross sectional area of the channel, L^2

Q = flow rate, L^3/T .

I = external loading rate, M/L^3T

K = decay coefficient, T^{-1}

The dispersion term arises during the averaging process due to the correlation of cross sectional velocity and concentration variations. Dispersion in natural stream is predominantly due to lateral velocity variations.

The analytical solution of Eq. (2.2) is possible and is generally of little practical use for modeling purpose for following reasons:

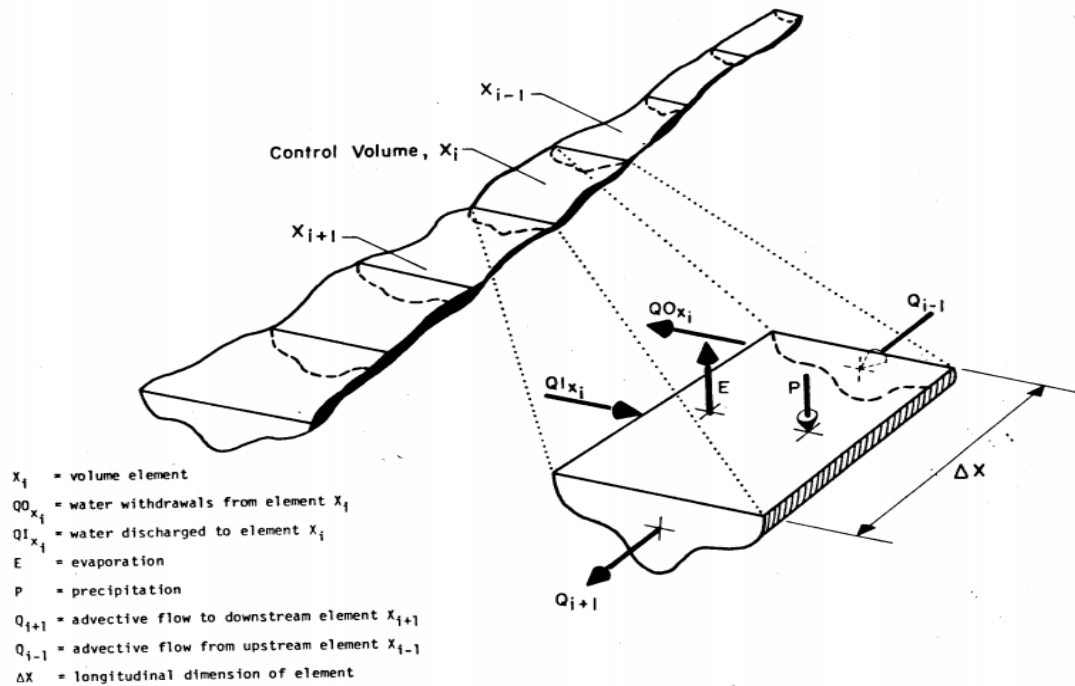


Figure 2.1: One - Dimensional Geometric Representations of River System (Chen and Wells, 1975)

- A and E_L are never constant over any appreciable reach of a natural channel.
- As shown by Sabol and Nordin (1978), experimental data taken in natural rivers do not support the assumption that 1-D mixing process can be considered to be Fickian and thus the analytical solution is a poor model of the phenomena.
- The 1-D dispersive process implied by Eq. (2.2) cannot be assumed until a tracer has progressed a distance from the source greater than (Fischer, 1967)

$$L = \frac{1.8l^2 U}{R U^*} \quad \dots (2.3)$$

Where,

l = characteristics mixing length (e.g. channel half width), L

R = hydraulic radius of the channel, L

U = average velocity, L/T

U^* = shear velocity, L/T

These inadequacies of the analytical solution have led to solve the Eq. (2.2) numerically in order to obtain dispersion predictions. In numerical solution, the river

is divided into a series of elementary reaches and finite-difference method is used to solve the governing mass transport equation to obtain the value of C at each computational reach for each time step.

2.5.2 Finite segment formulation of numerical solution

In finite segment method, the river is divided into a series of segment and the mass balance equation for each variable are formulated for, each segment. In Fig. 2.2, a 1-Driver is segmented into three equal reaches of length Δx . The continuous concentration distribution $C(x)$ is shown below together with finite segment concentrations at the midpoints of the segments C_{i-1} , C_i and C_{i+1} . Concentrations at the interfaces between the segments are also shown, where $C_{i-1,i}$ and $C_{i,i+1}$ are the interfacial concentrations of the segment i at its upstream and downstream faces, respectively.

Using the central difference technique, the slope of the continuous concentration distribution at the center of segment i is approximated as the difference of its interfacial concentrations divided by the segment length.

Thus,

$$\left. \frac{\partial C}{\partial x} \right|_i = \frac{C_{i,i+1} - C_{i-1,i}}{\Delta x} \quad \dots (2.4)$$

Advective transport is given by,

$$\left. \frac{\partial}{\partial x} (QC) \right|_i = \frac{(QC)_{i,i+1} - (QC)_{i-1,i}}{\Delta x} = \frac{Q_{i,i+1}C_{i,i+1} - Q_{i-1,i}C_{i-1,i}}{\Delta x} \quad \dots (2.5)$$

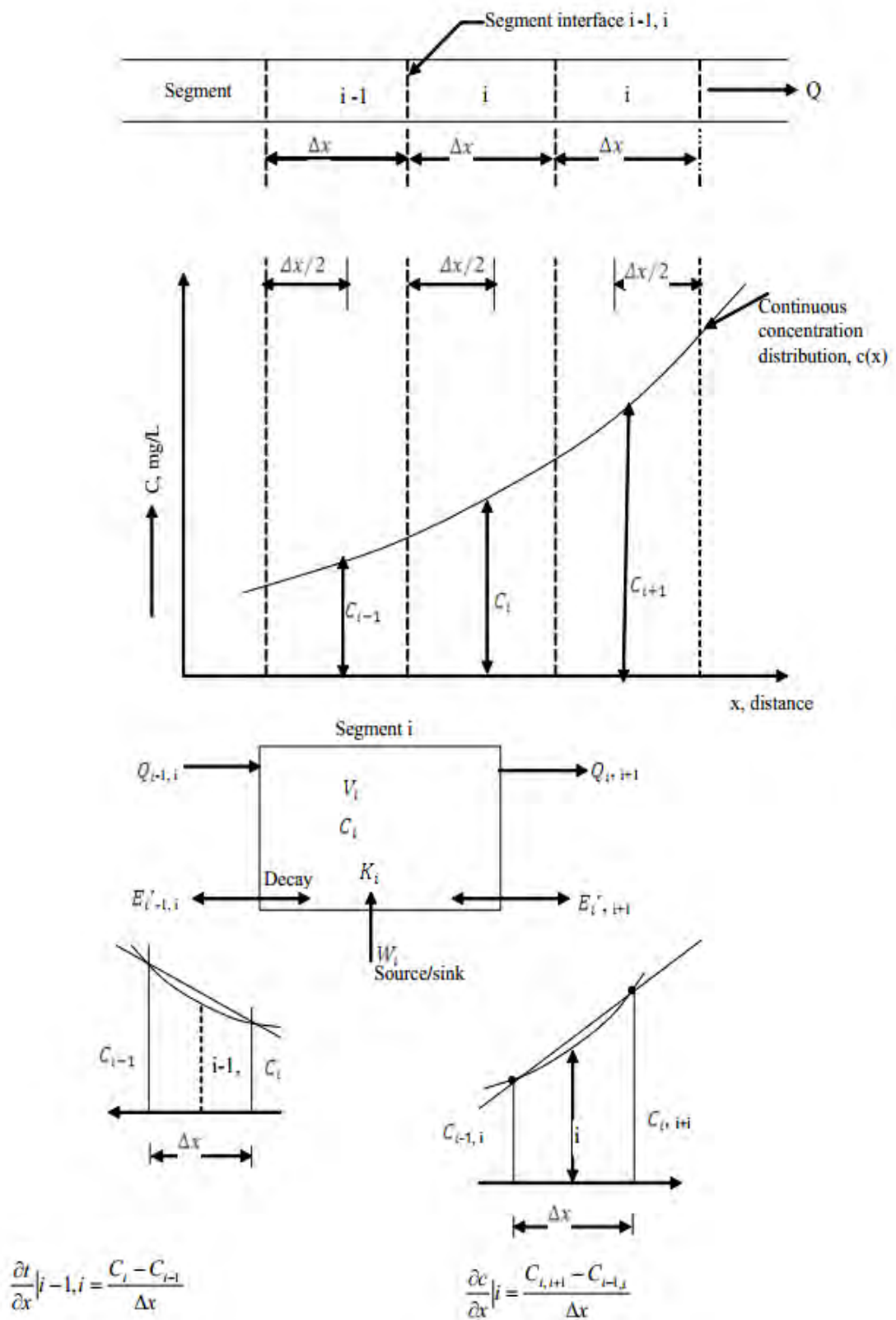


Figure 2.2: Definition sketch for the finite segment approximation

The interfacial concentration $C_{i, i+1}$ is related to the concentrations in the adjoining segments, that is, C_i and C_{i+1} . Assume the relationship is linear, of the following form

$$C_{i, i+1} = \alpha_{i, i+1} C_i + \beta_{i, i+1} C_{i+1} \quad \dots (2.6)$$

Where, α is the fraction of the upstream segment's concentration at the interface, β is the fraction of the downstream segment's concentration at the interface $i, i+1$, and

$$\beta_{i, i+1} = 1 - \alpha_{i, i+1} \quad \dots (2.7)$$

Substituting Eq. (2.6) into Eq. (2.5), the finite difference approximation of the spatial derivative of the advective mass balance term is

$$\left. \frac{\partial}{\partial x} (QC) \right|_i = \frac{Q_{i, i+1} (\alpha_{i, i+1} C_i + \beta_{i, i+1} C_{i+1}) - Q_{i-1, i} (\alpha_{i-1, i} C_{i-1} + \beta_{i-1, i} C_i)}{\Delta x} \quad \dots (2.8)$$

Dispersive transport is given by

$$\begin{aligned} \left. \frac{\partial C}{\partial x} (EA \frac{\partial C}{\partial x}) \right|_i &= \frac{(EA \frac{\partial C}{\partial x})_{i, i+1} - (EA \frac{\partial C}{\partial x})_{i-1, i}}{\Delta x} \\ &= \frac{E_{i, i+1} A_{i, i+1} \left. \frac{\partial C}{\partial x} \right|_{i, i+1} - E_{i-1, i} A_{i-1, i} \left. \frac{\partial C}{\partial x} \right|_{i-1, i}}{\Delta x} \quad \dots (2.9) \end{aligned}$$

In this expression the concentration derivatives are to be evaluated at the interfaces, not at the center of the segments as for advective term.

Therefore,

$$(EA \frac{\partial C}{\partial x})_{i, i+1} = E_{i, i+1} A_{i, i+1} \left(\frac{C_{i+1} - C_i}{\Delta x} \right) \quad \dots (2.10a)$$

and,

$$(EA \frac{\partial C}{\partial x})_{i-1,i} = E_{i-1,i} A_{i-1,i} (\frac{C_i - C_{i-1}}{\Delta x}) \quad \dots (2.10b)$$

Substituting $E' = \frac{EA}{\Delta x}$ in Eq. (2.10), the finite difference approximation for the dispersive term becomes:

$$\frac{\partial}{\partial x} (EA \frac{\partial C}{\partial x})_i = \frac{E'_{i,i+1} (C_{i+1} - C_i) - E'_{i-1,i} (C_i - C_{i-1})}{\Delta x} \quad \dots (2.11)$$

The approximations to the dispersive fluxes involve the concentrations at the centers of adjoining segments and do not depend on interfacial concentrations. These fluxes are independent of the weighting factors α and β . Multiplying the differential equation Eq. (2.2) by the volume, $V = A.\Delta x$, and substituting the advective and dispersive approximations, the resulting equation is

$$\begin{aligned} V_i \frac{\partial C_i}{\partial t} = & Q_{i-1,i} (\alpha_{i-1,i} C_{i-1} + \beta_{i-1} C_i) - Q_{i,i+1} (\alpha_{i,i+1} C_i + \beta_{i,i+1} C_{i+1}) \\ & + E'_{i,i+1} (C_{i+1} - C_i) - E'_{i-1,i} (C_i - C_{i-1}) - k_i C_i V_i \pm W_i \end{aligned} \quad \dots (2.12)$$

Where, $K_i C_i V_i$ is the kinetics loss rate and W_i is the external source or sink of mass in segment i .

Eq. (2.12) is the general expression used to evaluate the mass derivative for every segment during each time step Δt between initial and final time. Given concentration and volumes at time t , the new mass at $t + \Delta t$ can be calculated as:

$$(V_i C_i)_{t+\Delta t} = (V_i C_i)_t + \frac{\partial}{\partial t} (V_i C_i) \cdot \Delta t \quad \dots (2.13)$$

The new concentration can be calculated as

$$C_{i,t+\Delta t} = \frac{(V_i C_i)_{t+\Delta t}}{V_{i,t+\Delta t}} \quad \dots (2.14)$$

Where, Δt is the time step used in simulation.

2.5.3 Steps of model development

A model is a simplified representation of a complex process or phenomena. It can be defined as a theoretical construction together with assignment of numerical values to model parameters, incorporating some prior observations drawn from field and laboratory data and relating external inputs or forcing functions to system variables (Thomann and Mueller, 1987). Figure 2.3 shows the principal components of a mathematical modeling framework. The upper two steps ‘Theoretical Construction’ and ‘Numerical Specification’ constitute what is considered in a mathematical model. This is to distinguish the simple writing of equations for a model from the equally difficult task of assigning a set of representative numbers to inputs and parameters. Following this model specification, the steps are model calibration and model verification.

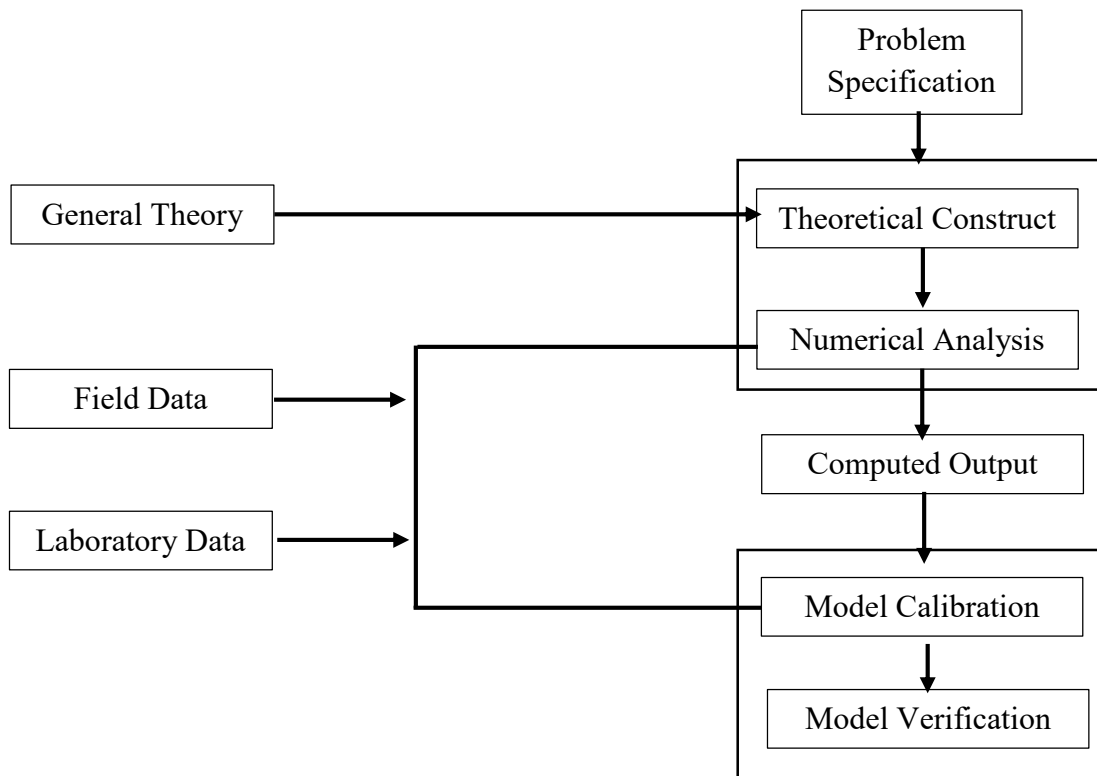


Figure 2.3: Principal steps for model development (Thomann and Mueller, 1987)

Model calibration

Calibration usually means iterative adjustment of the model parameters so that simulated and observed response of the system match within the desired level of accuracy. This is the first stage testing or tuning of a model to a set of field data, preferably a set of field data not used in the original model construction (i.e. data used for calibration should ideally be other than that used during early model development in a first comparison of measured and computed values). The calibration or tuning should include a consistent set of theoretically defensible parameters and inputs, i.e. parameters should not vary outside of the range reported in the literature nor should the parameters vary in an unstable fashion outside the range of accuracy.

Model verification

This involves subsequent testing of a calibrated model to additional field data, preferably under different external conditions (such as river flow or external load) to further examine model validity. The conditions under which the model is considered to be verified should be given, i.e. the range of model applicability physically, chemically or biologically should be specified. Conversely, any mechanisms identified as part of initial construct, but not incorporated in the verified model or vice versa, should be summarized.

Sensitivity analysis

A calibrated and verified model is processed for its sensitivity towards different water quality parameters and constants (physical and chemical); the model is run with varying conditions of a single parameter at a time. The model results are then plotted for comparison with the actual condition.

2.5.4 Components of models

A model consists of five components in its mathematical formulation. These are:

- a) External variables or forcing functions
- b) State variables
- c) Mathematical equations
- d) Parameters

e) Universal constants

External variables are variables or function of external nature that influence the state of ecosystem. The problem of modeling can be refrained as if the values of the forcing functions are varied that will influence the state of the total system. The example of some of the forcing functions is the input of pollutants to the river system, addition or removal of fishery etc. Temperature, solar radiation and precipitation are also the example of forcing functions.

State variables the system variables considered in the model. The selection of these variables is crucial but the choice is also obvious. For examples if we want to model the sediment deposit in a reservoir, it is natural to include the sediment concentration and velocity of streams as state variables. When the model is used in the content of management studies, the values of the state variable predicted by changing the forcing function can be considered as the result of the model as the model will contain relationship between the forcing function and state variables. Most models will consist more state variables than are directly required for the purpose of management.

The physical, biological and chemical processes in the ecosystem are represented in the model by means of mathematical equations. These are the relationships between two or more state variables and between forcing function and state variables.

The mathematical representation of the processes in the system contains coefficients or parameters. They can be considered constant for a specific purpose or system. However, only a few parameter values are known exactly and hence it becomes necessary to calibrate others. Most models will also contain universal constant such as gas constant, molecular weight etc. Such constants are of course not subject to calibrate.

2.5.6 Structure of a typical water quality model

The schematic diagram involving the kinetics of the mathematical model to predict temporal and spatial variation of vertically averaged water quality parameters is shown in Fig. 2.4. Phytoplankton dynamics and nutrients kinetics are based on a well-accepted framework (Di Toro et al., 1977; Thomann and Mueller, 1987; Wool et al.,

2009). Typical values for the kinetics coefficients and their temperature corrections are adopted from the literature (Bowie et al., 1985, Wool et al., 2009, Lee et al., 1991, Lung and Larson, 1995). Nine system variables such as phytoplankton, organic and inorganic phosphorus, organic, ammonia and nitrite-nitrate nitrogen, CBOD5, DO and suspended solids are considered in the modeling framework.

Four interacting systems such as (i) phytoplankton kinetics and transformation of (ii) phosphorus, (iii) nitrogen and (iv) DO are simulated in the mathematical modeling.

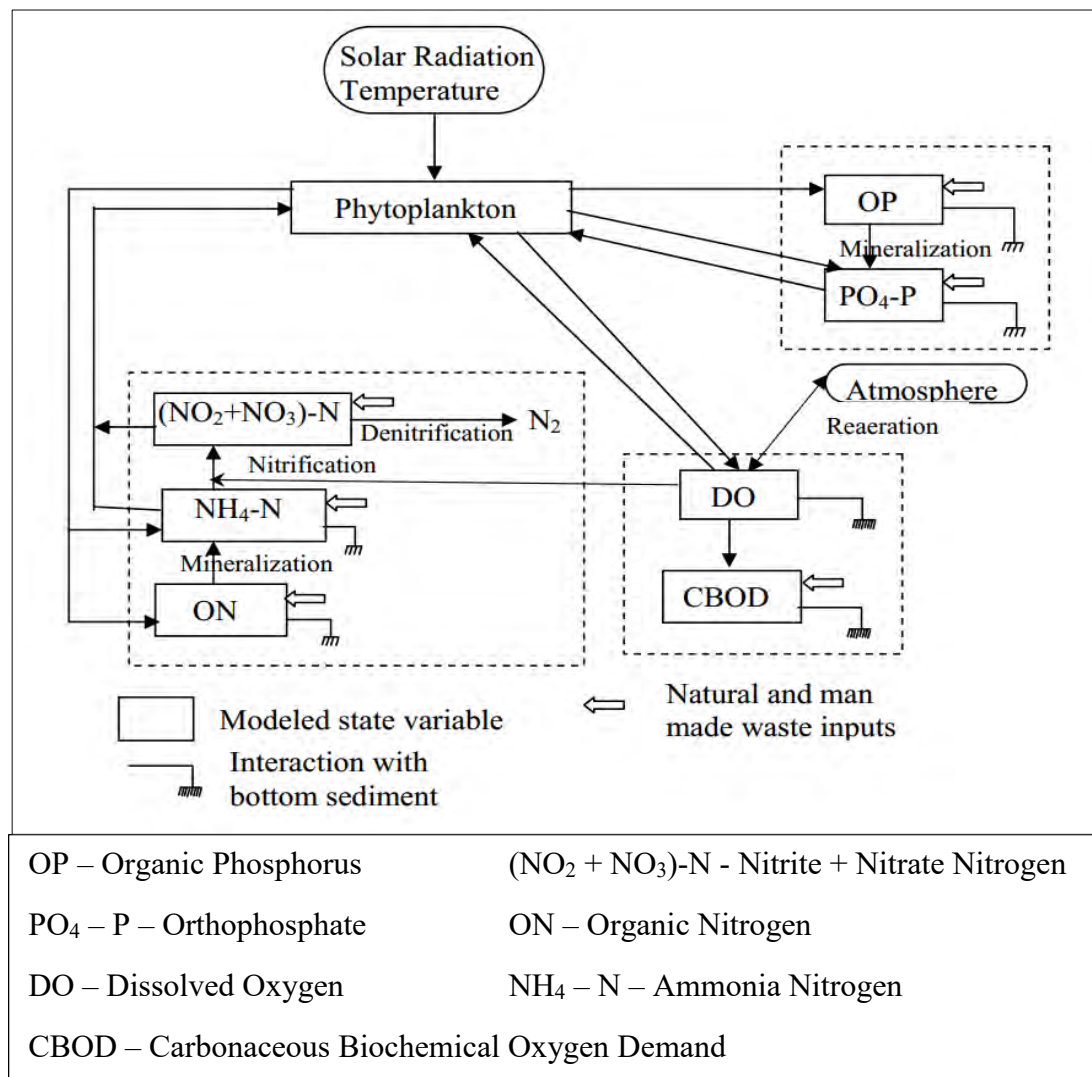


Figure 2.4: Structure of a typical water quality model showing principal kinetics interactions.

2.6 Phytoplankton Kinetics

Two approaches have been widely used to simulate phytoplankton (algae) in water quality models: (i) aggregating all algae into a single constituent and (ii) aggregating the algae into a few dominant functional groups. The first approach is commonly used in river water quality models. Most models express phytoplankton in terms of biomass (chlorophyll-a equivalent) rather than cell numbers. This facilitates the modeling of both nutrients cycles and food web dynamics since it allows a more direct linkage between the phytoplankton equations and the mass balance equations for both nutrients and higher tropic levels such as zooplankton and fish.

The principal kinetics of phytoplankton are the growth, death and settling of phytoplankton and grazing by zooplankton. For the total phytoplankton, the governing mass conservation equation can be written as

$$\frac{dP}{dt} = \left(G_P - D_P - \frac{V_P}{H} - C_g Z \right) P \quad \dots (2.15)$$

Where,

P = total phytoplankton concentration, gm chl-a / L

G_P = Growth rate of phytoplankton, day⁻¹

D_P = Death rate of phytoplankton, day⁻¹

V_P = Phytoplankton settling rate, day⁻¹

H = Mean depth, m

C_g = Zooplankton grazing rate, L/mg C/day

Z = Zooplankton carbon concentration, mg/L.

2.6.1 Phytoplankton growth rate

The growth rate of phytoplankton depends on three principal components (Thomann and Mueller, 1987); mainly temperature, solar radiation and nutrients. The classical approach is to assume that these effects are multiplicative (Di Toro et al., 1977), the phytoplankton growth rate can be written as

$$\begin{aligned} G_P &= (\text{Temperature effect}). (\text{Light effect}). (\text{Nutrient effect}) \\ &= G(T). G(I). G(N) \end{aligned} \quad \dots (2.16)$$

Temperature effect on phytoplankton growth rate

When the available light for growth is at an optimum level and nutrients are plentiful, the relationship of the temperature and growth rate can be determined from work of Eppley (1972), among others and is approximated by:

$$G_P = G_{\max} \cdot (1.066)^{T-20} \quad \dots (2.17)$$

Where, G_{\max} is the maximum growth rate of the phytoplankton at 20° C under optimum light and nutrient conditions. This growth rate is a function of the species of phytoplankton and can vary considerably. The value suggested for G_{\max} of 1.8/day is an average condition for a mixed phytoplankton population. Various species of phytoplankton have different growth rate and in general in the range of 1.5 – 2.7/day (Bowie et al., 1985; Thomann and Mueller, 1987).

Effect of solar radiation on phytoplankton growth rate

Light plays an important role in the growth of phytoplankton. The instantaneous rate of phytoplankton increases in proportion to the light intensity I to a saturating level I_s . Further increase in light intensity result in photo-inhibition and a subsequent decrease in photosynthesis. This behavior can be represented by:

$$F(I) = \frac{I}{I_s} e^{(1 - \frac{I}{I_s})} \quad \dots (2.18)$$

The light intensity $I(Z)$ at any depth Z below the free water surface is reduced by absorption and scattering, as given by Beer's law:

$$I(Z) = I_0 e^{-K_e Z} \quad \dots (2.19)$$

Where, I_0 = instantaneous incident visible radiation at surface, ly/day and K_e = light extinction coefficient, m^{-1} .

For the water column, the vertically averaged instantaneous light intensity function under the simplifying assumption

$$\begin{aligned} I_0 = I_a = I_T / f & \quad 0 < t < f \\ = 0 & \quad f < t < 1 \end{aligned}$$

Where, f is the photoperiod (fraction of day when sunlight is available) in day and I_T is the total daily solar radiation, light effect can be given by

$$G(I_a) = \iint F(I) dt dz$$

$$= \frac{2.718f}{K_e H} [e^{-\alpha_1} - e^{-\alpha_0}] \quad \dots (2.20)$$

Where, $\alpha_1 = \frac{I_a}{I_s} e^{-K_e H}$ and $\alpha_0 = \frac{I_a}{I_s}$

The extinction coefficient K_e depends on the inorganic solids, detritus particles as well as phytoplankton levels. The slope of the line $\ln(I/I_s)$ vs depth Z provides an estimate of K_e . Consider the depth Z_1 at which $I/I_s = 1\%$, then

$$K_e = 4.61 / Z \quad \dots (2.21)$$

Sverdrup et al. (1942) and Beeton (1958) and others have developed empirical relationships between the secchi depth Z_s and the extinction coefficient is given by

$$K_e = (1.7 \text{ to } 1.8) / Z \quad \dots (2.22)$$

The saturating light intensity I_s for mixed populations of phytoplankton is approximately 100 - 400 ly / day with 300 ly day as an approximate average. The value of $G(I_a)$ ranges from 0.10 to 0.50, that is non-optimal light conditions due to light extinction with depth is reduced the growth rate by about 50-90% (Thomann and Mueller, 1987).

Nutrient effect on phytoplankton growth rate

A modeling framework is evaluated by Michaelis-Menten for effect of nutrients (Nitrogen and Phosphorus) on phytoplankton growth rate presented by the range of

$$G(N) = \min \left\{ \frac{N_1}{k_{mN1} + N_1} ; \frac{N_1}{k_{mN2} + N_2} \right\} \quad \dots (2.23)$$

Where,

N_1 = Dissolved inorganic (ammonia + nitrate) nitrogen concentration, $\mu\text{g/L}$

N_2 = Dissolved inorganic phosphorus (orthophosphate) concentration, $\mu\text{g/L}$

k_{mN1} = Half saturation constant for nitrogen, $\mu\text{g/ L}$

k_{mN2} = Half saturation constant for phosphorus, $\mu\text{g/ L}$

k_{mN} is typically 10-20 $\mu\text{g/ L}$ for nitrogen and 1-5 $\mu\text{g/ L}$ for phosphorus (Thomann and Mueller, 1987). The full expression for the phytoplankton growth rate is given by,

$$G(P) = G_{max} (1.066)^{T-20} \left\{ \frac{2.718f}{K_e H} [e^{-a_1} - e^{-a_0}] \right\} \cdot \min \left\{ \frac{N_1}{k_{mN1} + N_1} ; \frac{N_1}{k_{mN2} + N_2} \right\} \quad \dots (2.24)$$

2.6.2 Phytoplankton death rate

Phytoplankton decay rate is mostly the combination of death rate and endogenous respiration rate. Endogenous respiration rate of phytoplankton is the rate at which the phytoplankton oxidize their organic carbon to CO_2 per unit weight of phytoplankton organic carbon. ‘The endogenous rate’ is temperature dependent (Riley et al., 1949) and determined by,

$$k_{IR}(T) = k_{IR} \theta_{IR}^{T-20} \quad \dots (2.25)$$

Where, k_{IR} = Endogenous respiration rate at 20°C (0.05 – 0.25 per day, approximate average is 0.15 per day) and θ_{IR} = temperature coefficient (1.085)

The total biomass reduction rate for the phytoplankton is given by

$$D_P = k_{IR}(T) + k_{ID} \quad \dots (2.26)$$

Where, k_{ID} = Death rate of phytoplankton, day^{-1} .

2.6.3 Settling of phytoplankton

The settling of phytoplankton is an important contribution to the overall mortality of the phytoplankton population, particularly in lakes and coastal waters. Settling is affected by vertical turbulence density gradients and the physiological state of the different species of phytoplankton. Settling rate of phytoplankton can be a significant source of nutrient to sediments and can play an important role in sediment oxygen demand (SOD).

2.7 Phosphorous Kinetics

Dissolved inorganic phosphorus is utilized by phytoplankton for growth and interacts with particulate inorganic phosphorus via adsorption-desorption mechanisms. A fraction of the phosphorus (Di Toro and Matystik, 1980) is released during phytoplankton respiration and death in the dissolved inorganic form and is readily available for uptake. The remaining fraction is released in the organic form. Organic Phosphorus is converted to dissolved inorganic form at a time dependent rate through the process of mineralization. Mineralization process is dependent on phytoplankton biomass and Michaelis-Menton type saturation kinetics based on algal biomass is used to describe this dependency.

The adsorption-desorption mechanisms are used to describe the interaction between dissolved inorganic phosphorus and suspended material in the water column. The subsequent settling of suspended solids together with sorbed inorganic phosphorus can act as a significant loss mechanism in water column and is a source of phosphorus to the sediment. The rates of reaction for adsorption-desorption are in the order of minutes versus reaction rates in order of days for the algal biological kinetics and so, permits an instantaneous equilibrium.

The total inorganic phosphorus in the system is the sum of dissolved inorganic and particulate inorganic phosphorus, i.e.

$$C_{TP} = C_{DP} + C_{PIP} \quad \dots (2.27)$$

If M is the concentration of total suspended solids, the particulate phosphorus can be defined as

$$C_{PIP} = C'_{PIP} \cdot M \quad \dots (2.28)$$

Where, C_{PIP} = concentration of phosphorus sorbed to solids, mg P/ Kg M and M = concentration of solids, Kg/ L.

The equilibrium between the dissolved inorganic phosphorus in the water column and the mass concentration of the solids is usually expressed in terms of a partition coefficient:

$$K_{PIP} = \frac{C'_{PIP}}{C_{DIP}} \quad \dots (2.29)$$

Where, K_{PIP} = partition coefficient for particulate phosphorus, mg P/ Kg M per (mg P/ L).

The total concentration may be expressed as-

$$C_{TIP} = C_{DIP} + K_{PIP} \cdot MC_{DIP} \quad \dots (2.30)$$

The fraction of dissolved and particulate inorganic phosphorus can be expressed as

$$f_{DIP} = \frac{C_{DIP}}{C_{TIP}} = \frac{1}{1 + K_{PIP} \cdot M} \quad \dots (2.31a)$$

$$f_{PIP} = 1 - f_{DIP} = \frac{K_{PIP} \cdot M}{1 + K_{PIP} \cdot M} \quad \dots (2.31b)$$

This process can be modeled as follows: the total inorganic phosphorous is computed as the sum of dissolved and sorbed inorganic phosphorous in the segment and then redistributed to the dissolved phase for the algal uptake and the particulate phase for settling, using an assigned fraction for each phase. The computational steps may be written as

$$TIP = DIP_{t-1} + PIP_{t-1} \quad \dots (2.32a)$$

$$DIP = f_{DIP} \cdot TIP \quad \dots (2.32b)$$

$$PIP = (1 - f_{DIP}) \cdot TIP \quad \dots (2.32c)$$

Where,

TIP = the total inorganic phosphorus, mg/L

DIP_{t-1} = the DIP resulting from the previous integration time step, mg/L

PIP_{t-1} = the sorbed inorganic phosphorus resulting from the previous integration step, mg/L

f_{DIP} = the fraction of the total inorganic phosphorus assigned to the dissolved phase, (unit less)

DIP = the new equilibrium dissolved inorganic phosphorus, available for algal uptake, mg/L

PIP = the new equilibrium sorbed inorganic phosphorus, which may settle to the sediment layer from the water column, mg/L

The governing mass-conservation equations can be written as

Organic Phosphorus (C_2)

$$\frac{dC_2}{dt} = f_{op} \cdot a_{pc} \cdot D_p \cdot P - k_{23} \theta_{23}^{T-20} \frac{P}{P + k_{mPc}} \cdot C_2 - \frac{V_{s2}(1-f_{D2})}{H} \cdot C_2 \quad \dots (2.33)$$

Inorganic Phosphorus (C_3)

$$\frac{dC_3}{dt} = (1 - f_{op}) \cdot a_{pc} \cdot D_p \cdot P + k_{23} \theta_{23}^{T-20} \frac{P}{P + k_{mPc}} \cdot C_2 - a_{pc} \cdot G_p \cdot P - \frac{V_{s3}(1-f_{D3})}{H} \cdot C_3 \quad \dots (2.34)$$

Where,

C_2 = concentration of organic phosphorus, mg / L

C_3 = concentration of inorganic phosphorus, mg / L

a_{pc} = ratio of phosphorus to carbon, mg P / mg C.

f_{op} = fraction of dead and respired phytoplankton recycled to the organic pool

k_{23} = organic phosphorus mineralization rate at 20° C, day⁻¹

θ_{23} = temperature co-efficient = 1.08

k_{mPc} = half saturation constant for phytoplankton limitation of phosphorus cycle

f_{D3} = dissolved fraction of inorganic phosphorus

f_{D2} = dissolved fraction of organic phosphorus

v_{s2} = organic matter settling velocity, m/day

v_{s3} = inorganic matter settling velocity, m/day

H = depth of water column, m

P = phytoplankton biomass carbon, µg Chl-a / L.

G_p = growth rate of phytoplankton, day⁻¹

D_p = death rate of phytoplankton, day⁻¹

2.8 Nitrogen Kinetics

Three nitrogen variables are modeled: organic nitrogen, ammonia nitrogen and nitrite-nitrate nitrogen. Ammonia and nitrate are used by the phytoplankton for growth. During algal respiration and death, a fraction of the cellular nitrogen is returned to the inorganic pool in the form of ammonia nitrogen. The remaining fraction is recycled to the organic nitrogen pool. The particulate fractions of organic nitrogen are settled out, leading to source of organic nitrogen in benthic layer.

The nitrogen cycle is modeled by first order transformation: (i) hydrolysis of organic nitrogen to ammonia nitrogen at a temperature dependent rate, (ii) oxidation of ammonia nitrogen to nitrate nitrogen at a temperature and oxygen dependent rate and (iii) de-nitrification at a temperature and oxygen dependent rate. The nitrogen recycled from algal decay into organic and ammonia nitrogen with a ratio of f_{ON} . A constant nitrogen / chlorophyll-a ratio is adopted. The inorganic nitrogen (ammonia and nitrate nitrogen) uptake by algal growth is modeled with an ammonia preference factor.

$$P_{NH3} = \frac{N_2}{k_{mN} + N_2} \cdot \frac{N_3}{k_{mN} + N_3} + \frac{N_2}{N_2 + N_3} \cdot \frac{k_{mN}}{k_{mN} + N_3} \quad \dots (2.35)$$

Where,

k_{mN} = half saturation constant in the nitrogen limitation function

N_2 = ammonia nitrogen concentration and N_3 = nitrate nitrogen concentration

The governing mass conservative equations for the nitrogen cycle can be written as

Organic Nitrogen (N_1)

$$\frac{dN_1}{dt} = f_{ON} \cdot a_{NC} \cdot D_p \cdot P - k_{12} \theta_{12}^{T-20} \frac{P}{P + 0.02} \cdot N_1 - \frac{V_{NI}(1 - f_{DON})}{H} \cdot N_1 \quad \dots (2.36)$$

Ammonia Nitrogen (N_2)

$$\begin{aligned} \frac{dN_2}{dt} = & (1 - f_{ON}) \cdot a_{NC} \cdot D_p \cdot P + k_{12} \theta_{12}^{T-20} \frac{P}{P + 0.02} \cdot N_1 \\ & - P_{NH3} \cdot a_{NC} \cdot G_P \cdot P - k_{23} \theta_{23}^{T-20} \frac{DO}{DO + k_{NIT}} \cdot N_2 \quad \dots (2.37) \end{aligned}$$

Nitrate Nitrogen (N_3)

$$\frac{dN_3}{dt} = k_{23}\theta_{23}^{T-20} \frac{DO}{DO + k_{NIT}} \cdot N_2 - (1 - P_{NH3}) \cdot a_{NC} \cdot G_P \cdot P - k_{3D}\theta_{3D}^{T-20} \frac{k_{NO3}}{k_{NO3} + DO} \cdot N_3 \quad \dots (2.38)$$

Where,

f_{ON} = fraction of organic nitrogen recycled from algal decay, unit less

a_{NC} = nitrogen / chlorophyll-a ratio

k_{12} = organic nitrogen mineralization rate, day⁻¹

θ_{12} = temperature correction coefficient

k_{23} = oxidation of ammonia nitrogen, day⁻¹

θ_{23} = temperature correction coefficient for ammonia oxidation

k_{3D} = nitrification rate, day⁻¹

θ_{3D} = temperature correction coefficient

k_{NIT} = half saturation constant for ammonia nitrogen oxidation

k_{NO3} = half saturation constant for nitrification

v_{NI} = settling velocity of particulate organic nitrogen

2.9 Dissolved Oxygen Kinetics

Five state variables are participant in the DO balance: phytoplankton carbon, ammonia, nitrate, CBOD and DO. The dissolved oxygen (DO) variation is modeled by quantifying the dependence of important oxygen production and consumption processes on a number of biological and physical factors. In a water body, the sources of DO are reaeration from the atmosphere and photosynthetic oxygen production. The major sinks of DO are oxidation of CBOD and NBOD waste input, sediment oxygen demand and use of oxygen for respiration by aquatic plants.

The time variation of the BOD and the DO content in a vertical water column is governed by

CBOD (L)

$$\frac{dL}{dt} = a_{OC} \cdot D_p \cdot P - k_d \theta_d^{T-20} \frac{C}{k_{BOD} + C} \cdot L - \frac{V_s(1-f_{DL})}{H} \cdot L - \frac{5}{4} \cdot \frac{32}{14} k_{3D} \theta_{3D}^{T-20} \frac{k_{NO3}}{k_{NO3} + DO} \cdot N_3 \quad \dots (2.39)$$

$$\begin{aligned} \frac{dC}{dt} = & k_2 \theta_2^{T-20} (C_s - C) + a_{OP} \cdot G_p \cdot P - k_d \theta_d^{T-20} \frac{C}{k_{BOD} + C} \cdot L \\ & - 4.57 \cdot k_{23} \cdot \theta_{23}^{T-20} \cdot \frac{C}{C + k_{NIT}} \cdot N_2 - a_{OP} \cdot k_{IR} \cdot P - \frac{SOD}{H} - 2.67 \cdot D_Z \cdot C_Z \end{aligned} \quad \dots (2.40)$$

Where,

C = vertically averaged DO concentration, mg / L

L = ultimate BOD concentration, mg / L

P = phytoplankton concentration, μ g / L chl-a

C_s = saturation value of DO concentration, mg / L

k_d = deoxygenation rate, day⁻¹

k_2 = reaeration rate, day⁻¹

k_{3D} = nitrification rate, day⁻¹

k_{BOD} = half saturation constant for BOD oxidation

a_{OP} = oxygen uptake or production per unit mass of algae, mg-O₂ / mg-C

a_{OC} = oxygen to carbon ratio for phytoplankton respiration, mg- O₂ / mg-C

SOD = sediment oxygen demand, gm / m².day

f_{DL} = fraction of dissolved BOD, unit less

D_Z and C_Z = death rate and concentration of zooplankton, respectively.

2.9.1 Reaeration co-efficient in river

The oxygen transfer coefficient in natural waters depends on (i) internal mixing and turbulence due to velocity gradients and fluctuation (ii) temperature (iii) wind speed (iv) waterfall, dams, rapids and (v) surface films.

Oxygen transfer as a function of internal mixing and turbulence has been the subject of much study and investigation in recent years. Holley (1975) has summarized the substantial literature on oxygen transfer, described the theory of oxygen transfer in some depth and explored the effect of the preceding influences. Bowie et al. (1985) have listed 31 formulas to be used in predicting k_2 in different water quality modelling. Most formulas have been developed based on hydraulic parameters such as depth and velocity, some also considered wind induced turbulent action on k_2 . This approach

would enable in predicting k_2 values at different flows to make computer simulations of streams water quality possible at different assumed conditions.

O'Connor & Dobbins (1956) proposed the following equation, which is now commonly used in predicting k_2 .

$$k_2 = \frac{(D_0 U)^{\frac{1}{2}}}{H^{\frac{3}{2}}} \quad \dots (2.41)$$

Where,

D_0 = molecular diffusion coefficient for oxygen in water, L^2 / T
 = $18.95 \times 10^{-4} \text{ ft}^2 / \text{day}$ ($1.76 \times 10^{-4} \text{ m}^2 / \text{day}$) at 20°C

U = current speed, L / T

H = average depth, L / T

For a particular stretch of river, H is the ratio of the volume to the surface area. This formula is valid for moderately deep to deep channels, $1 \leq H \leq 30 \text{ ft}$; $0.5 \leq U \leq 1.0 \text{ fps}$.

O'Connor & Dobbins also recommend that the formula is also applicable for shallow streams. If U is in ft / sec and H in ft , then the reaeration coefficient in day^{-1} is

$$k_2 = \frac{12.9 (U)^{\frac{1}{2}}}{H^{\frac{3}{2}}} \quad \dots (2.42)$$

O'Connor and Banks proposed the following formula to calculate k_2 , as a function of the mean tidal velocity and the wind speed (Thommann & Mueller, 1987):

$$k_2(20^\circ\text{C}) = \frac{3.9 V^{0.5}}{H^{\frac{3}{2}}} + \frac{0.728 W^{0.5} - 0.317 W + 0.0372 W^2}{H} \quad \dots (2.43)$$

Where,

V = tidal velocity, m/s

H = mean depth, m

W = wind speed, m/s at 10m above the water surface

A temperature correction coefficient of 1.024 is used for k_2 if temperature is other than 20°C .

2.9.2 Dissolved oxygen saturation

Dissolved oxygen saturation is an important water quality index used in predicting DO concentration. The DO saturation in water depends on water temperature, salinity and pressure. There are numerous formulas reported in the literature, based on temperature, salinity and pressure to calculate the DO saturation in the water body i.e. Elmore & Hayes, 1960; Bacca & Arnett, 1976; Johnson & Duke, 1976; Bauer et al., 1979; Benson & Krause, 1984.

The committee on Sanitary Engineering Research of the Sanitary Engineering Division of ASCE, conducted a study to determine the true saturation values through the normal range of water temperature and proposed the following equation for C_S for the temperature $0^\circ\text{C} \leq T \leq 30^\circ\text{C}$ (Elmore & Hayes, 1960):

$$C_S = 14.562 - 0.41022T + 0.007991T^2 - 0.000077774T^3 \quad \dots (2.44)$$

Where,

C_S = DO saturation, mg / L

T = water temperature, °C

The average relative error of Eq. (2.44) is 0.56% and the average absolute error is 0.05 mg/L. Also, this equation is applicable for zero dissolved chlorides. Hyer et al., (1971) developed an expression relating C_S to both water temperature and salinity, as:

$$C_S = 14.6244 - 0.367134T + 0.0044972T^2 - 0.0966S + 0.0002739S^2 \quad \dots (2.45)$$

Where,

T = water temperature, °C

S = salinity, ppt

Based on careful study of the mechanism of gaseous solubility, Hesong Hus (1988) developed a formula for C_S at equilibrium between gaseous phase and liquid phase as:

$$C_s = \exp \left\{ -17.15355 + 0.22629T + \frac{3.68938}{T} + \left[0.01166 - \frac{6.544}{T} \right] C_{ds} \right\} \quad \dots (2.46)$$

Where,

T = water temperature, °K

C_{ds} = chloride concentration, g/L

This formula is applicable to both fresh and sea water from 0°C to 50°C .

2.9.3 Oxygen production by algal biomass

The instantaneous rate of oxygen production by algal biomass due to photosynthesis ($\text{mg O}_2 / \text{L-day}$) can be expressed as

$$a_{OP}.G_p.P=0.00267 (CCHL).G_p.P \quad \dots (2.47)$$

Where,

P = concentration of phytoplankton, $\mu \text{ g chl-a / L}$

CCHL = ratio of organic carbon to chl-a (between 50 -100) and the stoichiometric equivalent of oxygen / carbon is 2.67.

2.9.4 Oxygen demanding waste inputs

The principal inputs affecting the DO are the municipal and industrial discharges of wastes, combined sewer outflows and separate sewer discharges, Such discharges include materials that exerts chemical oxygen demand (COD), carbonaceous biochemical oxygen demand (CBOD), nitrogenous biochemical oxygen demand (NBOD) and sediment oxygen demand (SOD), In domestic wastewaters, CBOO is exerted first before NBOO, normally as a result of a lag in the growth of the nitrifying bacteria necessary for oxidation: of the nitrogen forms; giving rise to the well-known two-stage BOD curve (Figure 2.5).

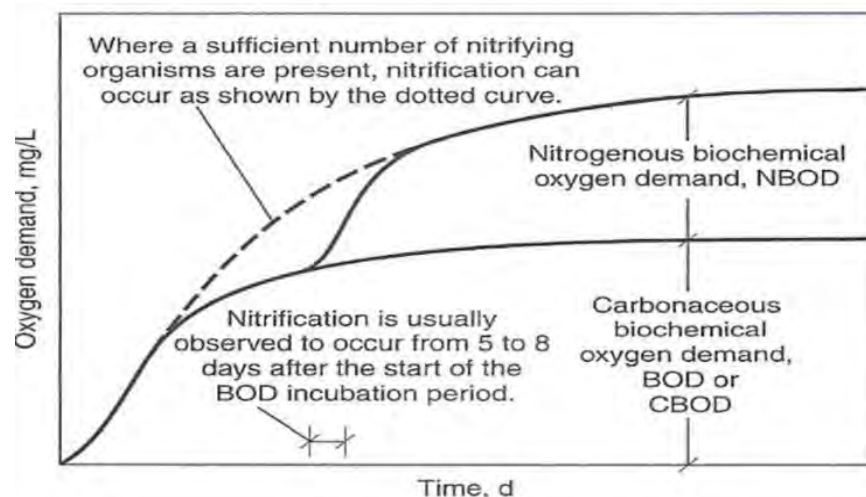


Figure 2.5: Definition sketch for the extraction of the carbonaceous and nitrogenous Biochemical Oxygen Demand in a waste sample (Metcalf and Eddy, 1977)

The CBOD is exerted by the presence of heterotrophic bacteria that are capable of deriving energy for oxidation from an organic carbon substrate. Municipal sewage and most rivers, estuaries and lakes contain large numbers of these heterotrophic organisms and the CBOD is exerted almost immediately. The introduction of oxygen demanding materials, either organic or inorganic, into a river cause depletion of the DO in water due to decomposition of the material using dissolved molecular oxygen.

2.9.5 Carbonaceous biochemical oxygen demand (CBOD)

There are two kinetics by which CBOD are simulated in water quality models: first order decay and simultaneous first order decay. In the latter case, CBOD is partitioned into more than one fraction; each fraction is degraded at a specific rate according to first order kinetics. The first order approximation for CBOD decay has been widely criticized, and multi-order or logarithmic models have been used by individual investigators. Martone (1976) in a study of BOD kinetics models, observed that first order kinetics did not universally describe observed BOD data. In a few cases, a two stage CBOD model resulted in a better statistical fit (McKewon et al. 1981). Although the short comings of the first order kinetics of CBOD have been widely discussed, the model is still the common method for simulating instream CBOD kinetics. Relative ease of computation, a long history of use and the absence of alternative formulations, which are universally and superior over a range of conditions, are probably responsible for this precedence.

The organic waste, as measured by CBOD are composed of two components:

- i) particulate BOD
- ii) dissolved BOD

Total BOD can be written as:

$$L = L_p + L_d \quad \dots (2.48a)$$

$$= f_p L + f_d L \quad \dots (2.48b)$$

Where, f_p and f_d are the fraction particulate and dissolved, respectively of the total BOD L . If L_p only settles without oxidation and L_d is oxidized, then for a control volume V , mass balance equation can be written as:

$$V \frac{dL}{dt} = v_s \cdot A \cdot L_p - k'_d \cdot V \cdot L_p$$

or,

$$\frac{dL}{dt} = - k_r \cdot L \quad \dots (2.49)$$

and, $k_r = v_s \cdot \frac{A}{V} \cdot L_p + k'_d \cdot f_d = k_s + k_d$

where k_s is the effective loss rate due to settling, k_d is the effective de-oxygenation rate and k_r , is the overall loss rate of CBOD from water column due to both settling and oxidation of soluble BOD.

Nearly all water quality models characterize CBOD decay with first order kinetics represented by

$$\frac{dL}{dt} = - k_d \cdot L \quad \dots (2.50)$$

Where,

L = ultimate BOD, mg / L

k_d = first order rate coefficient, day⁻¹

t = time, days

The rate of change of DO deficit in a stream is given by

$$\frac{dD}{dt} = k_d L_0 e^{-k_d t} - k_2 \cdot D \quad \dots (2.51)$$

The solutions of Eq. (2.49) and Eq. (2.50) give the classic Streeter-Phelps (1925) equation for the BOD and DO profiles along a river stretch and are given by the equations:

$$L = L_0 \cdot e^{-k_d t} \quad \dots (2.52)$$

and

$$D = \frac{k_d L}{k_2 - k_d} [e^{-k_d t} - e^{-k_2 t}] + D_0 e^{-k_2 t} \quad \dots (2.53)$$

Where,

D = DO deficit, mg / L

D_0 = initial DO deficit, mg / L

k_2 = stream reaeration rate, day⁻¹, base e

t = time of flow in the stretch, days.

The Streeter- Phelps equations are based on the assumption that BOD (point source) and oxygen are being removed along the stretch by the bacterial oxidation of the organic matter and oxygen is being replaced by reaeration at the surface.

This representation of BOD / DO for waste load allocation modelling would require to estimate the following three independent factors:

- (a) The magnitude of the ultimate BOD of the point sources and the resulting instream spatial distribution.
- (b) The magnitude and spatial distribution of the instream CBOD removal rate.
- (c) The ratio of point source ultimate BOD to 5-day CBOD.

The oxidation of the CBOD is a bacterially mediated process. The rate of k_d is a function

of the water temperature, the effect of temperature on k_d may be approximated by

$$(k_d)_T = (k_d)_{20} (1.047)^{T-20} \quad \dots (2.54)$$

Where,

$(k_d)_T$ = deoxygenation rate constant at temperature T° C

$(k_d)_{20}$ = deoxygenation rate constant at 20° C

The value of 1.047 was originated from the work of Phelps (1925). This value is an average value obtained from three separate studies with a reported standard deviation of 0.005. Studies by Schroeffer et al. (1964) indicated that the value of 1.047 is valid between 20° C and 30° C, but higher values are appropriate at lower temperatures. Fair

et al. (1968) suggest that base value of 1.11 and 1.15 for 10° C and 5°C respectively. The base 1.047 is reported to range from 1.02 to 1.09 (Zison et al., 1978).

The laboratory BOD removal rate k_l differ from instream BOD removal rate k_d , because the oxidation of BOD in natural water body includes phenomena that are not part of the BOD bottle rate. Such phenomena include bio sorption by biological slimes on river bottom. Stream turbulence and roughness and the density of attached organisms also affect the degree of this type of BOD removal. It is for this reason that attempts have been made to correlate k_d to channel characteristics such as depth, flow and wetted perimeter. As an approximation, values of k_d range from about 0.1 to 0.5 per day for deeper bodies of water (depth > 5 ft) to 0.5 to 3.0 per day for shallow stream (depth < 5 ft). Bosko (1966) expressed k_d interms of k_l for streams by the expression

$$k_d = k_l + n \left(\frac{V}{D} \right) \quad \dots (2.55)$$

Where,

k_l = laboratory determined CBOD rate

V = stream velocity, L / T

D = stream depth, L

n = coefficient of bed activity, is a function of stream slope, dimensionless.

In water quality modelling, the deoxygenation rate constant k_d are often correlated with the hydraulic parameters. Bansal (1975) attempted to predict deoxygenation rates based on Reynold's Number and Froude number. This approach was found to have limited applicability (Novotny & Krenkel, 1975). Wright and McDonnell (1979), from a review of 23 river systems and one laboratory flume resulting in 45 coefficient estimates from field data, obtained a range of k_d from 0.08 to 4.24 per day, for flow from 4.6 to 8760 cfs, wetted perimeters from 11.8 to 686 ft and depth from 0.9 to 32 ft. They suggested the following relationship at 20° C which gives a good fit to the observed data:

$$k_d = 10.3 Q^{-0.49} \quad \dots (2.56)$$

Where, Q = flow rate, ft³/s

Wright and McDonnell (1979) also observed that for flow condition greater than about 800 cfs, k_d is not a function of flow rate and consistent with bottle rates for the effluent. The lower limit of the applicability of this expression is approximately 10 ft³/sec. Below this flow rate, deoxygenation rates noted to consistently fall in the range of 2.5 -3.5 per day, independent of stream flow.

In Hydro-science (1971), the relationship between k_d at 20° C and depth is suggested

$$k_d = 0.3 \left(\frac{H}{8} \right)^{-0.434} \quad \text{for } 0 \leq H \leq 8 \quad \dots (2.57a)$$

$$= 0.3 \quad \text{for } H > 8 \quad \dots (2.57b)$$

Where, H is the depth in ft and k_d is in day⁻¹.

An expression based on channel wetted perimeter was also found successful in predicting k_d for flow rates between 10 and 800 cfs:

$$k_d = 39.6 P^{-0.84} \quad \dots (2.58)$$

Where, P is the wetted perimeter in ft.

2.9.6 Sediment oxygen demand (SOD)

Sediment oxygen demand is a term that includes oxygen demand from two separate processes: (a) biological respiration of all living organisms in the sediment and (b) oxidation of organic matter in the sediment. Oxygen demand by benthic sediments and organisms can represent a large fraction of oxygen consumption in surface water. Benthic deposits at any given location in an aquatic system are the result of transportation and deposition of organic materials. This organic matter can exert a high oxygen demand under some circumstances. In certain locations, benthic deposits may be responsible for about 50% of the total oxygen depletion in a given section of a river.

The organic matter oxygen demand is influenced by two different phenomena (Martin & Bella, 1971): firstly, the rate at which oxygen diffuses into the bottom sediments and is then consumed and secondly, the rate at which reduced organic substances are conveyed into the water column and are then oxidized. The organic matter settling to the bottom, are decomposed both aerobically and anaerobically, depending on specific conditions. The oxygen consumption in aerobic decomposition represents dissolved oxygen sink for the water body. The oxygen utilized per unit area and time ($\text{g O}_2 / \text{m}^2\text{-day}$) is the SOD.

For a control volume in contact with the bottom, the rate of dissolved oxygen depletion due to SOD is given by

$$r_s = \frac{k_s A_B}{V} = \frac{k_s}{H} \quad \dots (2.70)$$

Where,

r_s = rate of oxygen consumption or demand due to SOD, $\text{M/L}^3\text{T}$

k_s = sediment oxygen uptake rate, $\text{M/L}^2\text{T}$

A_B = contributing bottom area, L^2

V = volume of the overlying water column, L^3

H = depth of control volume, L

Measurements of k_s can be accomplished using a flux chamber to isolate the sediments from the overlying water. DO in the chamber is measured versus time, from which k_s can be determined. In-situ measurements are preferable but their reliability is often questionable because of spatial variability and because the bottom shear exerted by the flow is difficult to reproduce in the flux chamber. For preliminary analysis, the following can be used for k_s : 0.2 - 1.0 $\text{g O}_2 / \text{ft}^2\text{-day}$ (2 - 10 $\text{g O}_2 / \text{m}^2\text{-day}$) in the vicinity of municipal outfalls and natural estuaries mud, 0.02 - 0.10 $\text{g O}_2 / \text{ft}^2\text{-day}$ (0.2-1.0 $\text{g O}_2 / \text{m}^2\text{-day}$) for sandy bottom, and 0.005-0.01 $\text{g O}_2 / \text{ft}^2\text{-day}$ (0.05-0.10 $\text{g O}_2 / \text{m}^2\text{-day}$) for mineral soils.

The uptake rate k_s can be estimated based on solids deposition rates, by assuming that the rate of decomposition equals to that of deposition

$$k_s = r_o . a . R_d \quad \dots (2.71)$$

Where,

r_0 = oxidizable organic content of discharged solids, typically 0.5 to 0.6 for secondary effluent and 0.80 for primary effluent.

a = oxygen/sediment stoichiometric ratio = 1.07

R_d = solid deposition rate, M/L²T

The factors that influence oxygen depletion by sediments are sludge depth, overlying oxygen concentration, sediment resuspension, photosynthetic activity, salinity, pH and temperature.

The depth of deposit is of some interest since the uptake rate is dependent on this parameter. Oldaker et al. (1966) found a linear relationship between estimates of the ultimate amount of oxygen needed for complete stabilization and depth of sediment (from domestic sewage) over the range 1.5- 20 cm. Others (Owens et al., 1964; Fillos and Molof, 1972) have indicated that uptake is independent of sludge depth for depth greater than about 2- 8 cm.

It is generally assumed that the uptake is independent of the oxygen concentration in the overlying waters as concluded by Baity (1938) for 2- 5 mg/L DO range. Edwards and Owens (1965) indicated that the uptake rate varies as the DO to about the 0.45 power. The benthic oxygen consumption depends on the DO concentration in the overlying water. An empirical approach to correlate SOD with the overlying DO concentration (Edwards and Rolley, 1965; McDonnell and Hall, 1969) is given as:

$$SOD = a.C^b \quad \dots (2.72)$$

Where, a, b = empirically determined constants.

In the McDonnell and Hall (1969) study, b was found to be 0.30 and a to vary from 0.09 to 0.16, primarily as a function of the population density of benthic invertebrates. Lam et al. (1984) use a Michaelis - Menten relationship to express the effect of overlying oxygen on SOD

$$\frac{dC}{dt} = -\frac{k_s A_s}{V} \cdot \frac{C}{K_{O_2} + C} \quad \dots (2.73)$$

Where,

A_s = area of the sediment, m²

V = volume of water layer, m³

k_{O_2} = oxygen half saturation constant, mg/L.

Temperature effects on SOD are modeled approximately in the 10 - 30°C range by the following relationship

$$(k_b)_T = (k_b)_{20} \theta^{T-20} \quad \dots (2.74)$$

Where,

$(k_b)_T$ = the rate at ambient temperature, day⁻¹

$(k_b)_{20}$ = the rate at 20° e, day⁻¹

θ = the temperature coefficient for adjusting the rate.

The temperature coefficient for SOD as reported in the literature varies between 1.047-1.13. (Zison et al., 1978). A value of 1.065 is often used. Below 10° C, SOD decreases more rapidly than indicated by Eq. (2.74) and approaches zero in water temperature range of 0- 5° C. The biological effects on SOD is usually neglected while modelling SOD, because of complexity of modelling benthic micro-organisms. The spatial and seasonal variability in SOD caused by sediment biological processes and communities' results in variation in SOD that modelers appear to account for by varying the temperature coefficient.

Substrate variability are modeled by dividing the oxygen demanding materials (C, N) in the sediments into multiple compartments. The decay processes of sediment organic materials generate concentration of CBOD and NBOD constituents in interstitial waters. Then both CBOD and NBOD are released to the water column where they subsequently decay in the appropriate compartments. In addition to CBOD release, oxygen utilization in the interstitial water is computed as oxygen equivalents and diffusion into the interstitial water compartment is determined (Di Toro & Connolly, 1980).

2.9.7 Modelling of oxygen consumption

DO in the water is taken up by oxidation of carbonaceous organic wastes, the oxidation of ammonia to nitrate nitrogen during nitrification and the respiration of the phytoplankton. The oxidation of CBOD and ammonia are assumed to be first order reactions and temperature dependent. The algal respiration rate is typically in the range of 0.05-0.15 per day (Bowie et al., 1985, Thomann and Mueller; 1987) and a temperature co-efficient of 1.08 is assumed in the study.

In addition, DO is removed through respiration by the benthic organisms (SOD). SOD is determined by the diffusion exchange rate of DO from the water column to bottom sediment through the process of model calibration.

A computer program of the kinetic transformations of the modeled water quality parameters has been developed based on the mass balanced equations discussed above. The program is developed under the modelling framework of the WASP in FORTRAN 77 programming language.

CHAPTER THREE

METHODOLOGY

3.1 Introduction

This research work aims at assessment of water quality of Buriganga River and development of a 1-D water quality model to analyze the spatial and temporal distribution of different water quality parameters using finite difference (segment) method. The water quality assessment was based on systematic collection of water samples from selected locations of Buriganga River and analysis of the water samples (both in-situ and in laboratory) for important water quality parameters. The 1-D developed model was applied to the main reach of Buriganga river with a reach length of approximate 13 km. For executing and verifying the water quality model, extensive amount of data on hydrodynamic and water quality parameters are necessary. Different hydrodynamic parameters which are essential for preparing the water quality model such as river stage, cross sectional properties, mean water velocity, discharges were obtained from hydrodynamic model and preliminary data were collected from Bangladesh Water Development Board (BWDB). Water quality data was generated through collection and analysis of five sets of water samples during January 2017 and March 2018. Apart from these, secondary water quality data have also been collected from Department of Environment (DoE), Bangladesh and different reports and journals.

3.2 Study Area

In this study, portion of Buriganga river from Boshila Bridge to Somshan Ghat near Postagola Bridge is selected as the study reach to assess the existing water quality. In fact, almost all major urban and industrial establishments along Buriganga River are located within this reach. Water quality model development process needs considerable amount of field data, both temporal and spatial. In order to assess spatial variation of water quality, river water samples were collected from nine sampling locations along the selected reach of the Buriganga River during the months of

January, February and March of the year 2017 and February and March of the year 2018. These sampling locations are Boshila Bridge, West Hazaribagh, Hasan Nogar, Huzur Para, Nurbag, Showari Ghat, Sadar Ghat, Faridabad and Postagola Bridge. Again, direct measurements of wastewater discharges from major point sources (Rayer Bazar khal, Kamrangir Char khal) were carried out during the sampling period. The wastewater discharge and concentrations of water quality parameters (from laboratory testing) were used for estimating waste loads. Figure 3.1 and Table 3.1 show the study area and the GPS (Global Positioning System) data of sampling locations, respectively.

3.3 Collection of Water Samples

River water samples were collected from nine locations along the Buriganga river during the dry season of 2017 (January, February and March) and dry season of 2018 (February and March); during the dry season, water quality deteriorates and gets worse due to low river water flow (due to lower upstream flow and low precipitation) and heavy waste load discharging into the river. In each sampling location, two water samples were collected: one for measuring different water quality parameters and another for the determination of phytoplankton chlorophyll-a. Sampling in the river were done at the mid-stream of the selected locations and water samples were collected approximately 0.5 m to 0.7 m below the water surface. Water samples were then collected in 500 mL acid washed plastic bottles for further laboratory testing. Along with this 1.5-liter pre-washed dark plastic bottles were used for collecting water samples for chlorophyll-a measurement. This was done to avoid the direct entry of sunlight into the bottle. Before filling the samples, the sampling bottles were rinsed rigorously with the water being collected.

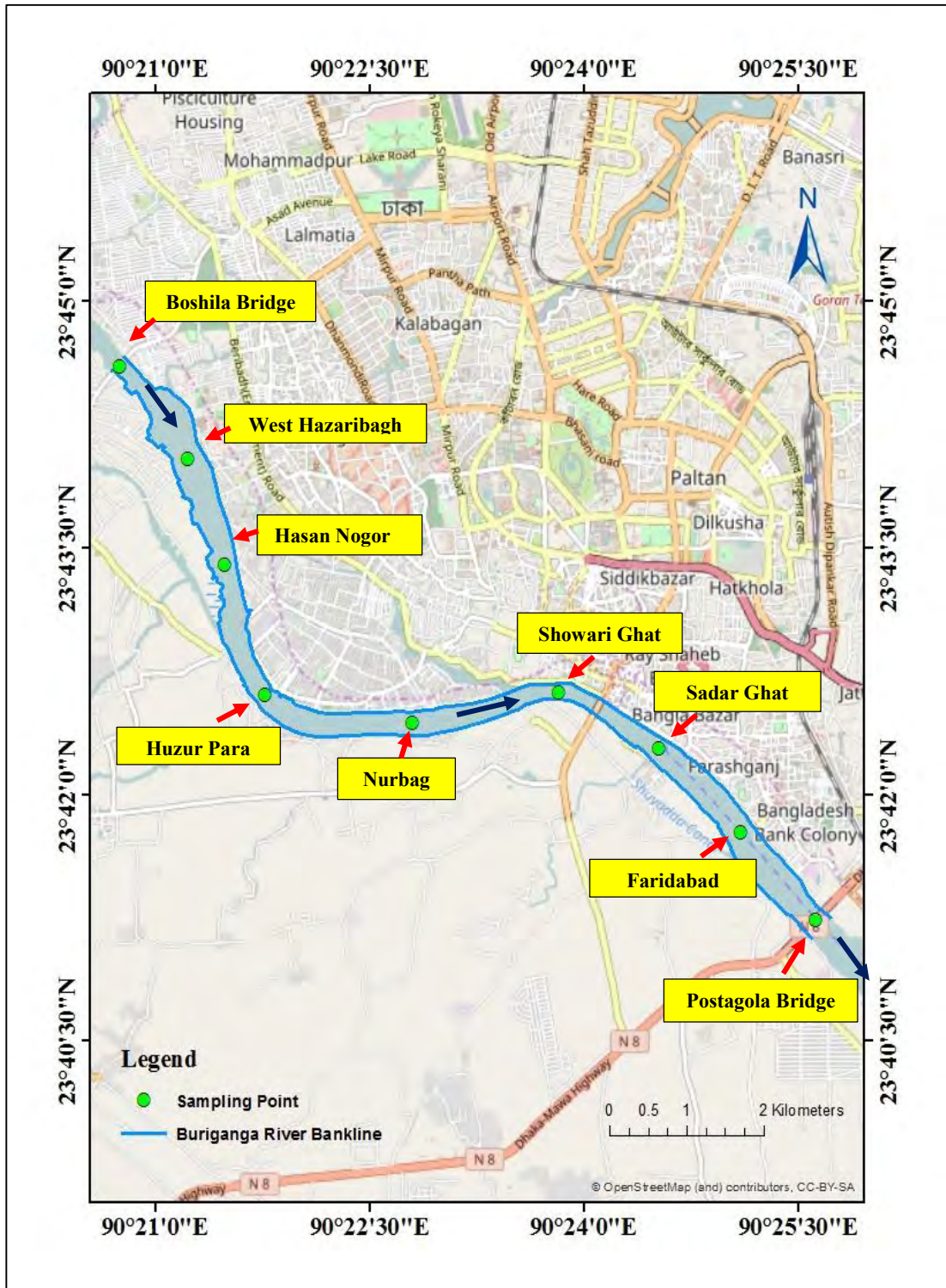


Figure 3.1: Study area showing the sampling locations

Table 3.1: Global Positioning System data of the sampling locations

Sl. No.	Sample ID	Latitude	Longitude	Location
1	B-1	23°44'35.79"N	90°20'44.76"E	Boshila Bridge
2	B-2	23°43'57.30"N	90°21'15.68"E	West Hazaribagh
3	B-3	23°43'6.88"N	90°21'32.86"E	Hasan Nogor
4	B-4	23°42'30.21"N	90°21'52.64"E	Huzur Para
5	B-5	23°42'25.15"N	90°22'45.96"E	Nurbag
6	B-6	23°42'37.32"N	90°23'45.30"E	Showari Ghat
7	B-7	23°42'16.56"N	90°24'30.03"E	Sadar Ghat
8	B-8	23°41'45.42"N	90°25'6.60"E	Faridabad
9	B-9	23°41'13.44"N	90°25'37.48"E	Postagola Bridge
10	WL-1	23°44'31.15"N	90°21'4.66"E	Rayer Bazar khal (d/s of Boshila Bridge)
11	WL-2	23°42'42.77"N	90°23'9.02"E	Kamrangir Char khal (d/s of Nurbag)

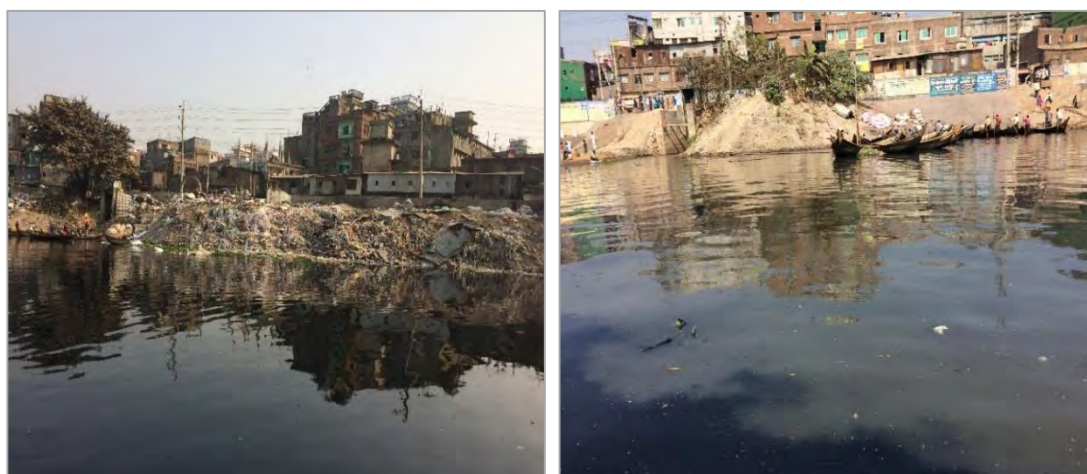


Figure 3.2: Present status of the Buriganga river

In-situ field measurements were done for several parameters (e.g., pH, DO, EC) because real time measurements always offer higher level of accuracy in measurements. Other parameters were measured in the laboratory by following the Standard Methods.



Figure 3.3: Collecting river water samples

3.4 In-situ Measurement of Water Quality

At each sampling location the following parameters were measured in-situ during sample collection:

- pH
- Temperature
- Dissolved Oxygen (DO)
- Electric Conductivity (EC)

Temperature and DO were measured at 0.5 m to 0.6 m below the water surface with a portable DO meter. After measuring the DO, water samples were collected from that selected location for other analyses. pH was measured with a portable pH meter and electrical conductivity was measured by using a portable conductivity meter.



Figure 3.4: Measuring Dissolved Oxygen of the river water at a selected location

3.5 Procedures for Laboratory Analysis of River Water Samples

Laboratory analysis was conducted to determine the following parameters:

- Biochemical Oxygen Demand (BOD)
- Chemical Oxygen Demand (COD)
- Ammonia Nitrogen ($\text{NH}_3\text{-N}$) and Nitrate Nitrogen ($\text{NO}_3\text{-N}$)
- Orthophosphate (PO_4^{3-})
- Suspended Solids (SS)
- Phytoplankton

For chemical oxygen demand (COD), 5-day biochemical oxygen demand (BOD_5) and Chlorophyll-a determination, collected water samples were immediately transferred to the laboratory. The remaining samples were preserved at 4°C in a refrigerator for further analysis. Measurement of ion concentrations (NH_3^- , NO_3^- , PO_4^{3-}) with a spectrophotometer always require filtered water samples. Also, determination of dissolve solids requires a filtered water sample. A portion (approx. 200 mL) of each collected water sample was filtered immediately after bringing those into the laboratory for these analyses. Determination of ammonia (NH_3^-), nitrate (NO_3^-) and orthophosphate (PO_4^{3-}) concentrations of the samples were carried out within 36 hours.



Figure 3.5: Filtering of river water samples

Ammonia, nitrate, orthophosphate concentrations were determined with a spectrophotometer (HACH, DR/4000 UV). Concentration of ammonia nitrogen ($\text{NH}_3\text{-N}$) was measured by the Nessler method (SM 4500- NH_3 B), concentration of nitrate nitrogen ($\text{NO}_3\text{-N}$) was measured by the cadmium reduction method (SM 4500- $\text{NO}_3\text{-N-F}$) and concentration of orthophosphate (PO_4^{3-}) was measured by the ascorbic acid method (SM 4500-P E). Suspended solids were determined from the difference between the total solids (TS) and the total dissolved solids (TDS) concentrations using oven dry method (SM 2540 D).



Figure 3.6: Measurement of ion concentrations (NH_3^- , NO_3^- , and PO_4^{3-}) in HACH DR-4000U spectrophotometer.



Figure 3.7: TDS beakers with water samples before drying in the oven (left) and cooling TDS beakers before weighing (right).

Chemical Oxygen Demand (COD) was measured using reactor digestion method (SM 5220 D). For measuring COD, HACH DR 2010 spectrophotometer was used. As the quality of river water was poor, high range (HR) COD vials (16 mm test tubes) were used for measuring COD.



Figure 3.8: Measuring COD in HACH DR-2010 spectrophotometer.

5 days Biochemical Oxygen Demand (BOD_5) was measured using Winkler bottle method. The water samples were filled in airtight bottles and incubated at 20 °C for 5 days. The dissolved oxygen (DO) content of the samples were determined before and after five days of incubation at 20°C and the BOD values were calculated from the difference between initial and final DO.



Figure 3.9: Preparing BOD bottles for DO measurement.

Phytoplankton chlorophyll-a was analyzed by the spectroscopic method (Aminot and Rey, 2000). Samples were filtered with GF/C filters in the laboratory. The filters were then soaked in 15 mL centrifuge tubes containing 10 mL 90% acetone and were kept in dark environment at 4°C for 24 hours. After centrifuging the extracts for 10 minutes, Chlorophyll-a concentration was estimated after measuring absorbance at different wavelengths according to the equations of Jeffrey and Humphrey (1975). For measuring chlorophyll-a concentration HACH DR-4000U spectrophotometer was used.

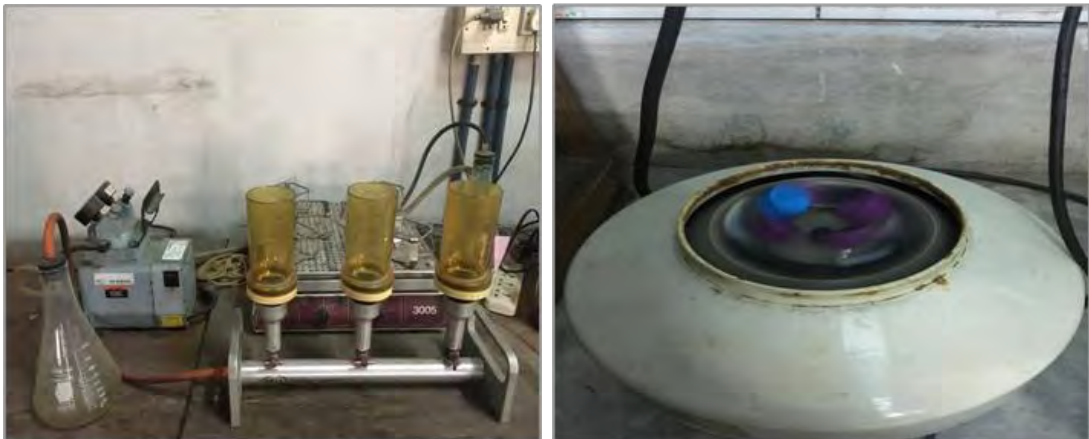


Figure 3.10: Apparatus used for filtration (left) and Centrifuge process is going on (right)

3.6 Modeling Approach

From the collected primary and secondary water quality data, a one-dimensional quasi-steady state water quality model has been developed using the finite segment approach under the modeling framework of WASP7.3, developed by U.S. Environmental Protection Agency (Wool et al., 2009). It is a freeware water quality modeling tool that helps users to interpret and predict water quality responses to natural phenomena and man-made pollution for various pollution management decisions. EUTRO is one of the salient components of WASP7.3 that is applicable for modeling eutrophication in the water column. EUTRO module was used to develop the water quality model for the study area. Here seven state variables were considered in the water quality model development. These are: Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), Ammonia-Nitrogen ($\text{NH}_3\text{-N}$), Nitrate-Nitrogen ($\text{NO}_3\text{-N}$), Orthophosphate (PO_4^{3-}), Total Suspended Solids (TSS) and Phytoplankton Chlorophyll-a.

The study reach was divided into nine longitudinal segments of various lengths. The geometry of these segments was determined from the channel morphometric data of the river and water level during the study period. The water quality model was calibrated using the primary field data and the hydrodynamic data (source: BWDB and HEC-RAS model) of the river during the month of February and March of 2017 and verification of the calibrated model was done by using the field sampling data and the hydrodynamic data of the river during the month of February and March of 2018. Kinetic constant values were estimated by trial and error method. For this, several runs were made by varying the kinetic constants and coefficients within the range given in the literature (Bowie et al, 1985; Karim, 1996; Ghosh and Mcbean, 1998) to minimize the differences between the computed and the observed values. After finalizing the kinetic constant values, water quality model was validated and used for future prediction.

CHAPTER FOUR

ASSESSMENT OF RIVER WATER QUALITY

4.1 Introduction

An extensive river water sampling campaign was conducted in order to collect water quality data of the Buriganga river in this study. Dry season of the year 2017 was the transition period for the relocation of tannery industries from Hazaribagh (near the Buriganga river) to Savar, Dhaka. Out of 154 tanneries that got plots in Savar Tannery Estate, 106 tanneries have already moved there from Hazaribagh up to March 2018 and started the production of wet blue leather in Savar. Therefore, dry season of 2017 (January to March 2017) was selected for extensive collection. Besides, in order to check the change in water quality of the river after the major tannery shifting, water samples were collected during the month of February and March of the year 2018. This Chapter presents an assessment of the water quality of Buriganga River based on analysis of water quality data generated in this study, with particular focus on the possible impact of tannery industry relocation.

4.2 Collection and Analysis of Water Samples

As mentioned in chapter three, water samples of Buriganga river water were collected from 9 locations during the dry season of the year 2017 and 2018 for laboratory testing. In order to estimate waste load input from major point sources, two major point sources were selected.

The water samples collected from the Buriganga River were tested for eleven water quality parameters. These parameters were selected because these reasonably describe the status of pollution of a river, when no special type of pollution is to be studied. The water quality parameters tested are:

- pH
- Dissolved Oxygen (DO)
- Water Temperature
- Electric Conductivity (EC)

- Biochemical Oxygen Demand (BOD)
- Chemical Oxygen Demand (COD)
- Ammonia as $\text{NH}_3 - \text{N}$
- Nitrate as $\text{NO}_3^- - \text{N}$
- Orthophosphate as $\text{PO}_4^{3-} - \text{P}$
- Total Solids (TS), Total Dissolved Solids (TDS), Total Suspended Solids (TSS)
- Chlorophyll – a

4.3 Water Quality of Buriganga River

Water samples were collected during first three months of the year 2017 and February and March month of the year 2018 from nine different monitoring locations and wastewater samples were collected from two major point sources along the Buriganga river. To summarize the findings of the data analyses, both from in-situ and laboratory testing, monitoring locations from B-1 (Boshila Bridge) to B-9 (Postagola Bridge) have been considered to represent the status of the Buriganga river (see Fig 4.1).

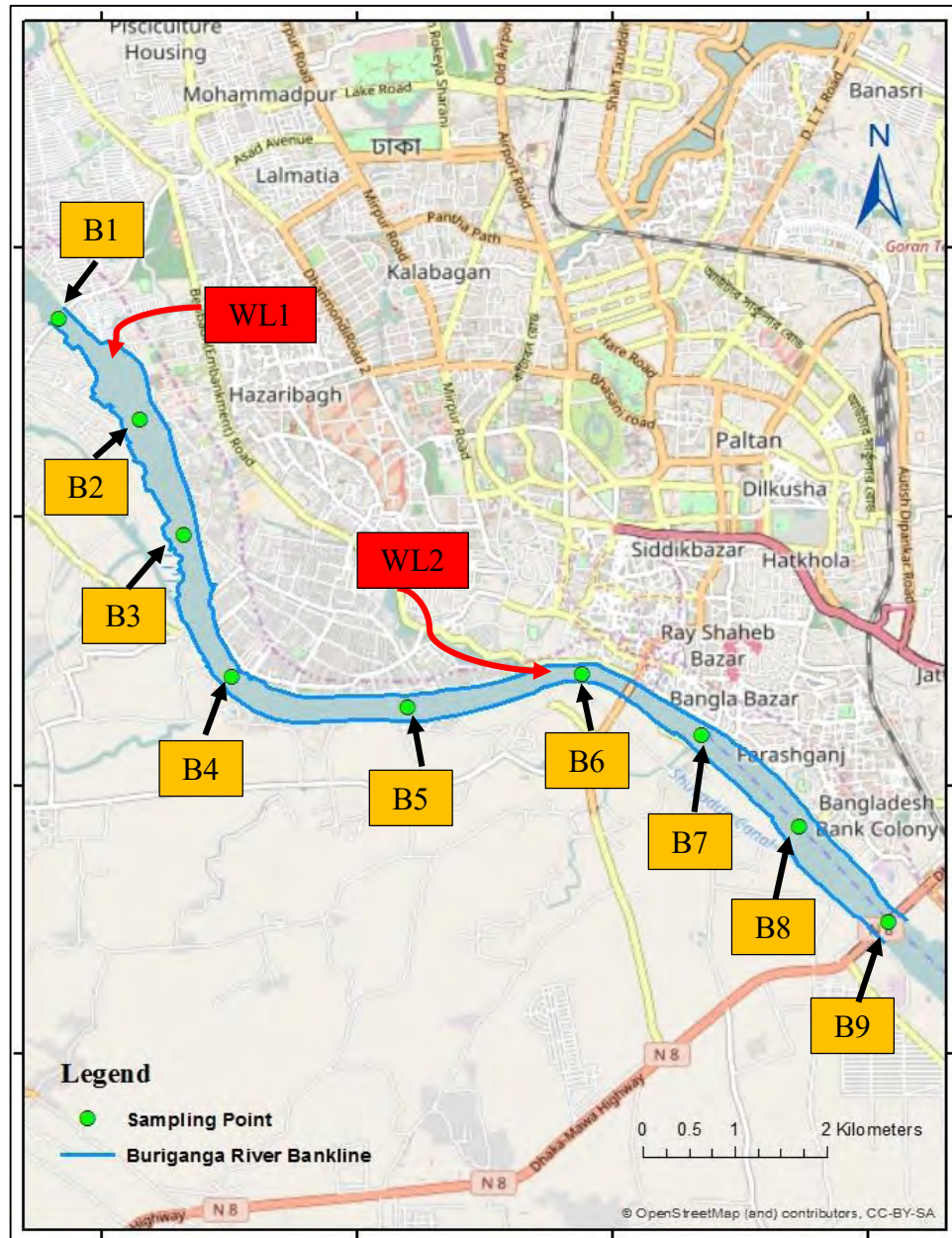


Figure 4.1: Sampling locations along Buriganga River

Tables 4.1 to 4.5 show the characteristics of the water samples collected from the Buriganga River during the dry season of the year 2017 and 2018. These data provide a good picture of the characteristics of the Buriganga River, including effect of tannery relocation on the water quality. This Section presents a detail analysis (parameter-wise) of the data presented in these Tables.

Table 4.1: Characteristics of water samples collected from Buriganga river during January, 2017

Parameters	Locations along the Buriganga River								
	B-1	B-2	B-3	B-4	B-5	B-6	B-7	B-8	B-9
pH	7.48	7.47	7.51	7.44	7.26	7.39	7.38	7.39	7.47
DO (mg/L)	0.31	0.28	0.3	0.31	0.3	0.25	0.24	0.33	0.35
Temp. (°C)	23.7	23.6	23.7	23.7	23.6	23.5	23.5	23.3	23.4
EC (μS/cm)	960	950	932	929	932	947	939	927	934
COD (mg/L)	85	89	66	65	68	102	101	79	78
BOD (mg/L)	24	22	14	12	12	30	28	18	14
Ammonia (mg/L)	10.25	8.75	8.5	8.75	10.75	12.5	12.35	12.4	12.25
Nitrate (mg/L)	1.5	3	2	1.5	1.5	3	2	2.5	2
Orthophosphate (mg/L)	3.38	2.62	2.04	1.28	1.44	1.9	1.68	1.74	1.62
Total Solids (mg/L)	582	576	563	553	552	558	559	559	558
TDS (mg/L)	548	546	534	530	531	535	531	528	529
TSS (mg/L)	34	30	29	23	21	23	28	31	29
Chlorophyll-a (μg/L)	13.99	13.4	10.84	10.43	11.07	10.02	11.19	10.84	9.13

Table 4.2: Characteristics of water samples collected from Buriganga river during February, 2017.

Parameters	Locations along the Buriganga River								
	B-1	B-2	B-3	B-4	B-5	B-6	B-7	B-8	B-9
pH	7.42	7.64	7.61	7.73	7.74	7.69	7.72	7.58	7.52
DO (mg/L)	0.26	0.23	0.25	0.28	0.29	0.24	0.25	0.28	0.33
Temp. (°C)	23.5	23.5	22.9	23	23.1	23	23	23.1	23.3
EC (µS/cm)	1,021	1,028	1,022	1,010	1,015	1,010	1,008	1,003	989
COD (mg/L)	108	105	105	96	111	130	112	94	83
BOD (mg/L)	28	30	28	24	32	36	32	24	24
Ammonia (mg/L)	13.65	13.45	13.3	13.43	13.5	14.28	13.8	14.15	13.9
Nitrate (mg/L)	3	4.5	3.5	3.5	3.5	5	3	3	2.5
Orthophosphate (mg/L)	3.4	2.25	2.25	1.8	2.4	2.5	1.9	2.05	2.05
Total Solids (mg/L)	636	649	633	619	621	622	613	584	572
TDS (mg/L)	609	616	605	601	599	596	577	553	548
TSS (mg/L)	27	33	28	18	22	26	36	31	24
Chlorophyll-a (µg/L)	4.84	10.41	10	9.05	9.05	6.16	6.57	8.22	8.22

Table 4.3: Characteristics of water samples collected from Buriganga river during March, 2017.

Parameters	Locations along the Buriganga River								
	B-1	B-2	B-3	B-4	B-5	B-6	B-7	B-8	B-9
pH	7.56	7.68	7.55	7.57	7.64	7.63	7.65	7.72	7.73
DO (mg/L)	0.24	0.21	0.22	0.27	0.28	0.24	0.22	0.28	0.32
Temp. (°C)	25.1	25.2	25.3	25.5	25.4	25	25.3	25.2	25.3
EC (µS/cm)	1,189	1,176	1,172	1,184	1,180	1,184	1,181	1,185	1,177
COD (mg/L)	119	113	120	126	120	138	121	111	96
BOD (mg/L)	28	34	28	28	28	34	28	25	20
Ammonia (mg/L)	14.2	14.53	13.8	14.5	14.7	16.4	15.95	16.18	16.15
Nitrate (mg/L)	3	6	4.5	4	4	5.5	3.5	3.5	3
Orthophosphate (mg/L)	5.54	5.38	4.92	4.74	5.26	5.3	4.58	3.56	3.44
Total Solids (mg/L)	746	734	726	715	706	700	683	691	682
TDS (mg/L)	703	695	691	696	680	643	648	655	654
TSS (mg/L)	43	39	35	19	26	57	35	36	28
Chlorophyll-a (µg/L)	1.75	3.53	3.15	1.86	1.86	1.69	0.87	4.86	2.52

Table 4.4: Characteristics of water samples collected from Buriganga river during February, 2018.

Parameters	Locations along the Buriganga River								
	B-1	B-2	B-3	B-4	B-5	B-6	B-7	B-8	B-9
pH	7.96	8.15	8.06	8.09	7.95	7.97	7.94	7.89	7.84
DO (mg/L)	0.39	0.36	0.32	0.35	0.28	0.22	0.27	0.3	0.32
Temp. (°C)	23.2	23.3	23.2	23	23.1	23.1	23.1	23	22.9
EC (μS/cm)	940	964	966	971	978	980	968	962	961
COD (mg/L)	67	57	62	59	59	82	78	67	63
BOD (mg/L)	16	12	14	14	12	22	20	16	14
Ammonia (mg/L)	10.5	12.25	11.25	11.25	11.75	13.25	12.5	11.5	11.75
Nitrate (mg/L)	1	1.5	1.5	1.5	1.5	2	2	1.5	1
Orthophosphate (mg/L)	2.96	2.8	2.66	2.98	2.7	3.14	2.88	2.48	2.54
Total Solids (mg/L)	599	598	607	596	607	597	594	580	576
TDS (mg/L)	575	574	581	571	584	572	579	564	562
TSS (mg/L)	24	24	26	25	23	25	15	16	14
Chlorophyll-a (μg/L)	2.31	5.91	3.94	3.73	5.44	4.08	6.22	2.31	2.49

Table 4.5: Characteristics of water samples collected from Buriganga river during March, 2018.

Parameters	Locations along the Buriganga River								
	B-1	B-2	B-3	B-4	B-5	B-6	B-7	B-8	B-9
pH	7.79	7.89	7.94	7.67	7.77	7.82	7.76	7.74	7.77
DO (mg/L)	0.36	0.35	0.31	0.34	0.3	0.21	0.3	0.3	0.31
Temp. (°C)	24.3	24.2	24.4	24.7	24.5	24.1	24	23.9	24.1
EC (µS/cm)	989	1,015	995	991	1,005	1,023	978	996	981
COD (mg/L)	74	77	69	65	68	83	80	73	71
BOD (mg/L)	18	20	18	16	16	24	20	18	18
Ammonia (mg/L)	10.8	13.25	13.13	12.85	12.68	13.75	12.68	12.25	12.38
Nitrate (mg/L)	2	3	2.5	2.5	2	3.5	2.5	1.5	2
Orthophosphate (mg/L)	3.14	3.56	2.89	2.78	2.92	3.18	2.98	2.67	2.72
Total Solids (mg/L)	632	640	627	619	626	638	602	609	617
TDS (mg/L)	599	603	598	588	600	606	578	590	596
TSS (mg/L)	33	37	29	31	26	32	24	19	21
Chlorophyll-a (µg/L)	2.03	4.72	3.55	2.8	3.65	2.89	3.55	3.57	2.51

pH

From the in-situ measurements, it was found that pH value of the Buriganga river varied from 7.26 to 8.145. In January 2017, pH value ranges from 7.26 to 7.51 along the Buriganga river. During February, slightly increase in pH value was found, ranging from 7.42 to 7.74; in March of 2017, pH ranged from 7.55 to 7.73. Higher pH value was found during the February, 2018 that ranged from 7.84 to 8.15. Highest pH was recorded near West Hazaribagh area which is located at the downstream of the Rayer Bazar khal (point source-1). According to ECR 1997, pH value for inland surface water should range from 6.50 to 8.50. It means that all the pH values from different monitoring locations of Buriganga River are within the national standards. Fig. 4.2 shows the spatial and variation of pH along the Buriganga river and Fig. 4.3 shows the temporal variations of pH at the monitoring locations of the Buriganga river.

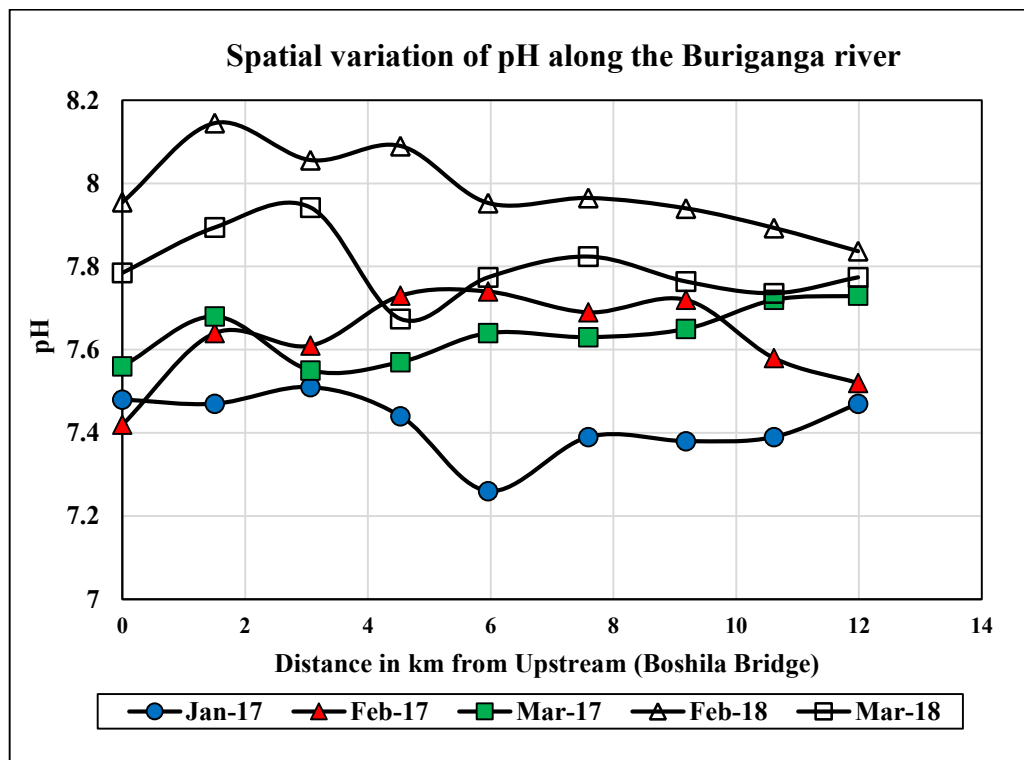


Figure 4.2: Spatial variation of pH along the Buriganga river

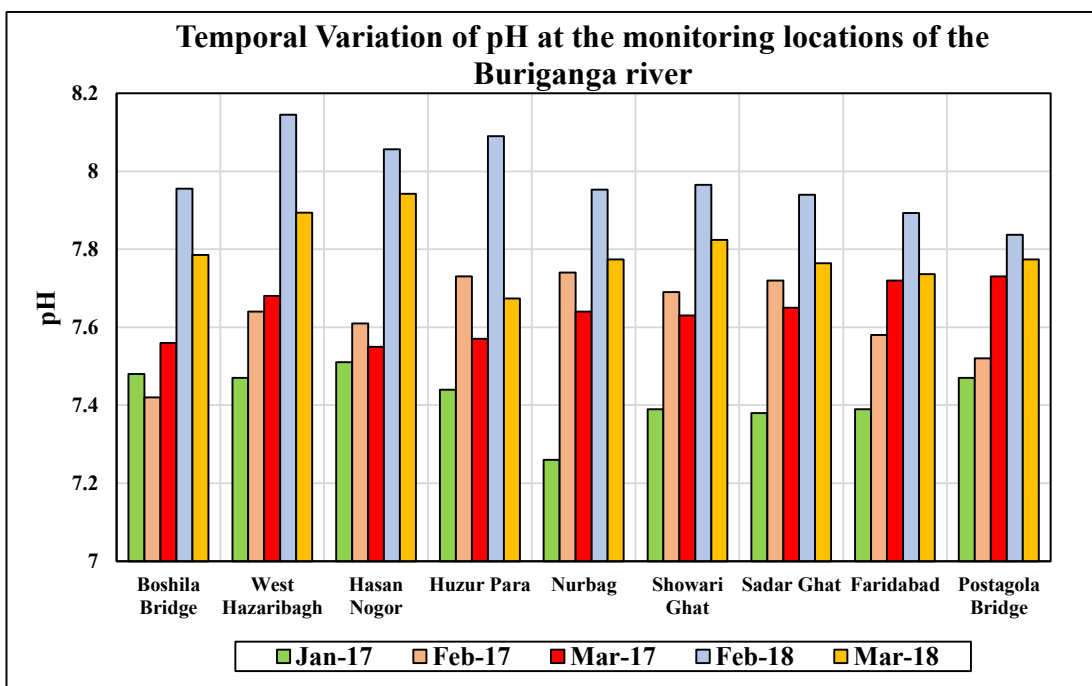


Figure 4.3: Temporal variation of pH at the monitoring locations of the Buriganga river

Dissolved Oxygen (DO)

Dissolved oxygen is one of the most important parameters in water quality assessment. Its presence is essential to maintain variety of forms of life in the water. Effects of biodegradable waste discharged in a water body are largely determined by the oxygen balance of the system. DO value decreases if oxygen demanding waste are discharged into water.

Along the Buriganga river, DO value has been found to be almost zero in all the monitoring locations. Dissolved oxygen varied from 0.21 to 0.39 mg/L, while minimum 5 mg/L DO is essential for the existence of healthy aquatic life in water. Lowest DO values were found in March 2017 as compared to other sampling times. DO value of 0.21 mg/L was found near West Hazaribagh during that period. Slight increases in DO values were found during the dry season of 2018 along the river, particularly in upstream locations near Hazaribagh, possibly indicating effect of relocation of tannery industries. Spatial variation of DO along the river has been shown in Fig. 4.4 and temporal variation of this parameter at monitoring locations of the river has been shown in Fig. 4.5. Figure 4.5 also clearly show the slight increase in DO

value at upstream sampling locations in the dry months of 2018, compared to those in 2017.

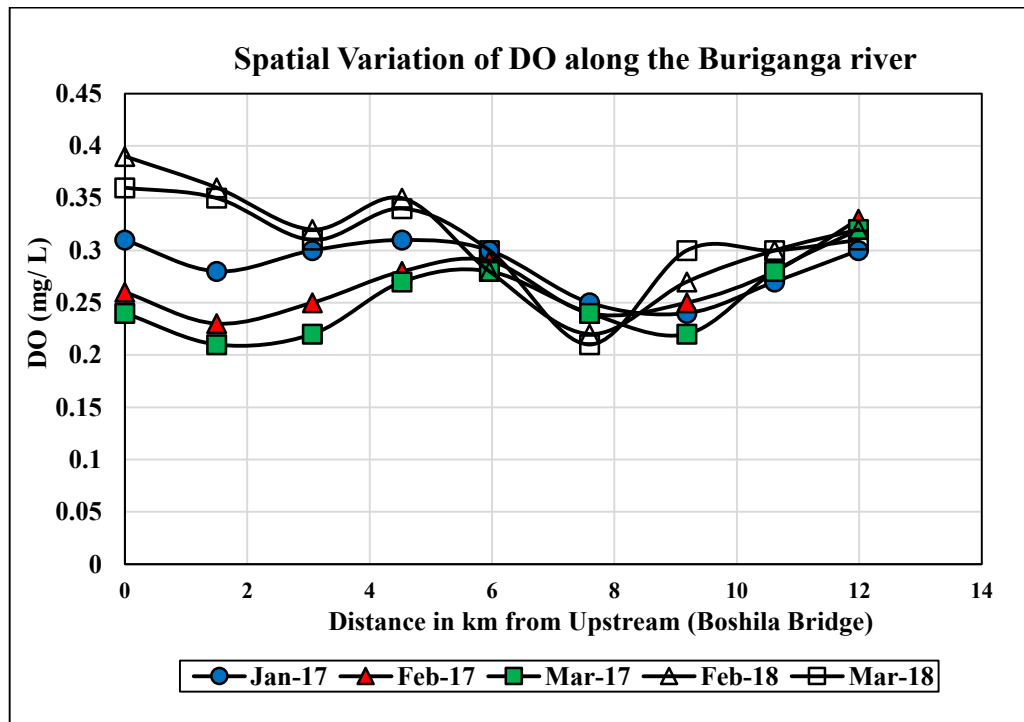


Figure 4.4: Spatial variation of DO along the Buriganga river

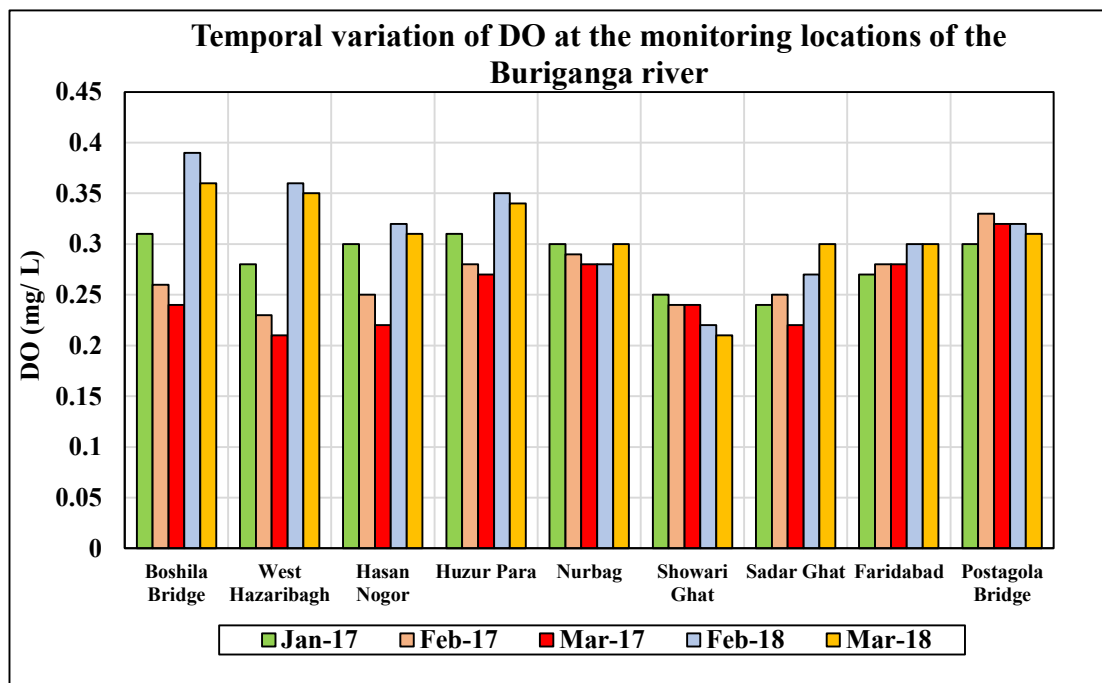


Figure 4.5: Temporal variation of DO at the monitoring locations of the Buriganga river

Water Temperature

Water temperature is also important because of its influence on water chemistry. The rate of chemical reactions increases at higher temperature, which in turn affects biological activity. An important example of the effects of temperature on water chemistry is its impact on oxygen. Warm water holds less oxygen than cool water. Some compounds are also more toxic to aquatic life at higher temperatures.

Water temperature was measured in-situ in this research. Water temperature varied from 22.9°C to 25°C along the Buriganga river in dry season during the sampling periods. Higher temperature was observed in March 2017 as compared to January and February of the year 2017 due to higher air temperature. During dry season of the year 2018, water temperature varied from 22.9°C to 24.7°C. Fig. 4.6 shows the spatial variation of water temperature along the Buriganga river. And temporal variation of water temperature at the monitoring locations of the river has been shown in Fig. 4.7.

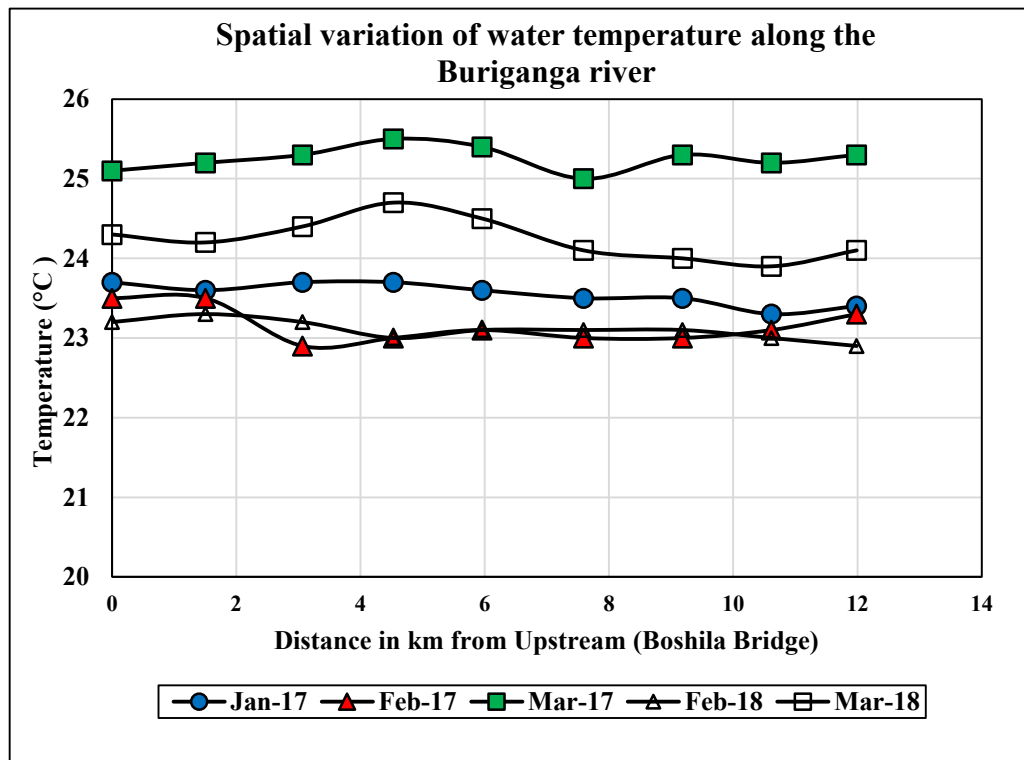


Figure 4.6: Spatial variation of water temperature along the Buriganga river.

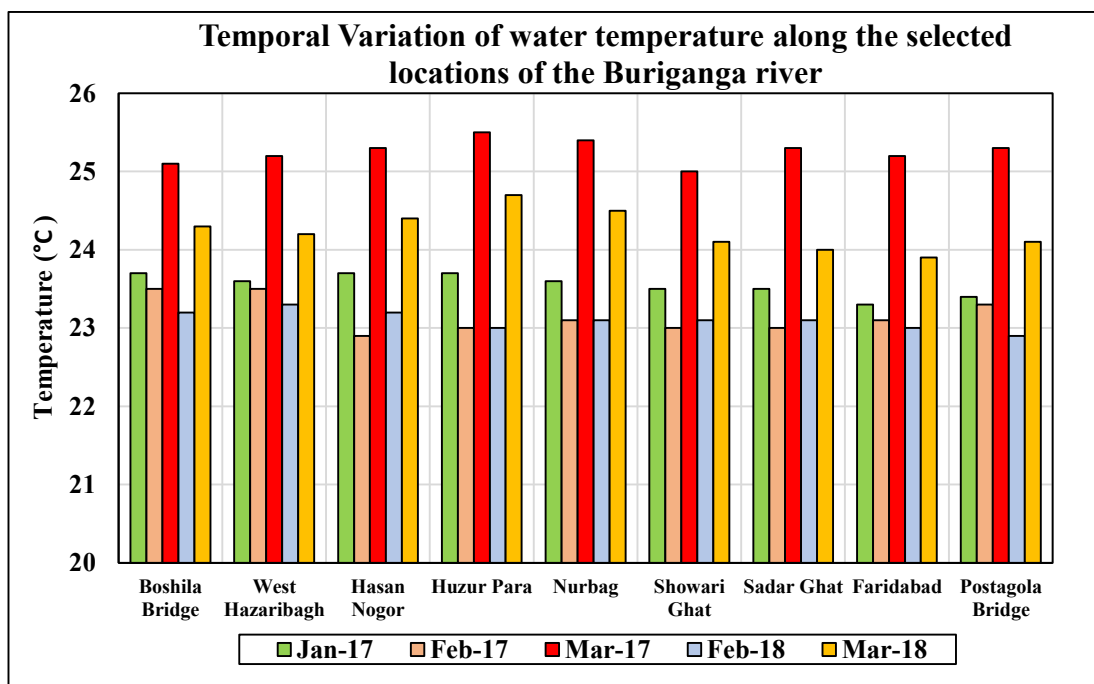


Figure 4.7: Temporal variation of water temperature at the monitoring locations of the Buriganga river

Electrical Conductivity (EC)

Electric conductivity depends on the dissolved ions present in water. Higher EC values indicate higher ionic concentration in water. Discharge of wastewater increases EC of receiving river water. Generally, in wet season, as the flow of the river increases dilution leads to lowering of EC values, while in the dry season, the flow of the river decreases, as a result the EC increases.

EC ranged from 900 to 1200 $\mu\text{S}/\text{cm}$ in Buriganga river during the sample collecting period i.e. dry season of the year 2017 and 2018. Maximum EC values found during March, 2017 which were around 1200 $\mu\text{S}/\text{cm}$ at almost all the selected monitoring locations. During the dry season of the year 2018, most of the EC values found were below 1000 $\mu\text{S}/\text{cm}$. It means ionic concentrations in river water were relatively less in 2018 than 2017. Significant reduction in EC value in March 2018 could be attributed to the shifting of a large number of tannery industries from Hazaribagh during this period. Fig. 4.8 shows the spatial variation of EC along the river and the seasonal variation of EC at the monitoring locations of the Buriganga river has been shown in Fig. 4.9.

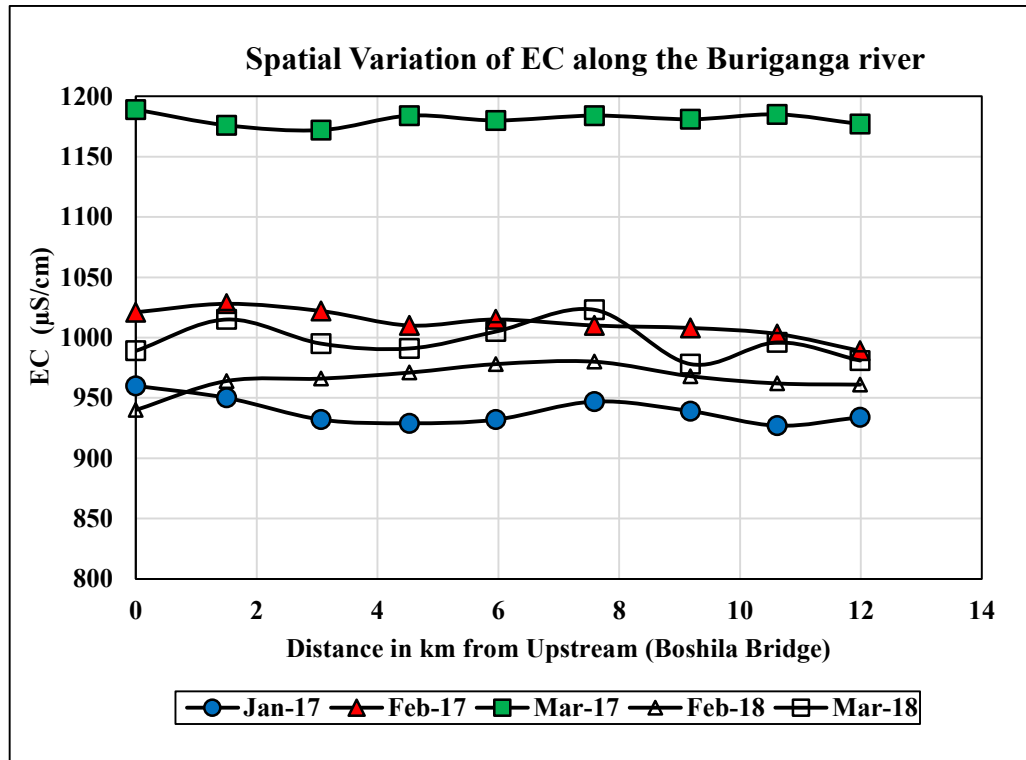


Figure 4.8: Spatial variation of EC along the Buriganga river.

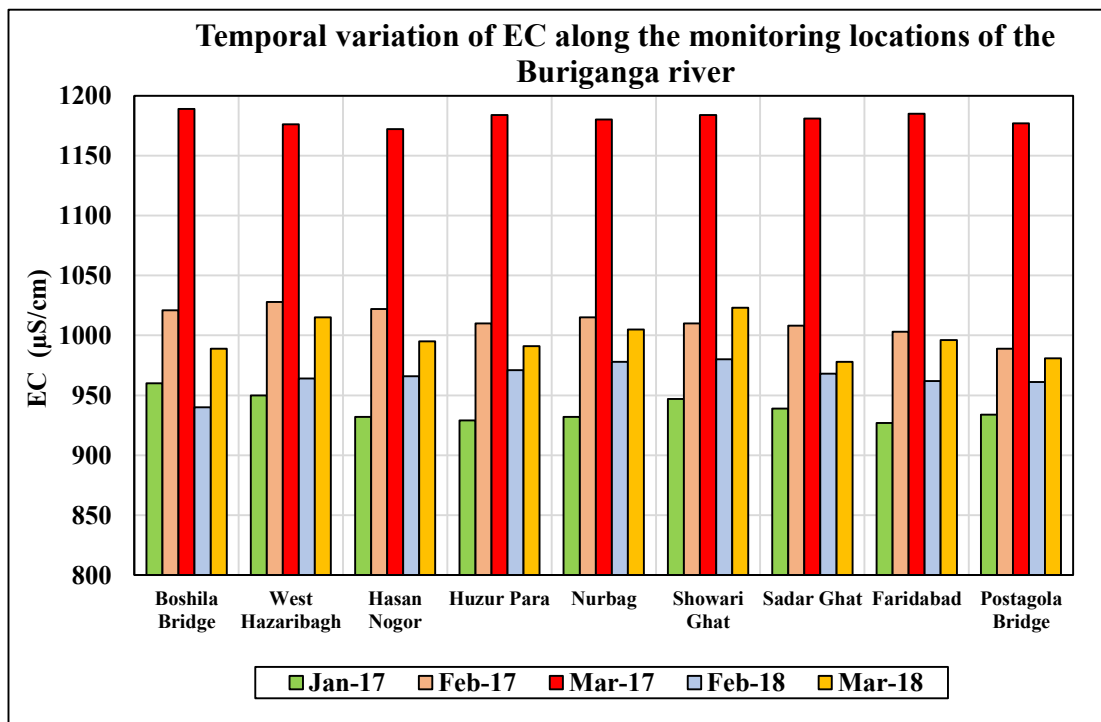


Figure 4.9: Temporal variation of EC at the monitoring locations of the Buriganga river

Chemical Oxygen Demand (COD)

In environmental chemistry, the chemical oxygen demand (COD) is an indicative measure of the amount of oxygen that can be consumed by reactions in a solution. A COD test can be used to quantify the amount of organics in water. The most common application of COD is in quantifying the amount of oxidizable pollutants found in surface water or wastewater.

In this study, COD values along the Buriganga river ranged from 65 to 140 mg/L during the dry season of 2017 and ranges from 55 to 85 mg/L during the dry season of 2018. It should be noted that there is no standard of COD for inland surface water. However, it is clear that the measured COD values of water samples in the year 2018 are much lower than those in 2017. Thus, river water quality in 2018 was much better than in 2017 in terms of COD, which could be attributed to the relocation of tannery industries from Hazaribagh. Maximum COD value was found at Showari Ghat in March 2017 which is located at the downstream of the Kamrangir Char khal. Lower COD value was observed at Huzur Para to Nurbag due to less pollution load in this area. Figure 4.10 and 4.11 shows the spatial and temporal variations of COD along the river.

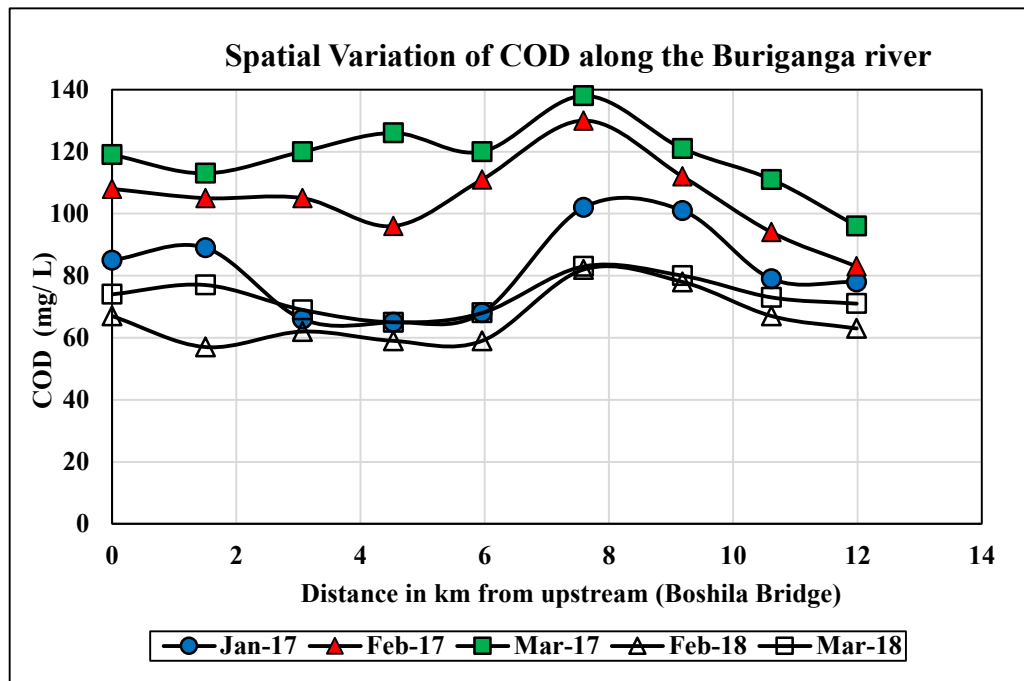


Figure 4.10: Spatial variation of COD along the Buriganga river.

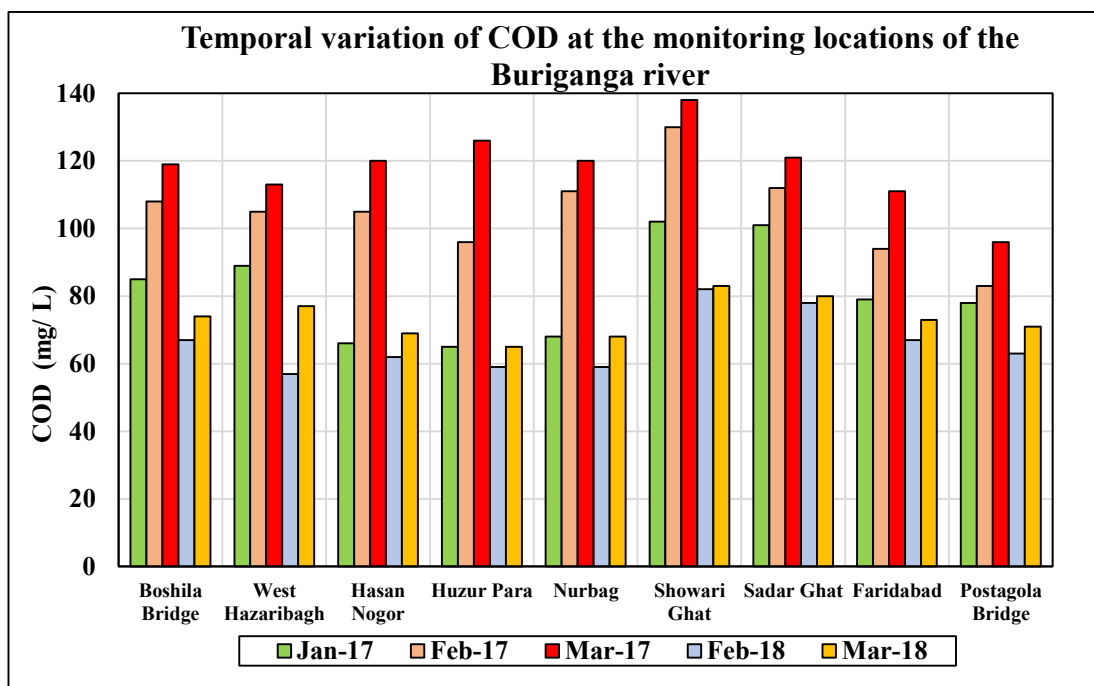


Figure 4.11: Temporal variation of COD at the monitoring locations of the Buriganga river

Biochemical Oxygen Demand (BOD₅)

The BOD₅ is a measure of the amount of oxygen that bacteria will consume in five days at 20°C while decomposing organic matters under aerobic conditions. High level of BOD₅ indicates the presence of excessive amount of biodegradable organic matter in the water. The DOE standard for BOD₅ in surface water body varies from 2 to 10 mg/L, depending on intended use of the water; all measured BOD₅ values exceeded these standards.

Along the river, BOD₅ varied from 14 to 36 mg/L during the dry season of 2017 and from 12 to 24 mg/L during the dry season of 2018. Higher BOD₅ values were found in March 2017 as compared to all other sampling times. Maximum BOD₅ was found at Showari Ghat in February and March 2017. These results are consistent with the trend of EC and COD (and also DO) in the Buriganga River water. Considering no other major changes along the stretch of the Buriganga River studied, the reduction of EC, COD and BOD₅ (as well as slight increase of DO) in the year 2018 compared to 2017 could be attributed to the shifting of tannery industries from Hazaribagh. Spatial variation of BOD₅ along the river has been shown in Figure 4.12 and temporal variation of BOD₅ at different selected locations has been shown in Figure 4.13.

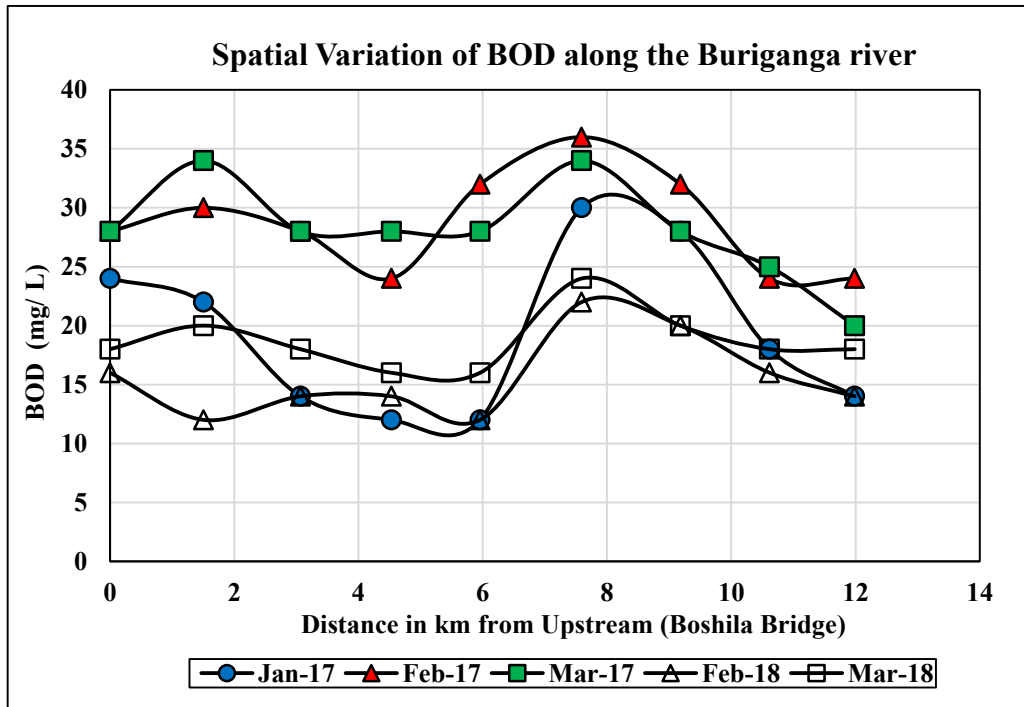


Figure 4.12: Spatial variation of BOD along the Buriganga river.

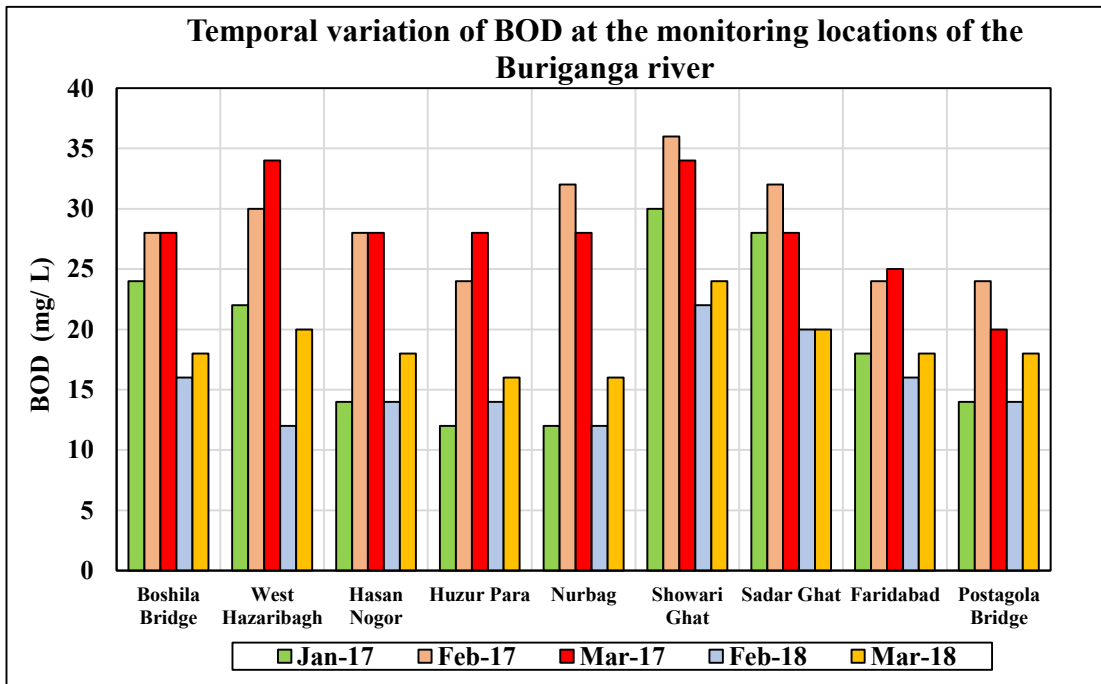


Figure 4.13: Temporal variation of BOD at the monitoring locations of the Buriganga river

Ammonia Concentrations (NH₃-N)

Along the Buriganga river, total ammonia concentrations varied from 8.5 to 16.4 mg/L during the study period. In January 2017, ammonia concentrations varied from 8.5 to 12.35 mg/L. In February 2017, small increase in ammonia concentrations was found, with concentration varying from 13.3 to 14.15 mg/L. In March 2017, maximum ammonia concentrations were recorded along the river as compared to all other sampling times. Highest ammonia (16.4 mg/L) was found at Showari Ghat during that time. Lower ammonia concentrations were observed during February and March of 2018 as compared to 2017. As discussed earlier, this reduction is most likely due to the shifting of large number tannery industries from Hazaribagh. There is no standard of ammonia for inland surface water; however, the drinking water standard for ammonia is 0.5 mg/L. The level of NH₃-N found in Buriganga River was significantly higher than the acceptable level (0.5 mg/L) in almost all the sampling locations. Figure 4.14 shows the spatial variation of ammonia along the Buriganga river and Figures 4.15 shows the temporal variation of ammonia at different monitoring locations.

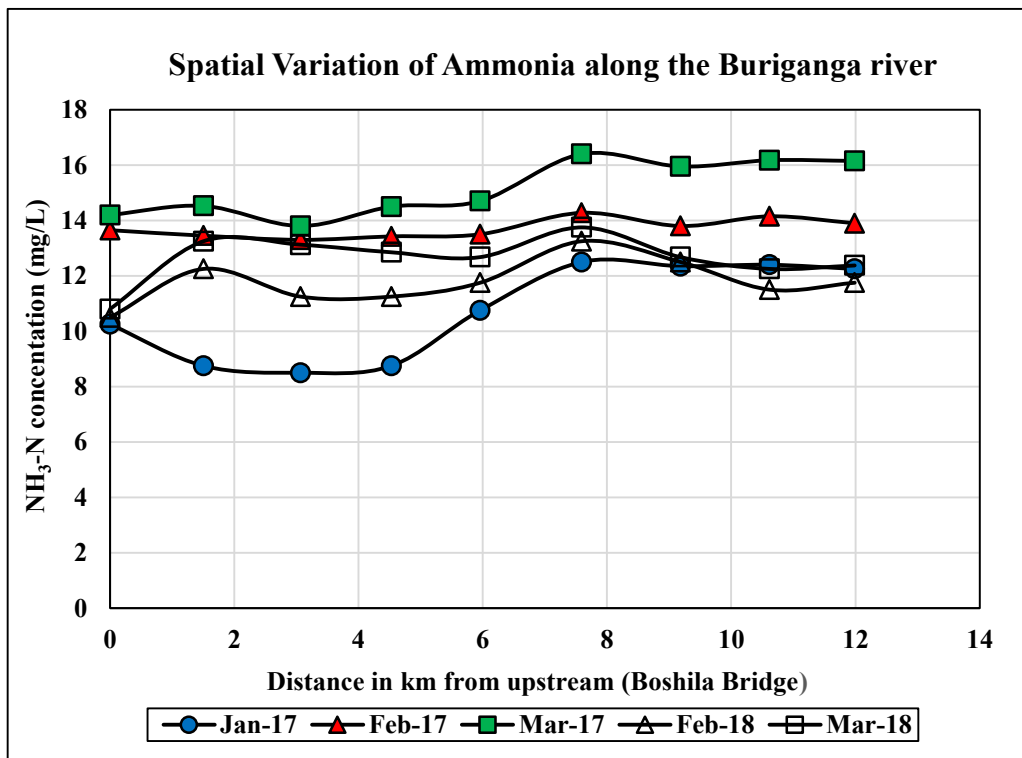


Figure 4.14: Spatial variation of Amonia along the Buriganga river.

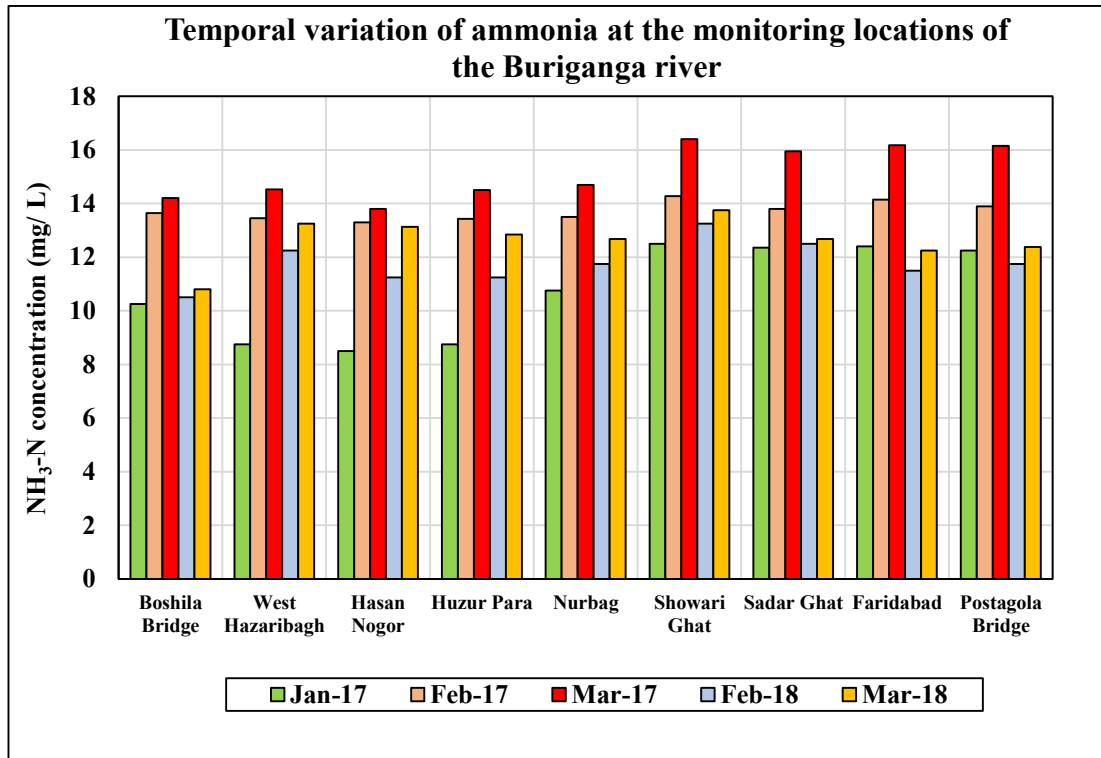


Figure 4.15: Temporal variation of Ammonia at the monitoring locations of the Buriganga river

Nitrate Concentration (NO₃-N)

During January, February and March of 2017, the nitrate concentrations along the river varied from 1.5 to 3 mg/L, 2.5 to 4.5 mg/L and 3 to 6 mg/L, respectively. Relatively higher nitrate concentrations were found in West Hazaribagh and Showari Ghat as compared to other monitoring locations. During 2017, highest nitrate concentration was recorded at 6 mg/L at West Hazaribagh and lowest value was found 1.5 mg/L at Huzur Para and Nurbag. During 2018, relatively less nitrate concentrations were found in river water than 2017, and concentrations varied from 1 to 3.5 mg/L. Figure 4.16 and 4.17 shows the spatial and temporal variation of nitrate along the river respectively.

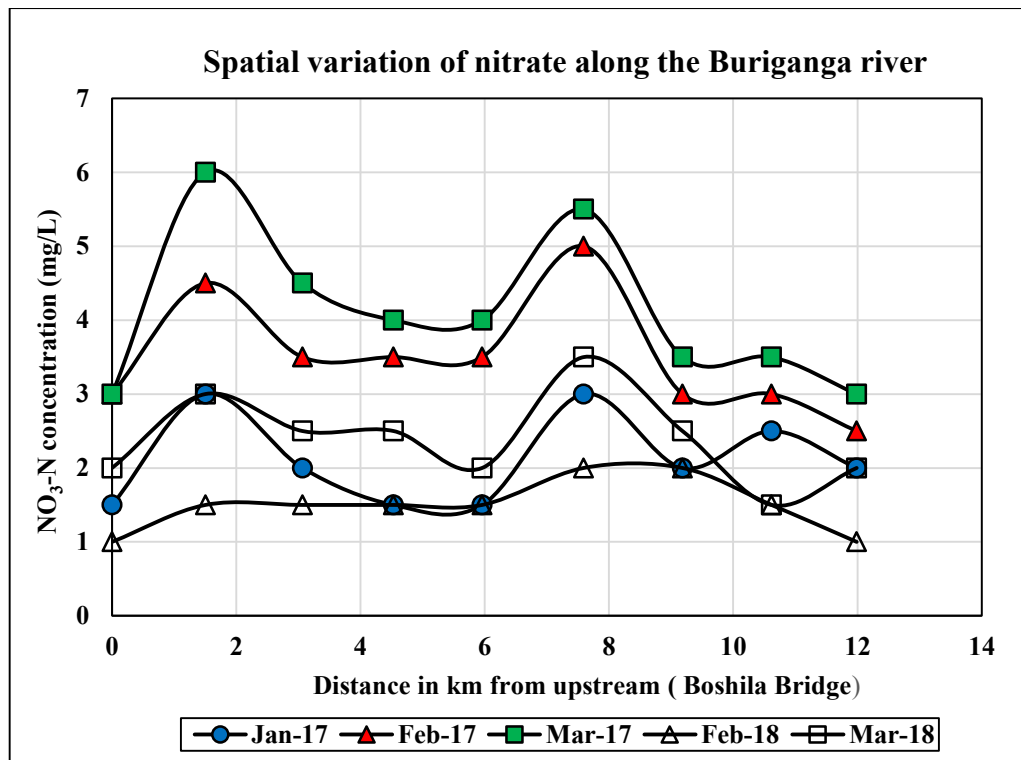


Figure 4.16: Spatial variation of Nitrate along the Buriganga river.

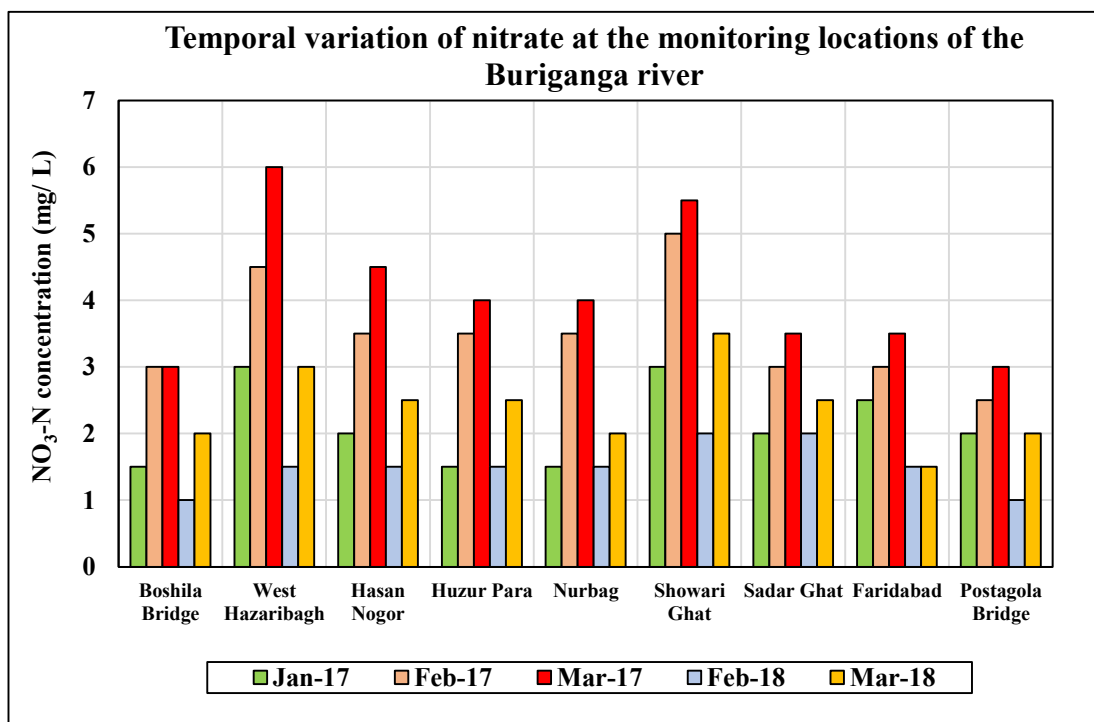


Figure 4.17: Temporal variation of Nitrate at the monitoring locations of the Buriganga river

Orthophosphate Concentration (PO_4^{3-})

Orthophosphate concentrations varied from 1.28 to 5.54 mg/L along the Buriganga river during the dry season of 2017 and 2018. Highest orthophosphate concentration was found 5.54 mg/L at Boshila Bridge in March 2017 whereas lowest concentration was found 1.28 mg/L at Huzur Para in January 2017. There is no standard for Phosphate for inland river water in Bangladesh; however, all the observed values for PO_4 were found below the DoE drinking water standard (6 mg/L) for orthophosphate. During 2018, small spatial variation of orthophosphate concentration was observed along the river. Also, lesser orthophosphate concentrations were found during 2018 as compared to 2017. Figure 4.18 shows the spatial variation of orthophosphate along the river. The temporal variation of orthophosphate concentration at the monitoring locations has been shown in Figure 4.19.

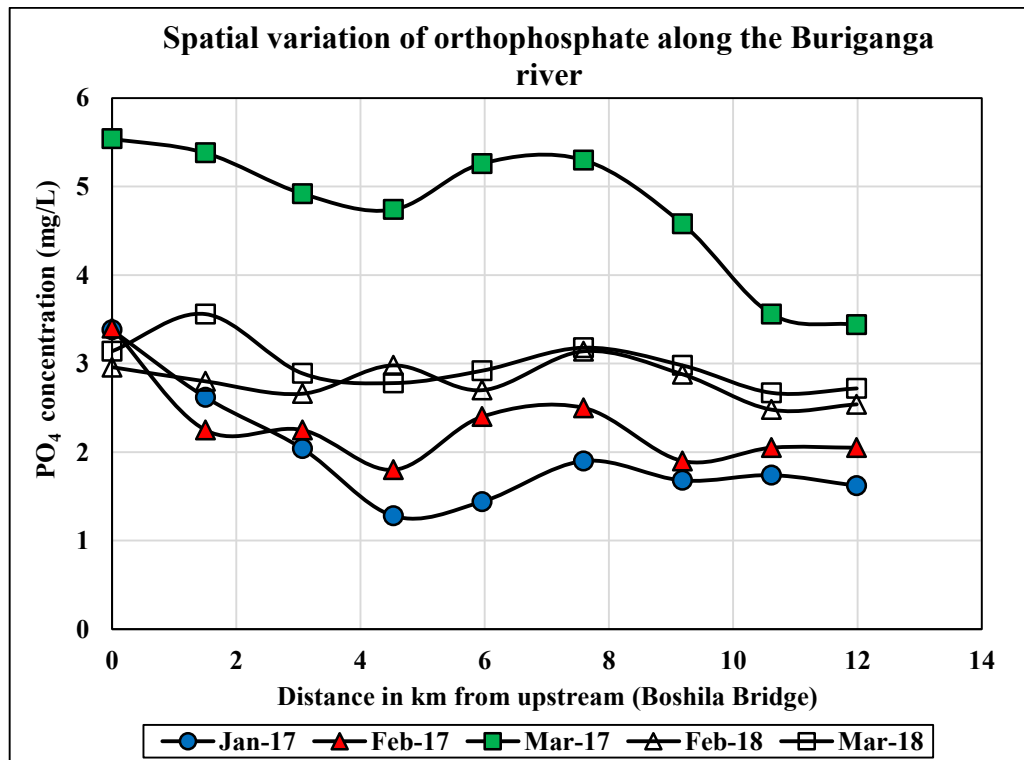


Figure 4.18: Spatial variation of Orthophosphate along the Buriganga river.

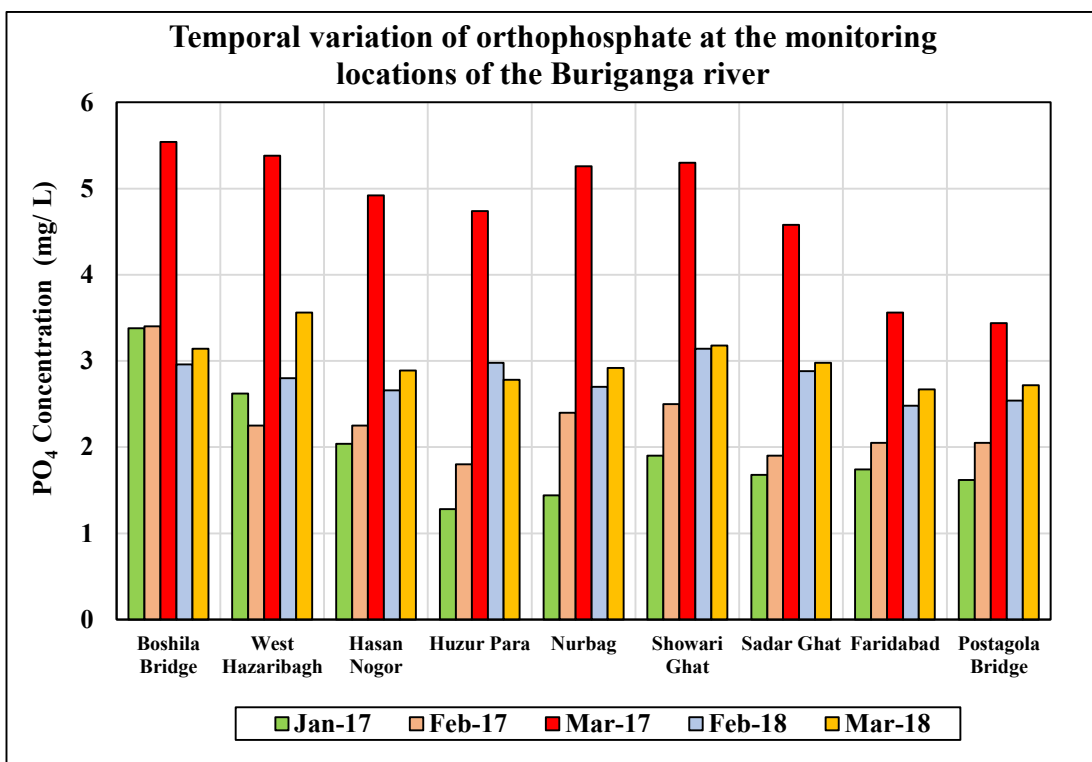


Figure 4.19: Temporal variation of Orthophosphate at the monitoring locations of the Buriganga river

Total Solids (TS)

Total solids is a measure of the suspended and dissolved solids in water. Total solids concentrations varied from 552 to 746 mg/L during dry season of 2017 and from 576 to 640 mg/L during dry season of 2018. Highest value of TS was 746 mg/L recorded at Boshila Bridge in March 2017 and the lowest value was 552 mg/L obtained at Nurbag in January 2017. TS concentrations obtained along the river in March 2017 were much higher than those concentrations obtained in other sampling periods. Spatial and temporal variations of TS have been shown in Figure 4.20 and 4.21, respectively.

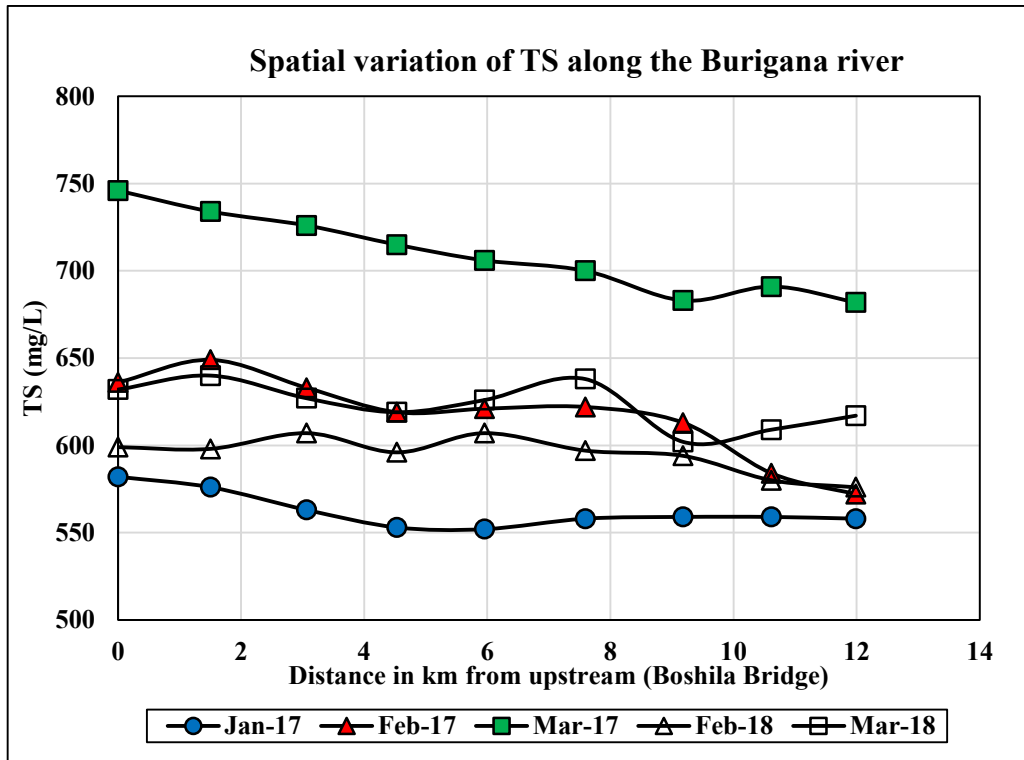


Figure 4.20: Spatial variation of TS along the Buriganga river.

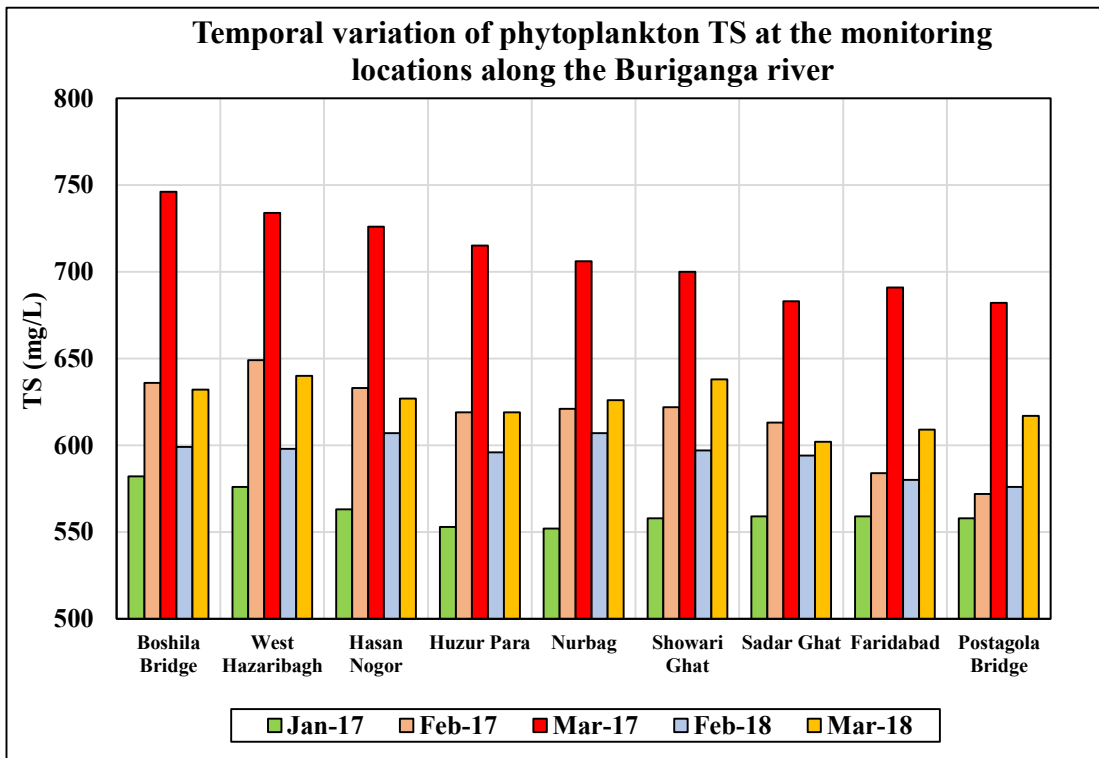


Figure 4.21: Temporal variation of TS at the monitoring locations of the Buriganga river

Total Suspended Solids

Along the Buriganga river, concentrations of TSS varied from 18 to 57 mg/L during the dry season of 2017 and from 14 to 37 mg/L during the dry season of 2018. Highest value of TSS has been obtained in March 2017 at Showari Ghat (57 mg/L). Lowest value of TSS has been obtained in February 2018 at Postagola Bridge (14 mg/L). Most of the TSS concentrations varied between 20 to 30 mg/L. Figure 4.22 shows the spatial variation of TSS concentrations along the river and Figure 4.23 shows the temporal variation of TSS concentrations at the monitoring locations of the river.

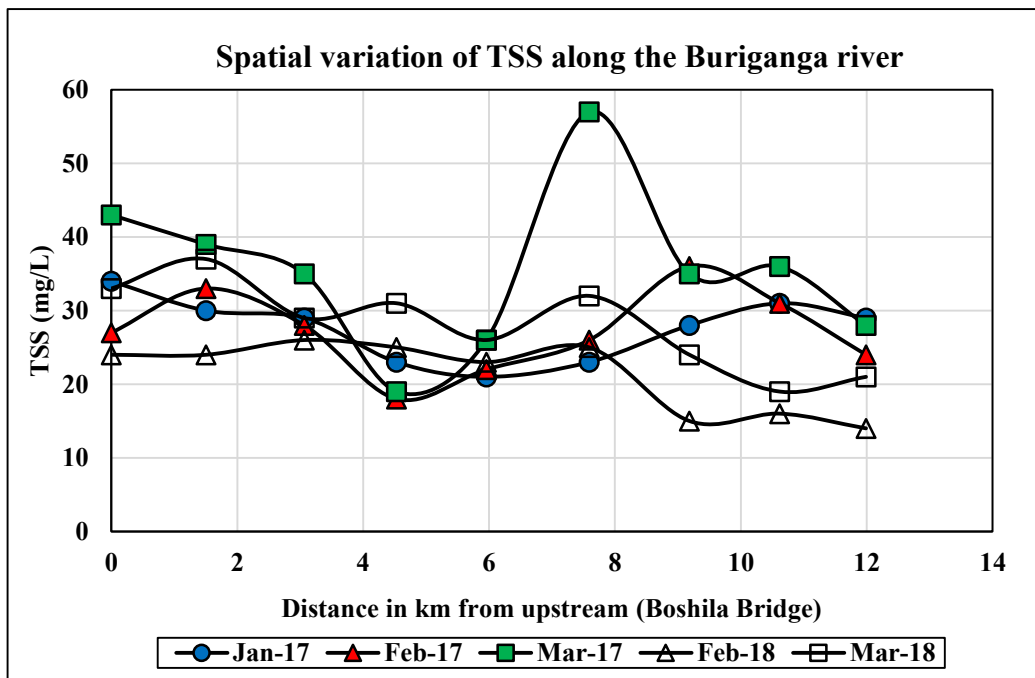


Figure 4.22: Spatial variation of TSS along the Buriganga river.

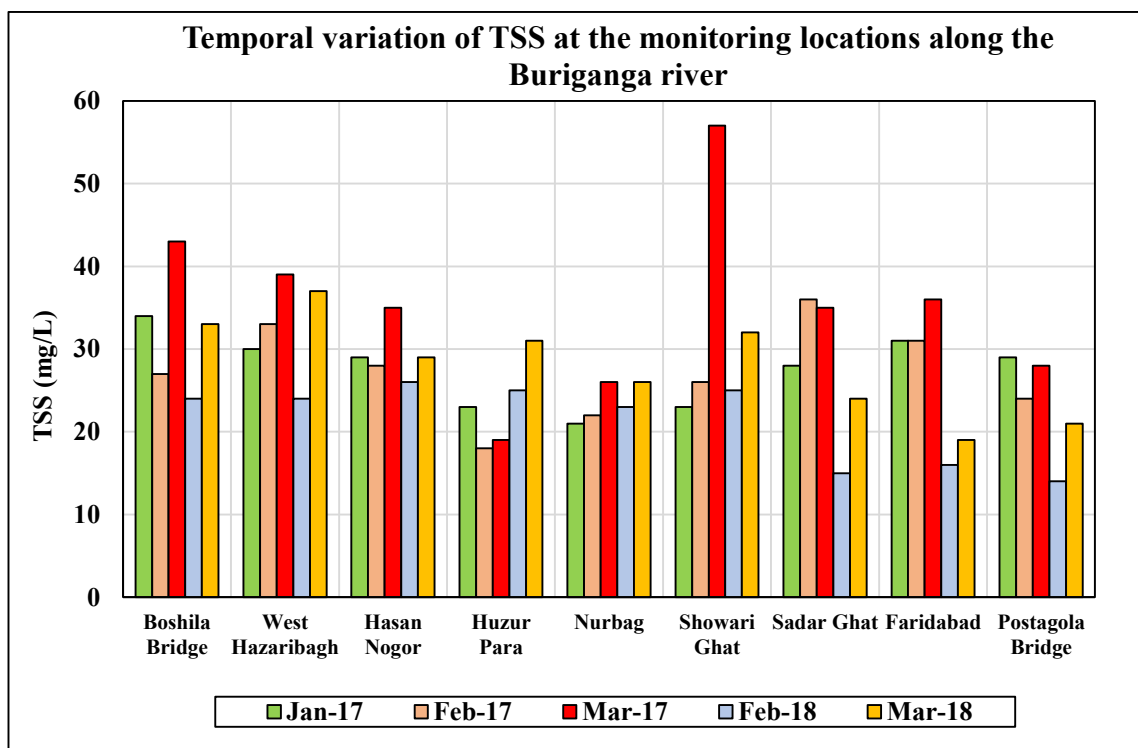


Figure 4.23: Temporal variation of TSS at the monitoring locations of the Buriganga river

Phytoplankton Chlorophyll-a

Along the Buriganga river, phytoplankton chlorophyll-a concentrations varied from 0.87 to 14.0 $\mu\text{g/L}$ during dry season of 2017 and from 1.48 to 5.92 $\mu\text{g/L}$ during the dry season of 2018. Higher values of chlorophyll-a concentration were observed during January 2017. Lowest chlorophyll-a concentration was found 0.87 $\mu\text{g/L}$ at Sadar Ghat in March 2017. During 2017, highest value of chlorophyll-a was 14.0 observed at Boshila Bridge in January 2017. During 2018, relatively small chlorophyll-a concentrations were obtained along the river. Lower values of chlorophyll-a are consistent with relatively lower concentration of governing nutrients (P and N) in Buriganga River water in 2018. Highest value of concentration was 5.92 $\mu\text{g/L}$ found at West Hazaribagh during 2018. Figure 4.24 shows the spatial variation of chlorophyll-a concentrations along the river. Temporal variation of chlorophyll-a at the monitoring locations has been shown in Figure 4.25.

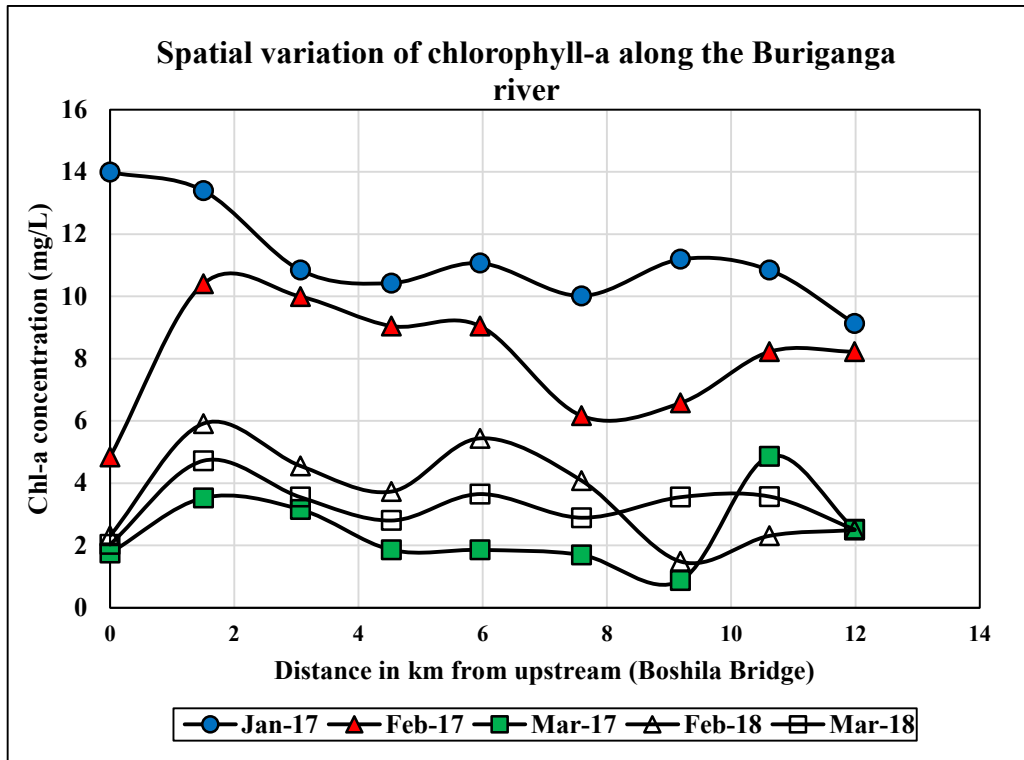


Figure 4.24: Spatial variation of Chlorophyll-a along the Buriganga river.

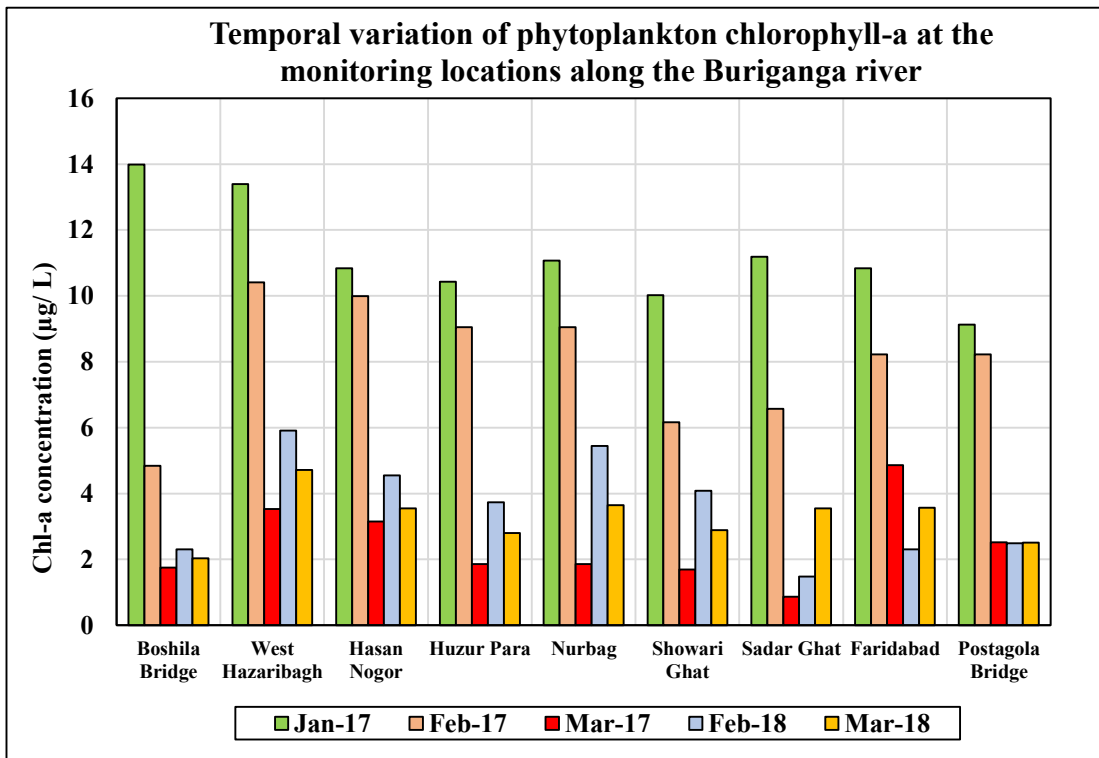


Figure 4.25: Temporal variation of Chlorophyll-a at the monitoring locations of the Buriganga river

4.4 Assessment of Pollution Loads

Generally, assessment of the impacts of pollutants in a river mainly depends on the sources of pollution discharging into the river and the river hydraulics. These items were addressed in the study with the latest information/data. In this study, two major point sources have been considered that contribute towards the pollution of the Buriganga river. These are:

- Rayer Bazar khal
- Kamrangir Char khal

The tannery wastes from the Hazaribagh tannery area were mostly discharged along with domestic wastes from the neighboring unsewered areas through these two khals into the Buriganga river.

4.4.1 Methodology for assessment of pollution loads

Discharge measurements were carried out using float method for these point sources. The basic idea is to measure the time that it takes a floating object to travel a specified distance downstream. From this method, discharge can be calculated as:

$$\text{Discharge, } Q = A \times V$$

Where,

A = Width of channel \times Average depth of water;

V = Distance traveled/ time to travel (meter traveled divided by seconds)

Then waste load for each parameter was computed by the following equation:

$$\text{Waster Loading Rate} = \text{Wastewater Flow} \times \text{Concentration}$$

4.4.2 Summary of pollution loads

Tables 4.6 and 4.7 show the flow, BOD₅, ammonia-nitrogen (NH₃-N), nitrate-nitrogen (NO₃-N), orthophosphate (PO₄³⁻), total suspended solids concentrations and phytoplankton chlorophyll-a of the discharges at the two selected point sources during 2017 and 2018 respectively. Comparison of the data presented in Table 4.6 and Table 4.7 clearly indicate a significant reduction of pollutant concentration in 2018 compared

to those in 2017. For example, BOD₅ concentration in discharges through Rayer Bazar khal varied from 55 to 208 mg/L in the dry months of 2017; while it varied from 28 to 34 mg/L in 2018 during the same period, showing a significant reduction. These reductions could be attributed to the shifting of significant number of tannery industries from Hazaribagh.

Besides Table 4.8 and 4.9 shows the average loading rates of the selected pollutants through the two point sources during 2017 and 2018. These tables show significant reduction in pollution loading in the year 2018 due to reduction in pollutant concentration in the discharges compared to those in the year 2017.

Table 4.6: Concentration of pollutants at two major point sources discharging into Buriganga River during 2017

Point Source	Time	Q (m ³ /s)	NH ₃ -N (mg/L)	NO ₃ -N (mg/L)	Ortho-phosphate (mg/L)	BOD ₅ (mg/L)	TSS (mg/L)
Rayer Bazar khal	Jan 2017	0.8	36.25	2.5	5.15	208	109
	Feb 2017	0.8	22.38	2.5	4.64	128	81
	Mar 2017	0.8	17.9	2	3.75	55	55
Kamrangir Char khal	Jan 2017	1.2	19	2.5	4.2	48	32
	Feb 2017	1.2	19.13	3	5.3	132	60
	Mar 2017	1.2	20	3	6.24	168	108

Table 4.7: Concentration of pollutants at two major point sources discharging into Buriganga River during 2018

Point Source	Time	Q (m ³ /s)	NH ₃ -N (mg/L)	NO ₃ -N (mg/L)	Ortho-phosphate (mg/L)	BOD ₅ (mg/L)	TSS (mg/L)
Rayer Bazar khal	Feb 2018	0.8	13	1.5	3.86	28	34
	Mar 2017	0.8	12.75	1.5	3.93	34	29
Kamrangir Char khal	Feb 2018	1.2	15	2.5	3.56	38	33
	Mar 2018	1.2	15.35	3	3.71	40	31

Table 4.8: Pollutant loading (kg/day) through two major point sources during 2017

Point Source	Time	Q (m ³ /s)	NH ₃ -N	NO ₃ -N	Ortho-phosphate	Ult. BOD	TSS
Rayer Bazar khal	Jan 2017	0.8	2,500	172	355	18,593	7,534
	Feb 2017	0.8	1,543	172	320	11,473	5,598
	Mar 2017	0.8	1,234	138	259	4,769	3,801
Kamrangir Char khal	Jan 2017	1.2	1,965	259	435	6,428	3,317
	Feb 2017	1.2	1,978	311	549	17,832	6,220
	Mar 2017	1.2	2,069	311	646	22,083	11197

Table 4.9: Pollutant loading (kg/day) through two major point sources during 2018

Point Source	Time	Q (m³/s)	NH₃-N	NO₃-N	Ortho-phosphate	Ult. BOD	TSS
Rayer Bazar khal	Feb 2018	0.8	896	104	267	2,626	2,350
	Mar 2017	0.8	879	104	272	2,972	2,004
Kamrangir Char khal	Feb 2018	1.2	1,552	259	369	4,976	3,421
	Mar 2018	1.2	1,588	311	385	5,288	3,214

CHAPTER FIVE

MODELING STUDY: DEVELOPMENT AND APPLICATION

5.1 Introduction

The main objective of the present study was to assess the impacts of relocation of tannery industries on water quality of Buriganga river. In the present study, the reach of the Buriganga river from the Boshila Bridge to Somshan Ghat near Postagola Bridge was selected as the study area for the development of water quality model. Total length of the study reach is about 13 km. Waste loadings from the tannery industries are discharged into the river through Rayer Bazar khal and Kamrangir Char khal. In this portion of the river, both of this major point sources are connected with the Buriganga river system. This portion of the river was therefore selected for water quality modeling. In this research, a kinetic module of the water quality model was developed for each system variables in water column under the modelling framework of Water Quality Analysis and Simulation Program (WASP). WASP is a finite difference model using box model approach. It is a freeware tool developed by United States Environmental Protection Agency (US EPA). For this study, WASP version 7.3 was used for assessment of the impacts.

The model setup is done according to the characteristics of river. A hydrodynamic model (developed in HEC-RAS tool) was used to simulate the hydrodynamic data of the river during the dry season of the year 2017 and 2018, as required by the water quality model. The water quality model was calibrated and verified using the water quality and the hydrodynamic data of the river during the dry period (January, February and March of 2017 and February and March of 2018). Sensitivity of the model was tested by varying different key parameters considered in the model on the computed water quality profiles. Finally, a number of load reduction scenarios were developed to assess the tannery shifting impacts on the water quality parameters of Buriganga river.

The conceptual flow diagram shown in Fig. 5.1 describes the integration of the hydrodynamic modules and the input parameters that are needed for water quality modeling

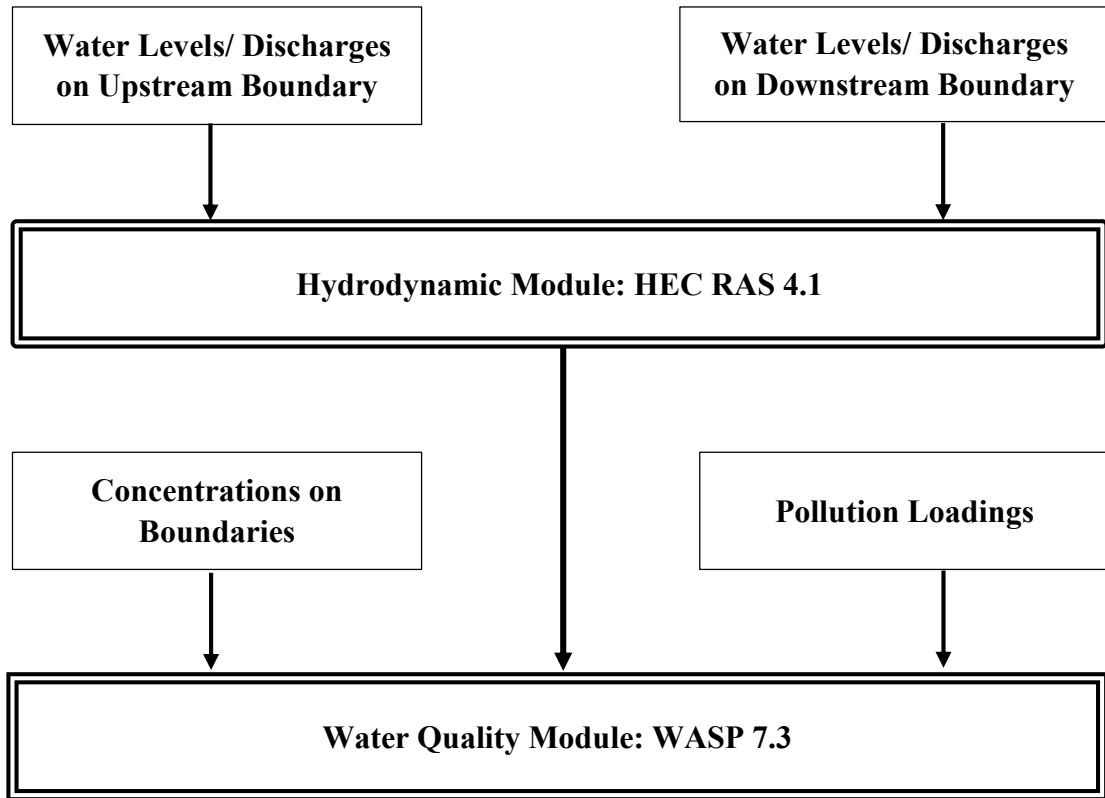


Figure 5.1: Conceptual flow diagram of integrated water quality modeling

5.2 Hydrodynamic Model

5.2.1 Setup

The basic hydrodynamic (HD) model setup used for the Buriganga river was developed by using HEC-RAS tool. The tool allows user to perform one-dimensional steady and unsteady flow river hydraulics calculations. In order to obtain the water depth and water velocities at different water quality monitoring locations, a HD model for river system is required. The HD model was calibrated for the dry season of the year 2017 and 2018. Figure 5.2 depicts the river network system for the HD model.

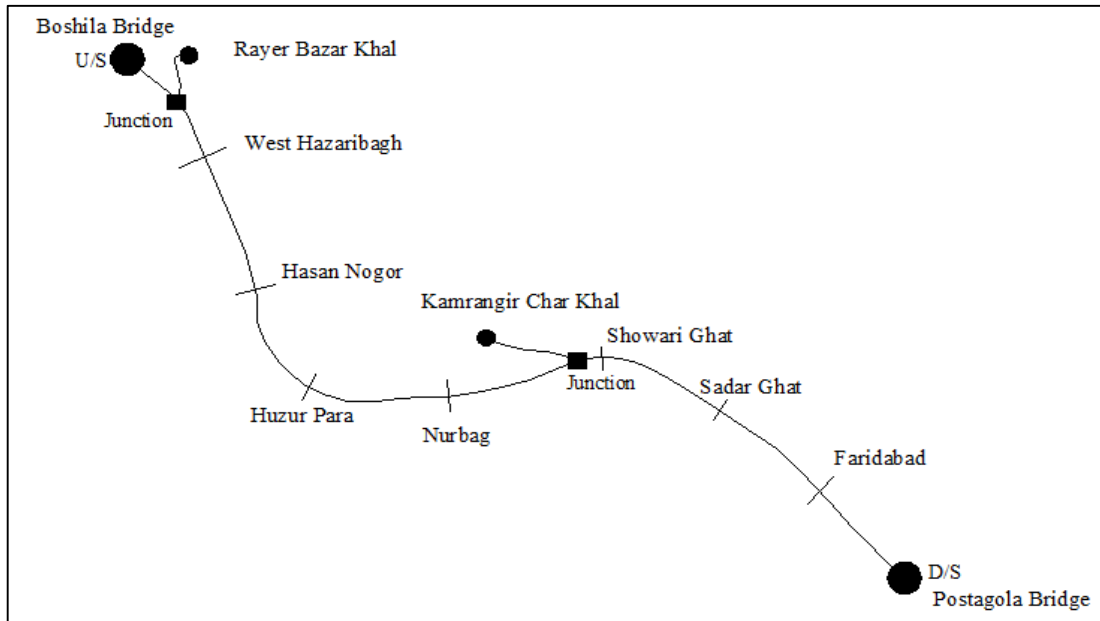


Figure 5.2: River network system for the hydrodynamic model

5.2.2 Hydrometric data collection and processing

The hydrodynamic characteristics of the river are closely related with the advective mass transport of the water quality model. Discharge along the river at a reference section at a specific time is an essential part to model the concentration of the water quality parameters. Generally, Bangladesh Water Development Board (BWDB) is the authority for discharge measurement of the rivers of Bangladesh at all the important locations. BWDB discontinued to take any discharge measurements during the dry period after the year of 2006. Now BWDB only takes discharge measurements during the wet period as part of flood monitoring. But BWDB measures water level at several stations (SW 42: Dhaka Mill Barack and SW 43: Hariharpara) of the Buriganga river throughout the year. The recorded water level data of these stations were collected from BWDB for the dry season of 2017 and 2018. To overcome the difficulty of non-availability of discharge data, a discharge rating curve was developed from the dry season discharge data of the year 2006. By using that rating curve equation, discharge data for the year 2017 and 2018 were prepared. WL and discharge data of the year 2006, 2017 and 2018 were provided in the appendix part. Since during different dry seasons, the variation of water levels along the river were very small, it is assumed that the measured discharges from the rating curve equation is nearly accurate. Figure 5.3 shows the variation of discharges (observed and

estimated from the rating curve equation) during the dry season of the year 2006. Figure 5.4 shows the yearly variation of water levels at SW 42 (Dhaka Mill Barrack) station of Buriganga river. Discharges along the Buriganga River generated by using rating curve equation during dry season of the year 2017 and 2018 are shown in Fig. 5.5 and 5.6, respectively.

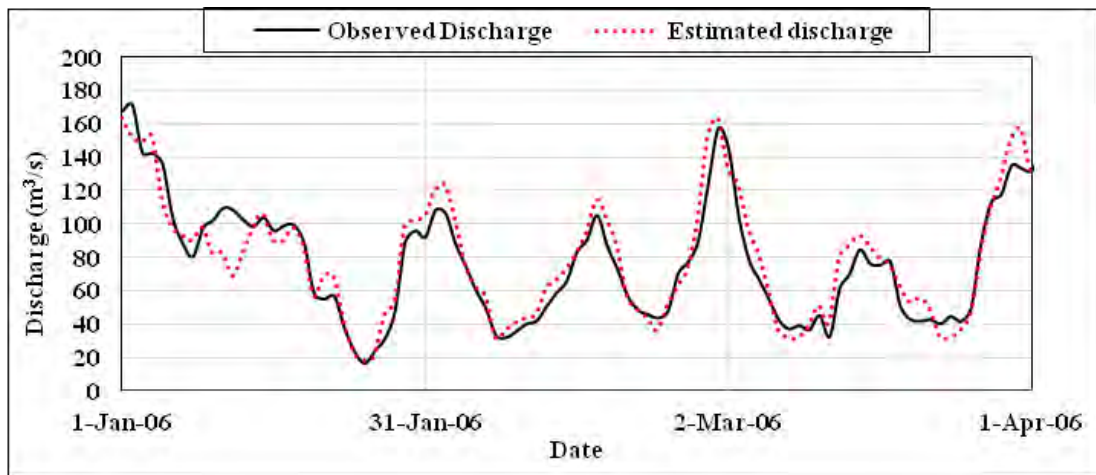


Figure 5.3: Variation of discharges (observed and estimated) during the dry season of the year 2006

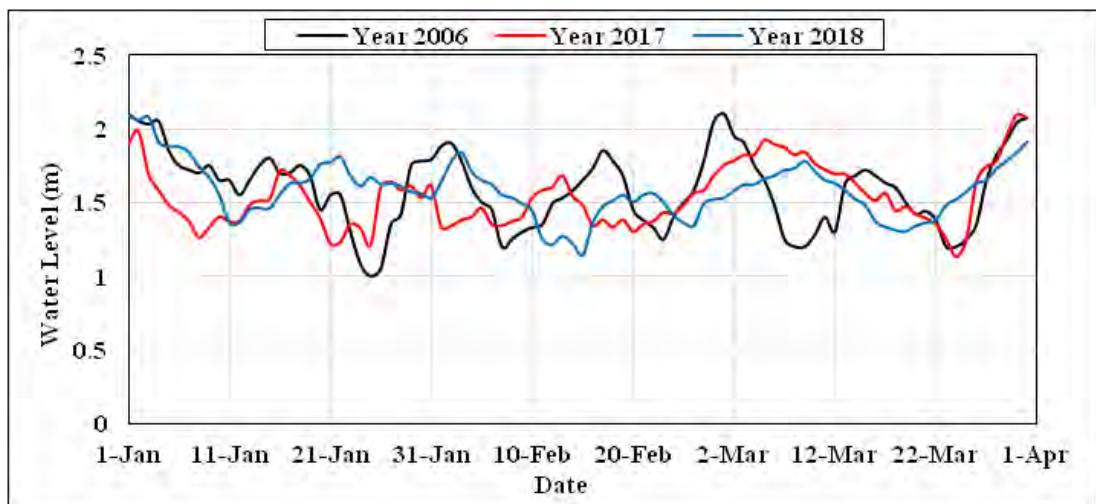


Figure 5.4: Yearly variation of water levels at SW 42

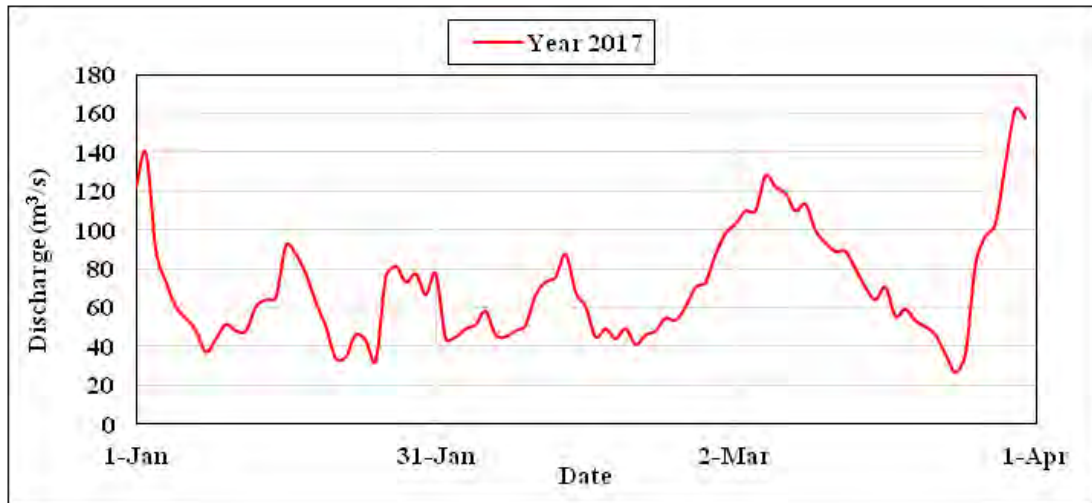


Figure 5.5: Discharge along the Buriganga river during dry season of 2017

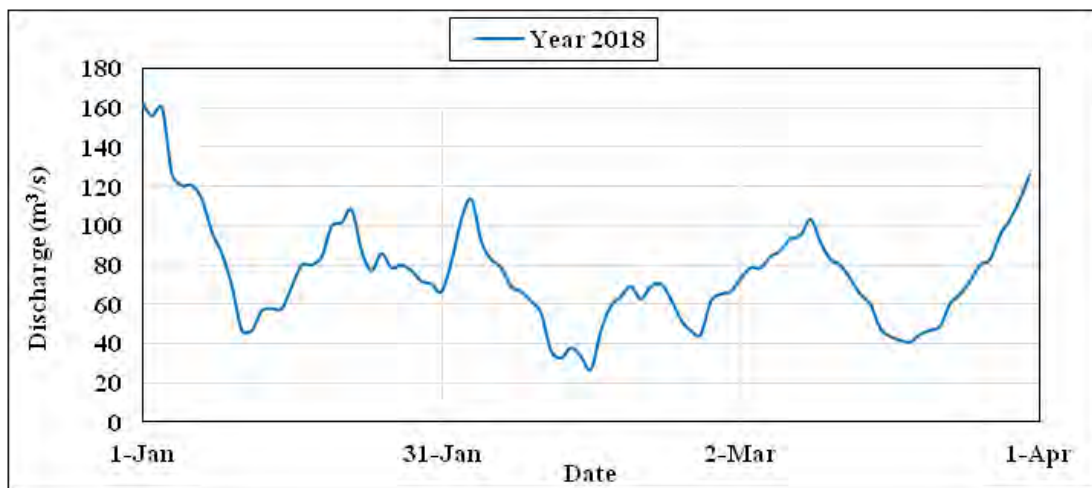


Figure 5.6: Discharge along the Buriganga river during dry season of 2018

The cross-sectional profiles data of the Buriganga river were also provided as input in the hydrodynamic model. Cross sectional profile data were also collected from BWDB. Although with a reach length of 13 km having only 9 cross sectional profiles, it is very tough to get better result from the hydrodynamic model. Therefore, interpolated cross sections were used in between the collected cross-sectional profiles. Figure 5.7 shows the interpolated cross sections for the hydrodynamic model.

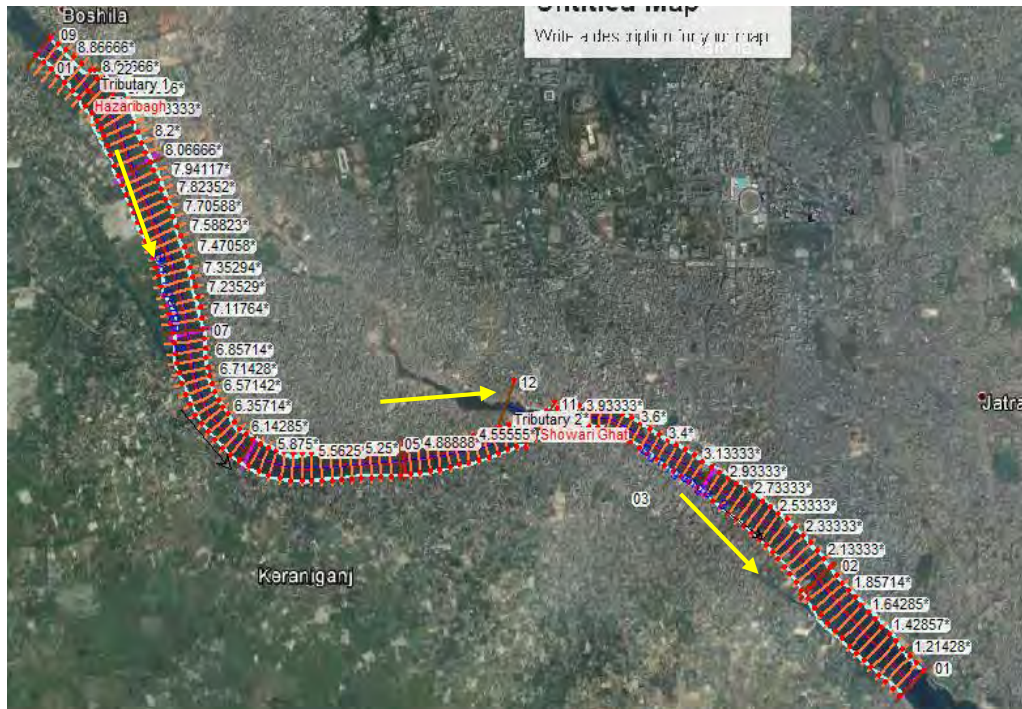


Figure 5.7: Interpolated cross sections for the hydrodynamic model (HEC-RAS)

For setting boundary conditions in the hydrodynamic model, it is necessary to calculate the slope of the river. Both the BWDB water stations (SW 42 and SW 43) are located at the downstream of the study reach. The distance between these two stations is approximately 5.60 km. For measuring the maximum slope of the river, annual maximum water level (m, PWD) and the corresponding date were taken at the SW 42 station from 1985 to 2006. Again, water level at SW 43 on the same date were taken. From the difference between these two water levels, slope was measured for each year. And finally, the maximum slope of the river was calculated. Table 5.1 describes the measurement of slopes of Buriganga river for different years. The maximum slope found for the river was 0.00008929 m/m. From literature, the maximum slope of Buriganga river was found 0.0000839 m/m (Rumana, 2006).

Table 5.1: Measurement of slopes of Buriganga river for different years

Maximum slope of the river = 0.00008929 m/m.

Date	Annual Maximum Water Level, m PWD at SW 42	Water Level at SW 43 on the Corresponding Date, m PWD	Difference in Water Level between the Stations, m	Slope
07-Aug-85	5.385	5.07	0.315	0.00005625
09-Aug-86	4.975	4.8	0.175	0.00003125
22-Aug-87	6.63	6.21	0.42	0.00007500
04-Sep-88	7.565	7.065	0.5	0.00008929
24-Jul-89	5.07	4.725	0.345	0.00006161
25-Aug-90	5.34	4.895	0.645	0.00007946
16-Sep-91	5.6	5.36	0.24	0.00004286
01-Sep-92	4.305	4.065	0.24	0.00004286
04-Sep-93	5.6	5.275	0.325	0.00005804
24-Aug-94	5	4.815	0.185	0.00003304
16-Jul-95	6.08	5.76	0.32	0.00005714
05-Jul-96	5.05	4.86	0.185	0.00003304
22-Jul-97	5.36	5.315	0.04	0.00000714
11-Sep-98	7.24	7.13	0.105	0.00001875
01-Sep-99	5.81	5.645	0.16	0.00002857
13-Aug-00	5.74	5.6	0.135	0.00002411
09-Aug-01	5.09	4.965	0.125	0.00002232
02-Aug-02	5.76	5.63	0.125	0.00002232
19-Jul-03	5.86	5.575	0.285	0.00005089
27-Jul-04	6.66	6.43	0.23	0.00004107
26-Jul-05	5.29	5.06	0.23	0.00004107
30-Jul-06	4.57	4.465	0.105	0.00001875
07-Aug-07	5.98	5.81	0.165	0.00002946
08-Sep-08	5.68	5.58	0.1	0.00001786
27-Aug-09	5.05	4.82	0.23	0.00004107
14-Sep-10	5.13	5.09	0.04	0.00000714
21-Aug-11	5.09	5.025	0.065	0.00001161
23-Jul-12	4.90	4.59	0.31	0.00005536
12-Sep-13	4.86	4.795	0.065	0.00001161
01-Sep-14	5.07	5.03	0.035	0.00000625

5.2.3 Calibration of hydrodynamic model

Calibration is the adjustment of a model's parameters, such as roughness and hydraulic structure coefficients, so that it reproduces observed data to an acceptable accuracy. Model reliability depends upon its calibration and validation of results as it is one of

the very important steps before putting the model in use. In this study calibration has been done through the adjustment of Manning's roughness coefficients. Manning's n is the key tuning parameter of the 1-D HEC-RAS model whose appropriate value is very significant for accuracy, depending on the factors like surface roughness, vegetation cover or land use channel irregularities, etc. From usual practice of hydrodynamic model of Bangladeshi rivers, trial value of the Manning's n ranged from 0.013 to 0.030. For the selected reach based on the information collected during the field visit on the bed materials and the flood plains, the Manning's roughness coefficient of 0.025 for the main river and 0.028 for the overbanks are considered reasonable and hence were used in the model. The hydrodynamic model was calibrated by using these values of Manning's n . Figure 5.8 shows the observed and simulated water level from HEC-RAS model at SW 42 station.

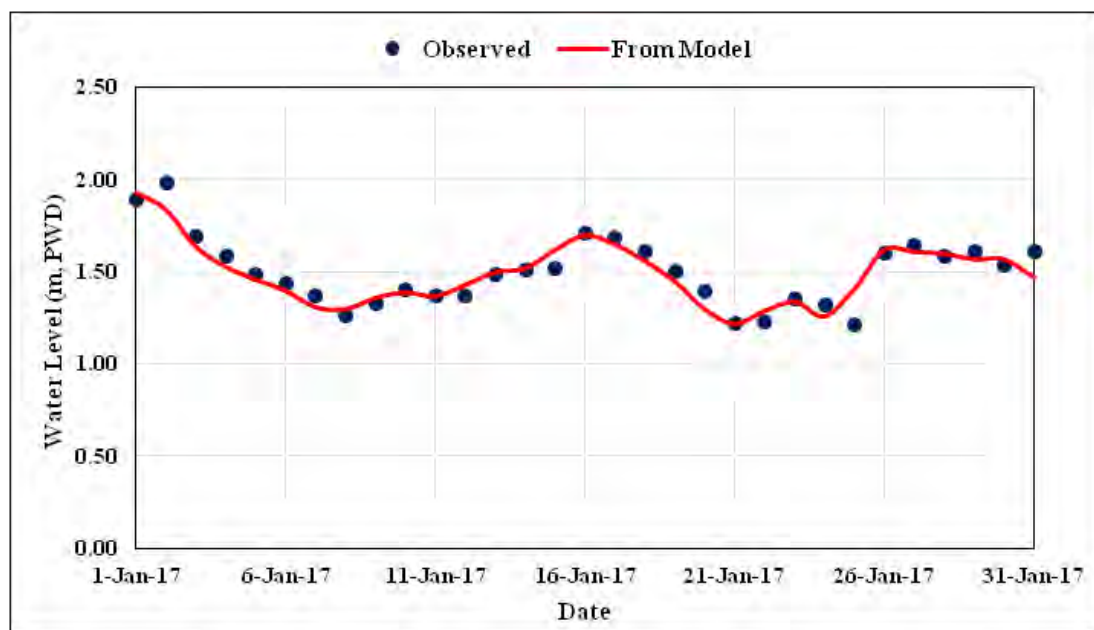


Figure 5.8: Observed and simulated water level (m, PWD) at SW 42 station

5.3 Water Quality Modeling Approach

In this study, a one-dimensional quasi-steady state water quality model has been developed using the finite segment approach under the modeling framework of WASP7.3. The model was developed by U.S. Environmental Protection Agency (Wool et al., 2009). This model helps users to interpret and predict water quality

responses to natural phenomena and pollutions for various pollution management policies and decisions. WASP 7.3 has several modules or components. EUTRO is a component of WASP7.3 that is applicable for modeling eutrophication in the water column. EUTRO deals with DO, BOD, nutrients, phytoplankton and periphyton of a river system. In this research, EUTRO module was used to develop water quality model for the study area.

Seven state variables: Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), Ammonia-Nitrogen, Nitrate-Nitrogen, Orthophosphate, Total Suspended Solids (TSS) and Phytoplankton Chlorophyll-a were considered in the water quality model development. Two variables: Organic Nitrogen and Organic Phosphorous are considered constant in this model. Organic nitrogen and organic phosphorous were not measured during the laboratory analysis due to time constraints and laboratory limitations. Taking a variable constant indicates to WASP that the user wants to hold the mass of this system constant and not allow the equations pertaining to this system to be calculated but allow its mass to influence the rates and fate of the other system's that can be affected by the presence of this systems mass. The study reaches were divided into several longitudinal segments of various lengths. The geometry (volume) of segments was determined from the channel morphometric data of the river and the water level during the study period which were collected from BWDB and from the simulation of hydrodynamic model.

The water quality model was calibrated and verified using the water quality (primary field data) of the monitoring locations and the loading data from the major point sources of the rivers during the dry period of 2017 and 2018, respectively. Several runs were made by varying the kinetic constants and coefficients within the range given in the literature (Bowie et al, 1985; Karim, 1996; Ghosh and Mcbean, 1998) to minimize the differences between the computed and the observed profiles.

5.3.1 Model segmentation

For water quality modelling, the study reach was divided into 9 longitudinal segments of various lengths. The segment configuration of the study area and major point source discharges are shown in Figure 5.9. As per the basic concept of one dimensional finite segment approximation, it is assumed that the water quality parameters are well mixed within a river segment, thus allowing computation of the water quality parameters in the longitudinal direction only. The geometry (volume) of 9 segments were determined from the channel morphometric data of the river (BWDB) and the recorded water level during the study period.

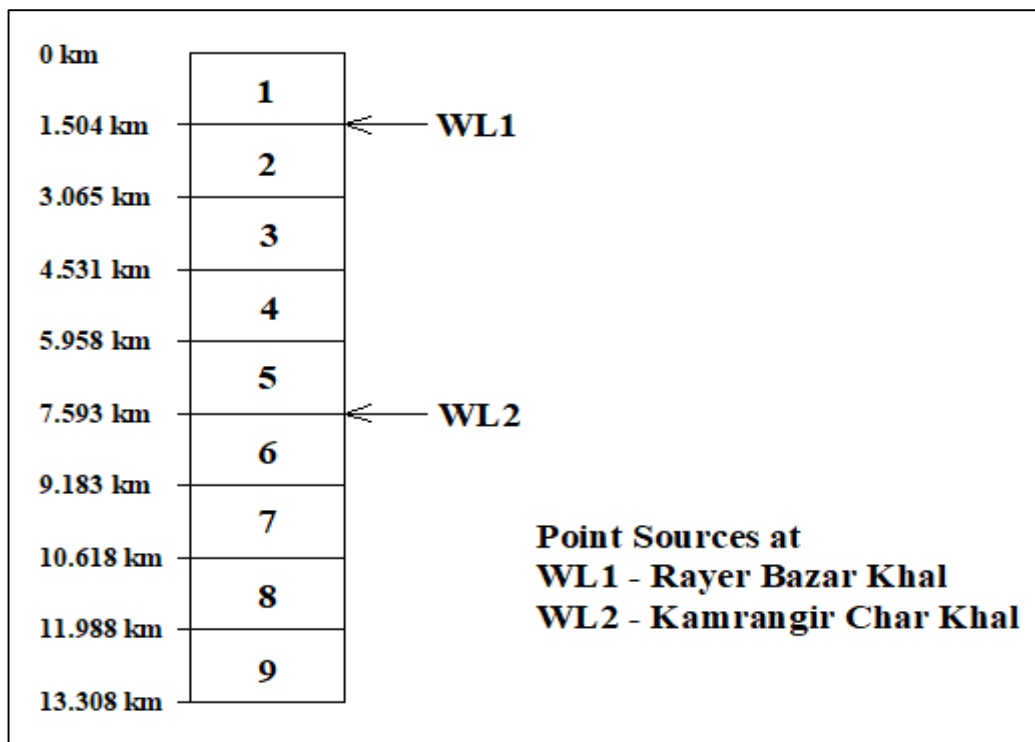


Figure 5.9: Segment configuration of the study reach and point loadings

5.3.2 Flows and Exchanges

For streams and rivers, the hydrodynamic characteristic is closely related with the advective mass transport of the water quality model. For the model, discharge parameter of the river was provided from the prepared discharge data of the year 2017 and 2018. The discharges of Rayer Bazar Khal and Kamrangir Char Khal were measured by using float method during the study period. The average daily flow of

Rayer Bazar khal and Kamrangir Char khal are about $0.8 \text{ m}^3/\text{s}$ and $1.2 \text{ m}^3/\text{s}$, respectively.

In WASP, the flow group works exactly the same way as the exchange group. In the case of flow exchanges, since there is no data available for the dispersion coefficient for the Buriganga river, a value of $75 \text{ m}^2/\text{sec}$ was adopted from the literature (Bowie et al. 1985) during model calibration.

5.3.3 Initial and boundary conditions

The most upstream segment of the Buriganga river started at the Boshila Bridge (segment #1); the most downstream segment of the river ended at the Postagola Bridge (segment #9). Rayer Bazar khal (point source) contributes to West Hazaribagh (segment #2) and Kamrangir Char khal (another point source) contributes to Showari Ghat (segment #6) were also taken as boundaries. The water quality parameters measured at the above mentioned locations were taken as the boundary concentrations. The time variable boundary conditions were provided for the time steps January 15, February 16 and March 25 of 2017 for model calibration and February 16 and March 20 of 2018 for model verification. Table 5.2 and 5.3 shows the boundary concentrations of the water quality parameters for the year 2017 and 2018, respectively.

Water quality parameter concentrations at the selected monitoring locations along the river at the beginning of the simulation were used as initial conditions. During 2017, parameter concentrations measured on January 15 were taken as the initial concentrations for model calibration. Parameter concentrations on February 16, 2018 were used as the initial concentrations for model verification.

Table 5.2: Boundary concentrations of the water quality parameters for the year 2017

Boundaries	Month	NH ₃ -N	NO ₃ -N	Ortho - PO ₄	chl-a	DO	Ult. BOD	TSS
		mg/L	mg/L	mg/L	µg/L	mg/L	mg/L	mg/L
Segment-1 (Boshila Bridge)	January	10.25	1.5	3.38	13.99	0.31	31	34
	February	13.65	3	3.4	4.84	0.26	36	27
	March	14.2	3	5.54	1.75	0.24	35	43
Segment-9 (Postagola Bridge)	January	12.25	2	1.62	9.13	0.3	18	29
	February	13.9	2.5	2.05	8.22	0.33	31	24
	March	16.15	3	3.44	2.52	0.32	25	28
Segment-2 (West Hazaribagh)	January	8.75	3	2.62	13.40	0.28	29	30
	February	13.45	4.5	2.25	10.41	0.23	39	33
	March	14.53	6	5.38	3.53	0.21	43	39
Segment-6 (Showari Ghat)	January	12.5	3	1.9	10.02	0.25	39	23
	February	14.28	5	2.5	6.16	0.24	47	26
	March	16.4	5.5	5.3	1.69	0.24	43	57

Table 5.3: Boundary concentrations of the water quality parameters for the year 2018

Boundaries	Month	NH ₃ -N	NO ₃ -N	Ortho - PO ₄	chl-a	DO	Ult. BOD	TSS
		mg/L	mg/L	mg/L	µg/L	mg/L	mg/L	mg/L
Segment-1 (Boshila Bridge)	February	10.5	1	2.96	2.31	0.39	21	24
	March	10.8	2	3.14	2.03	0.36	23	33
Segment-9 (Postagola Bridge)	February	11.75	1	2.54	2.49	0.32	18	14
	March	12.375	2	2.72	2.51	0.31	23	21
Segment-2 (West Hazaribagh)	February	12.25	1.5	2.8	5.92	0.36	16	24
	March	13.25	3	3.56	4.72	0.35	26	37
Segment-6 (Showari Ghat)	February	13.25	2	3.14	4.08	0.32	29	25
	March	13.75	3.5	3.18	2.89	0.31	31	32

5.3.4 Pollution loads

As mentioned in Chapter 4, Rayer Bazar khal and Kamrangir Char khal are the two major point sources that have been considered to contribute towards the pollution of the Buriganga river. Pollution loads from these point sources are the major inputs to the model. These loadings have been incorporated in the model along with the initial and boundary conditions. In Table 4.8 and 4.9 of Chapter 4, pollutant loadings through these major point sources during the year 2017 and 2018, respectively, have been shown.

5.3.5 Environmental parameters

Several environmental parameters that are essential for the water quality model have been collected from Bangladesh Meteorological Department (BMD). The time variable daily solar radiation, wind speed, air temperature and fraction of daylight were the variables used as input in the model within specific time period. The time variable light extinction functions were assumed and added in this model on spatial basis.

5.4 Calibration of the Water Quality Model

Calibration of a model involves minimizing of deviation between measured field condition and model output by adjusting different parameters and constants used in the model. In this process, a number of simulations are performed to match the observed data through adjustments of model coefficients within acceptable limits/ bounds established in the literature. The model has been calibrated with the water quality data collected in February and March of 2017 through the field measurements and laboratory investigations. The required values of the kinetic constants and coefficients were taken from the literature related to water quality modeling works (Bowie et al., 1985; Lung and Larson, 1995; Ghosh and Mcbean, 1998; Ahmed, 2005; Karim et al., 2000; Wool et al., 2009).

For model calibration, several runs were made by varying the kinetic constants and coefficients within the range given in literature to minimize the difference between the computed and observed profiles. Table 5.4 show the calibrated value of the kinetics coefficients in the water column as finally adopted in the model together with the

ranges of these values as reported in the literature. Figure 5.10-5.16 shows the calibration results for DO, ultimate BOD, NH₃-N, NO₃-N, ortho-PO₄, TSS and phytoplankton chlorophyll-a as compared with the actual field data for the month of February, 2017 and March 2017.

Table 5.4: Summary of calibrated values of kinetic parameters used in the model

Parameter description	Value	Range in literature
Nitrification rate constant at 20°C (day ⁻¹)	0.02	0.002-0.10
Nitrification temperature coefficient	1.07	
Half saturation constant for nitrification oxygen limit (mg O ₂ /L)	1.8	1.5-2
Denitrification rate constant at 20°C (day ⁻¹)	0.09	0.002-0.10
Denitrification temperature coefficient	1.04	
Half saturation constant for denitrification oxygen limit (mg O/L)	0.1	
Dissolved organic nitrogen mineralization rate constant at 20°C (day ⁻¹)	0.03	0.01-1.08
Dissolved organic nitrogen mineralization temperature coefficient	1.08	
Organic nitrogen decay rate constant in sediments at 20°C (day ⁻¹)	0.0004	
Organic nitrogen decay in sediment temperature coefficient	1.08	
Fraction of phytoplankton death recycled to organic nitrogen	0.3	
Mineralization rate constant for dissolved organic phosphorus at 20°C	0.03	0.001-0.05
Dissolved organic phosphorus mineralization temperature coefficient	1.08	
Organic phosphorus decay rate constant in sediments at 20°C (day ⁻¹)	0.0004	
Organic phosphorus decay in sediments temperature coefficient	1.08	
Fraction of phytoplankton death recycled to organic phosphorus	0.5	
BOD decay rate constant at 20 °C (day ⁻¹)	0.25	0.05-0.50
BOD decay rate temperature correction coefficient	1.046	
BOD decay rate constant in sediments at 20 °C (day ⁻¹)	0.0004	
BOD decay rate in sediments temperature coefficient	1.08	
BOD half saturation oxygen limit (mg O/L)	0.5	0-0.5
Elevation above sea level (meters) used for DO saturation	1.3	
Oxygen to carbon stoichiometric ratio	2.67	
Sediment oxygen demand (gm/m ² /day)	3-10	

Parameter description	Value	Range in literature
Phytoplankton maximum growth rate constant at 20°C (day ⁻¹)	2.0	1-2.7
Phytoplankton growth temperature coefficient	1.066	
Phytoplankton carbon to chlorophyll ratio	50	50-100
Phytoplankton half-saturation constant for nitrogen uptake (mg N/L)	0.025	0.005-0.05
Phytoplankton half-saturation constant for phosphorus uptake (mg P/L)	0.001	0.0005-0.005
Phytoplankton endogenous respiration rate constant at 20°C (day ⁻¹)	0.075	
Phytoplankton respiration temperature coefficient	1.045	0.05-0.25
Phytoplankton death rate constant (non-zooplankton predation) (day ⁻¹)	0.02	
Phytoplankton zooplankton grazing rate constant (day ⁻¹)	0	0.01-0.25
Nutrient limitation option	1	0-5
Phytoplankton phosphorus to carbon ratio	0.025	0-1
Phytoplankton nitrogen to carbon ratio	0.25	0.01-0.047
Phytoplankton half-saturation for recycle of nitrogen and phosphorus (mg Phyt C/L)	1.0	0.1-0.43
Phytoplankton maximum quantum yield constant	720	
Phytoplankton optimal light saturation	300	

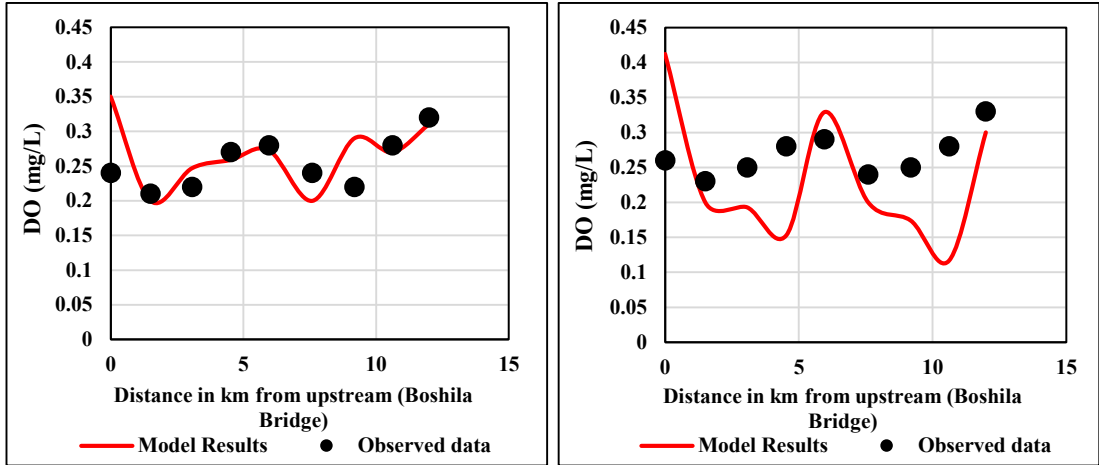


Figure 5.10: Model calibration results for DO during February and March 2017

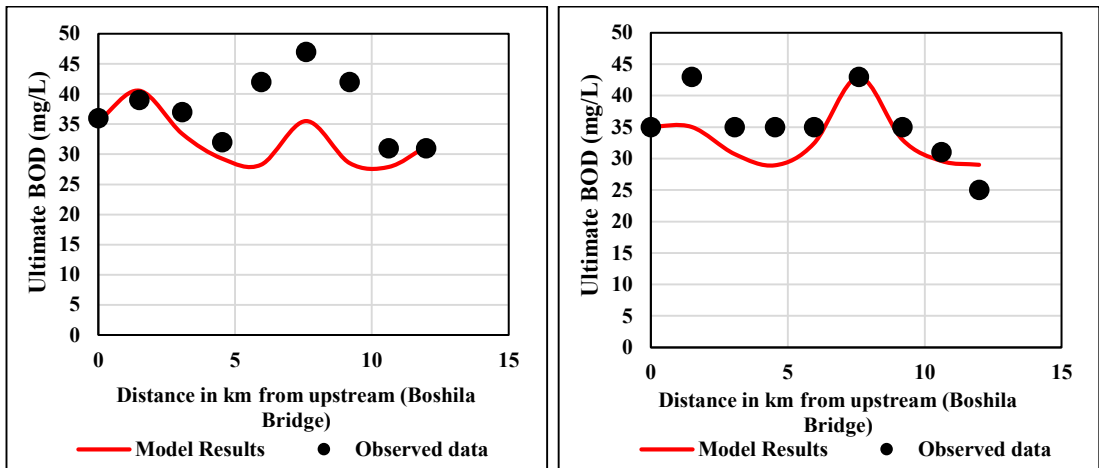


Figure 5.11: Model calibration results for ultimate BOD during February and March 2017

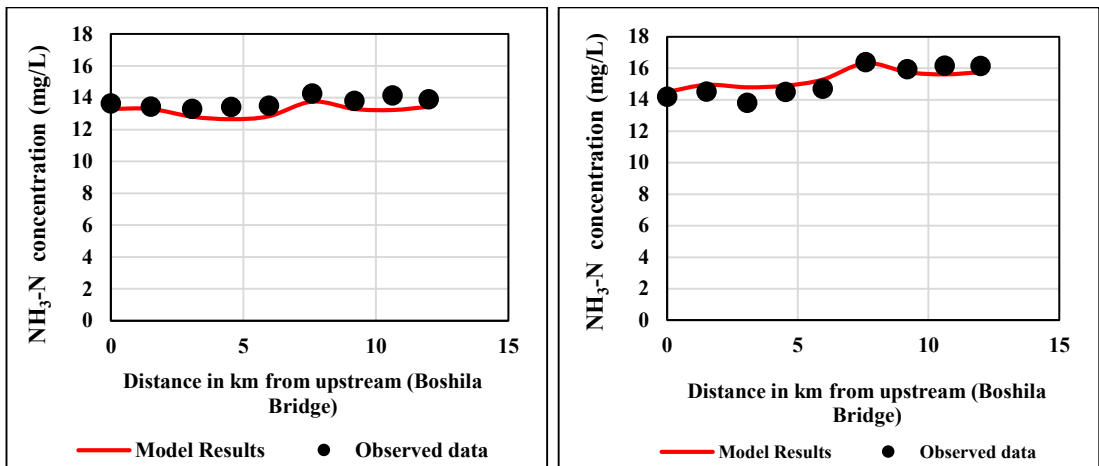


Figure 5.12: Model calibration results for $\text{NH}_3\text{-N}$ during February 2017 and March 2017

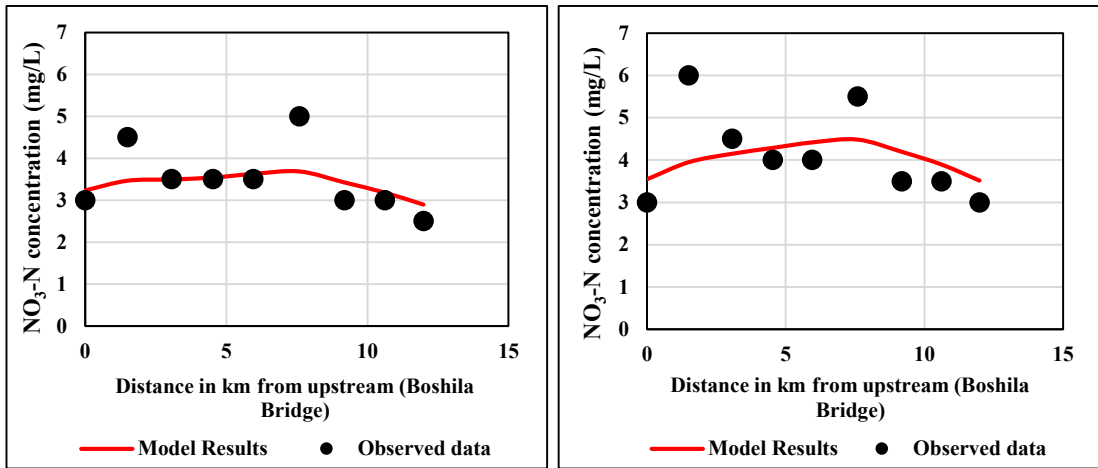


Figure 5.13: Model calibration results for NO₃-N during February 2017 and March 2017

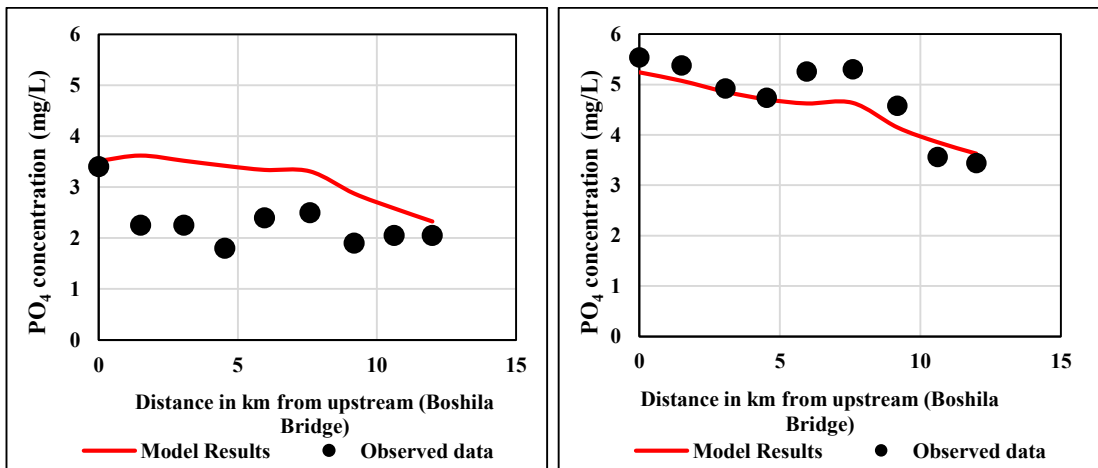


Figure 5.14: Model calibration results for ortho-PO₄ during February 2017 and March 2017

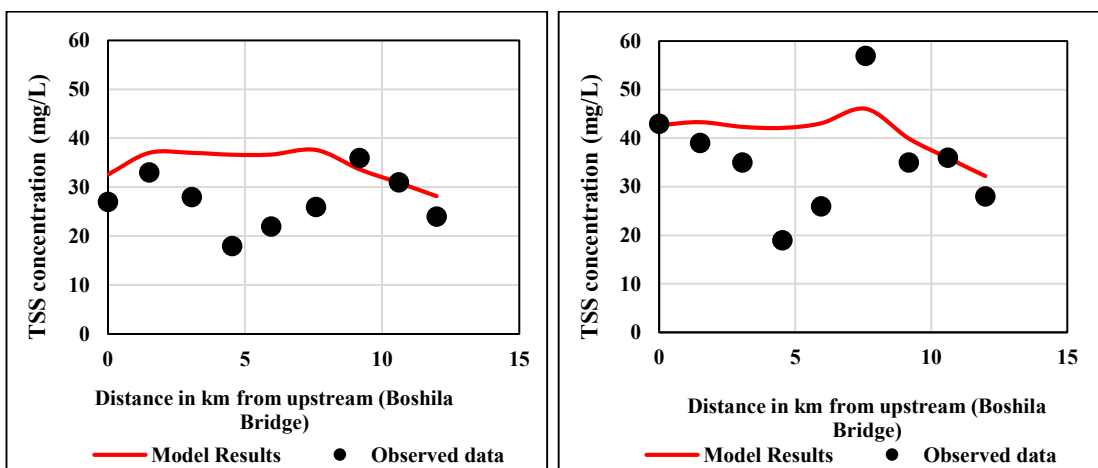


Figure 5.15: Model calibration results for TSS during February 2017 and March 2017

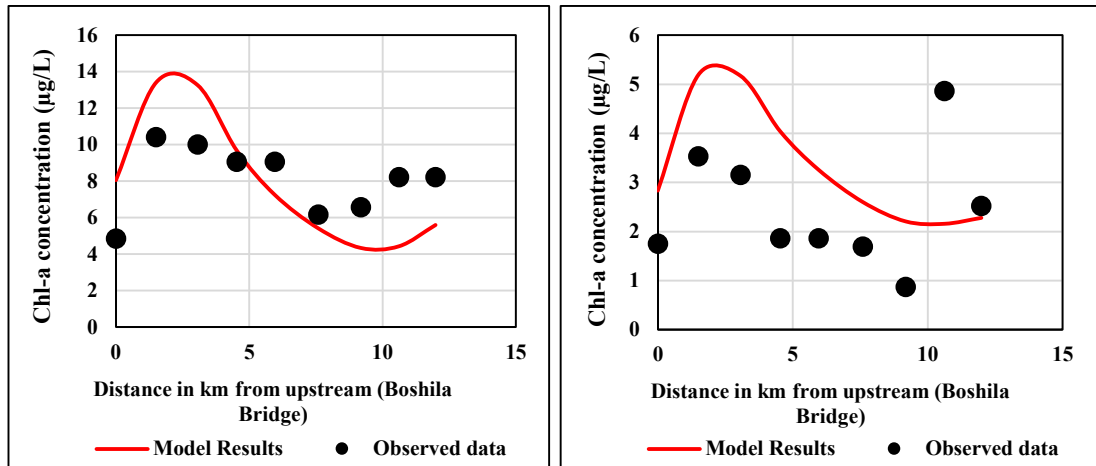


Figure 5.16: Model calibration results for phytoplankton chlorophyll-a during February 2017 and March 2017

5.5 Model Verification

Model verification is the process of demonstration of model fit for a distinctly different set of environmental conditions (different loading conditions) with the same suite of coefficients used in calibration. The predictive capability of the calibrated model was tested for the observed data in February and March 2018, using the same values of the kinetics constants and coefficients as listed in Table 5.4. As mentioned earlier, most of the tannery industries shifted from Hazaribagh to Savar during the dry season of the year 2017, and during the dry season of the year 2018, an improvement in water quality of the Buriganga river was observed (as discussed in Chapter 4). It is observed that the model predictions reasonably reproduced the spatial trends of the water quality parameters after the relocation of the tannery industries. Figure 5.17-5.23 shows the model verification results for DO, ultimate BOD, $\text{NH}_3\text{-N}$, $\text{NO}_3\text{-N}$, ortho- PO_4 , and phytoplankton chlorophyll-a during March 2018.

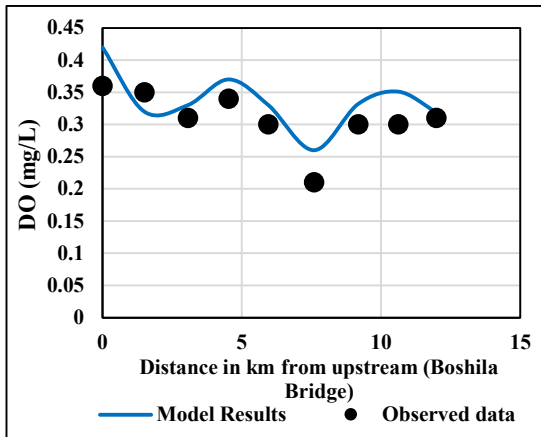


Figure 5.17: Model verification results for DO during March 2018.

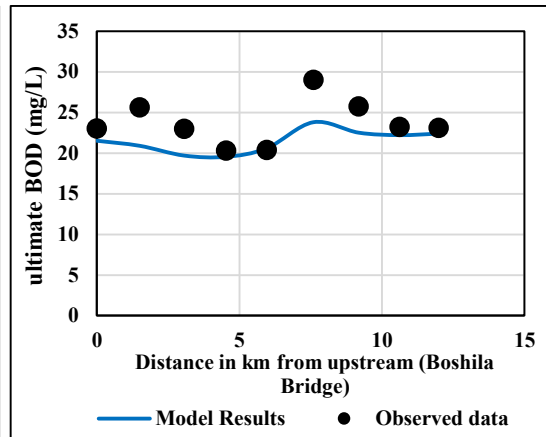


Figure 5.18: Model verification results for ultimate BOD during March 2018.

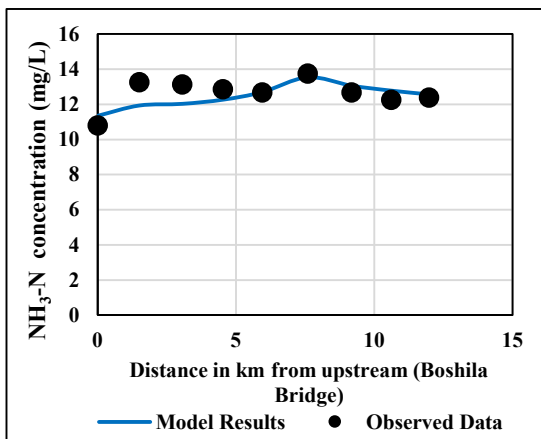


Figure 5.19: Model verification results for NH₃-N during March 2018.

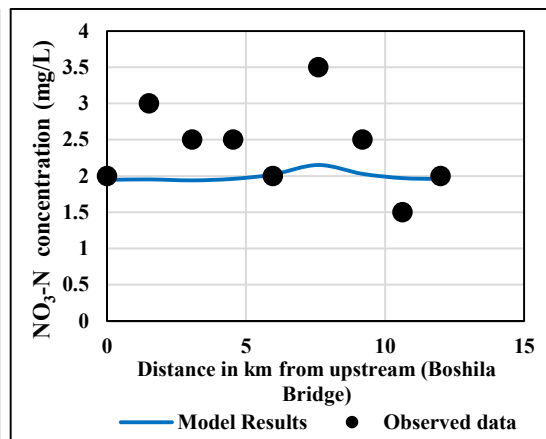


Figure 5.20: Model verification results for NO₃-N during March 2018.

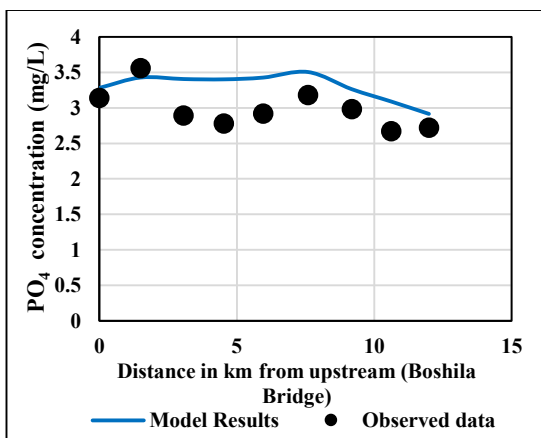


Figure 5.21: Model verification results for ortho-PO₄ during March 2018.

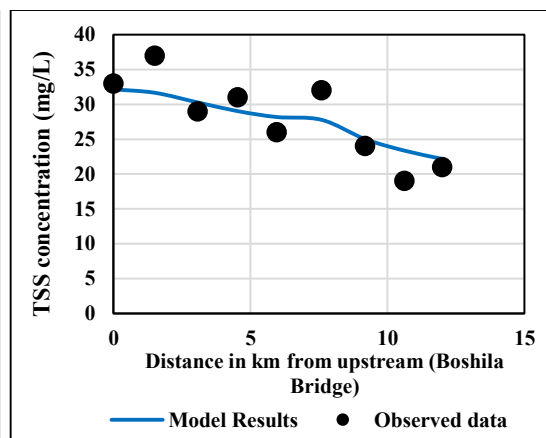


Figure 5.22: Model verification results for TSS during March 2018.

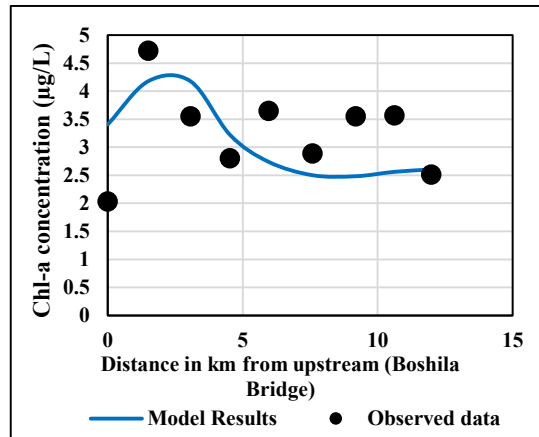


Figure 5.23: Model verification results for phytoplankton chlorophyll-a during March 2018.

5.6 Model Sensitivity Analysis

Generally, sensitivity analysis of the model is conducted to test the relative importance of the model coefficients to predict concentrations. Through sensitivity analysis of a model, one can identify the importance of variability in key parameters that should be taken into account in the process of model calibration. Only one parameter or coefficient being tested was allowed to vary during the sensitivity analysis process at a time, while all others were held constant. Sensitivity of the model was analyzed to determine the effects of dispersion coefficient and deoxygenation coefficient on the concentration profile of the key water quality parameters.

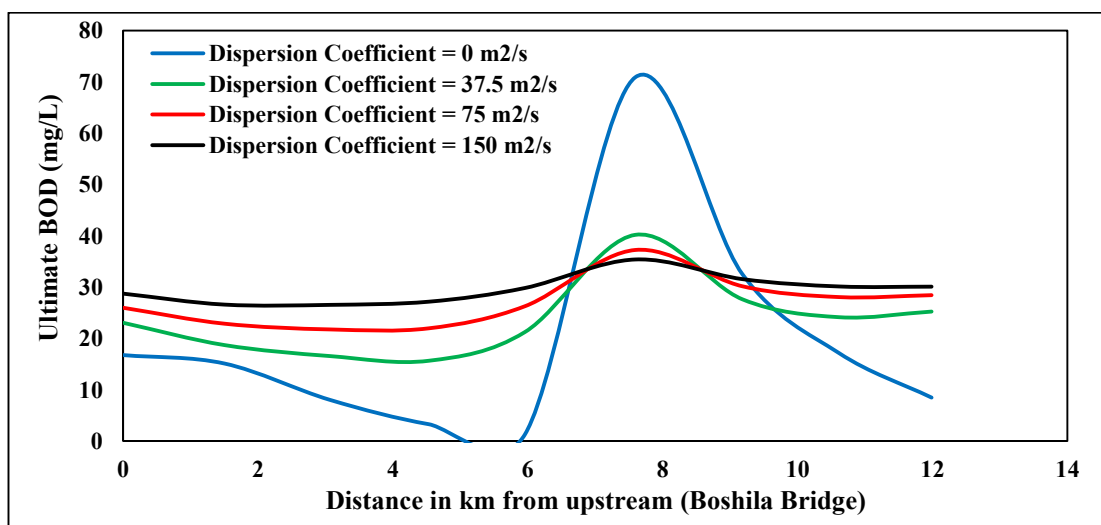
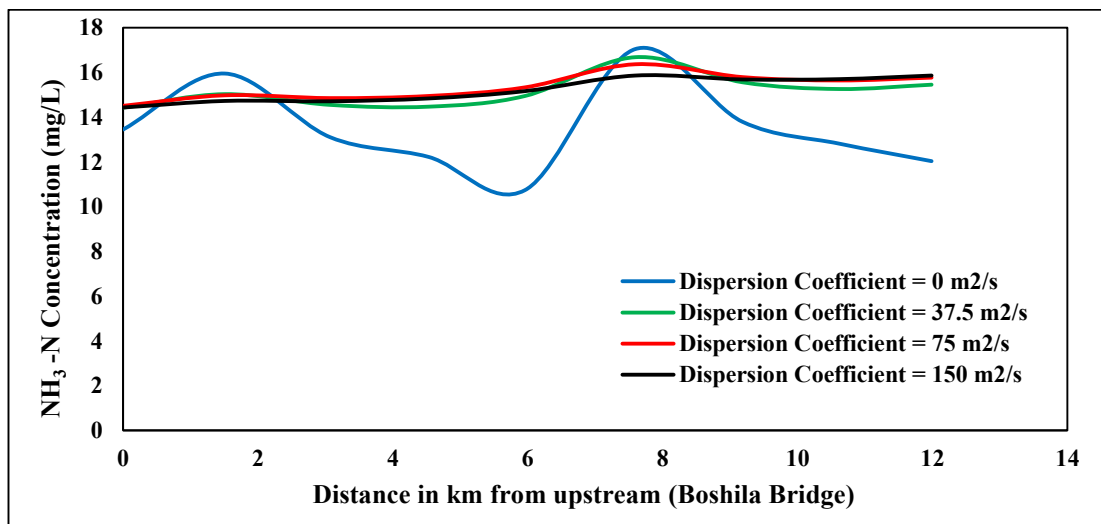
5.6.1 Sensitivity to dispersion coefficient

Dispersion in the mass transport equation plays an important role in mixing of a system with tidal fluctuation. Thus, reduced dispersion coefficient is likely to increase pollutant concentration in a segment of a system. Increased mixing in the water column tends to reduce the concentration by transporting it into the up and downstream. As mentioned earlier in this chapter, for Buriganga river, a value of $75 \text{ m}^2/\text{s}$ has been taken as the dispersion coefficient during model calibration. Sensitivity of the model to dispersion was performed in calibrated model for March 2017 by considering:

- (i) dispersion coefficient = 0 (i.e., a purely advective system)

- (ii) dispersion coefficient = $150 \text{ m}^2 / \text{sec}$ (i.e., twice the calibrated value),
- (iii) dispersion coefficient = $37.5 \text{ m}^2 / \text{sec}$ (i.e., half of the calibrated value).

The results of sensitivity of dispersion coefficient are presented in Fig. 5.24. The results show that the dispersion coefficient has significant effect on the concentration profile of major water quality parameters, e.g., NH_3 -N and ultimate BOD and phytoplankton chlorophyll-a near the junction of the point sources with the river. As the Buriganga river is a tidal river with very low fresh water flow from Turag and Daleswari during dry season, dispersive transport is significant, which has been considered with due importance in the model to predict the concentration profile of the water quality parameters.



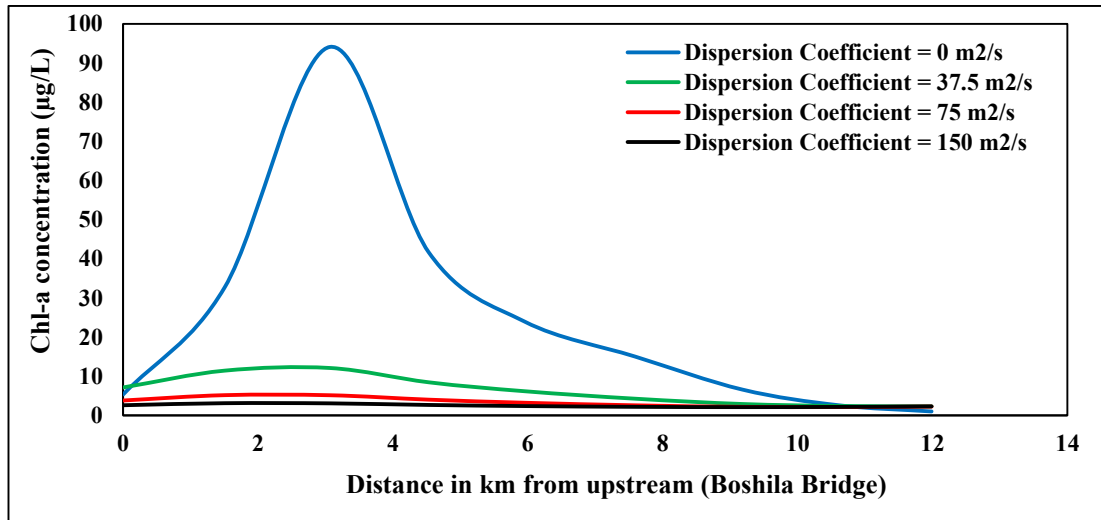


Figure 5.24: Model sensitivity analysis: Effect of dispersion co-efficient in Buriganga river on 25 March 2017.

5.6.2 Sensitivity to BOD decay rate constant (k_d)

In literature, a wide range of values of k_d is reported (Bowie et al., 1985) indicating a substantial variation in the rate coefficient. The uncertainty of k_d justifies the sensitivity analysis of this parameter. The model was calibrated and verified with k_d equals to 0.25 day^{-1} . Two values of k_d , half and two times of calibrated value i.e. 0.125 day^{-1} and 0.5 day^{-1} were taken to examine the sensitivity. The results of the sensitivity of k_d over this test range are plotted in Fig. 5.25. It is observed from Fig. 5.25, that as expected an increase in k_d causes decrease in BOD and DO concentration and vice versa. The result follows the theory as increase in k_d result in higher BOD oxidation using more dissolved oxygen.

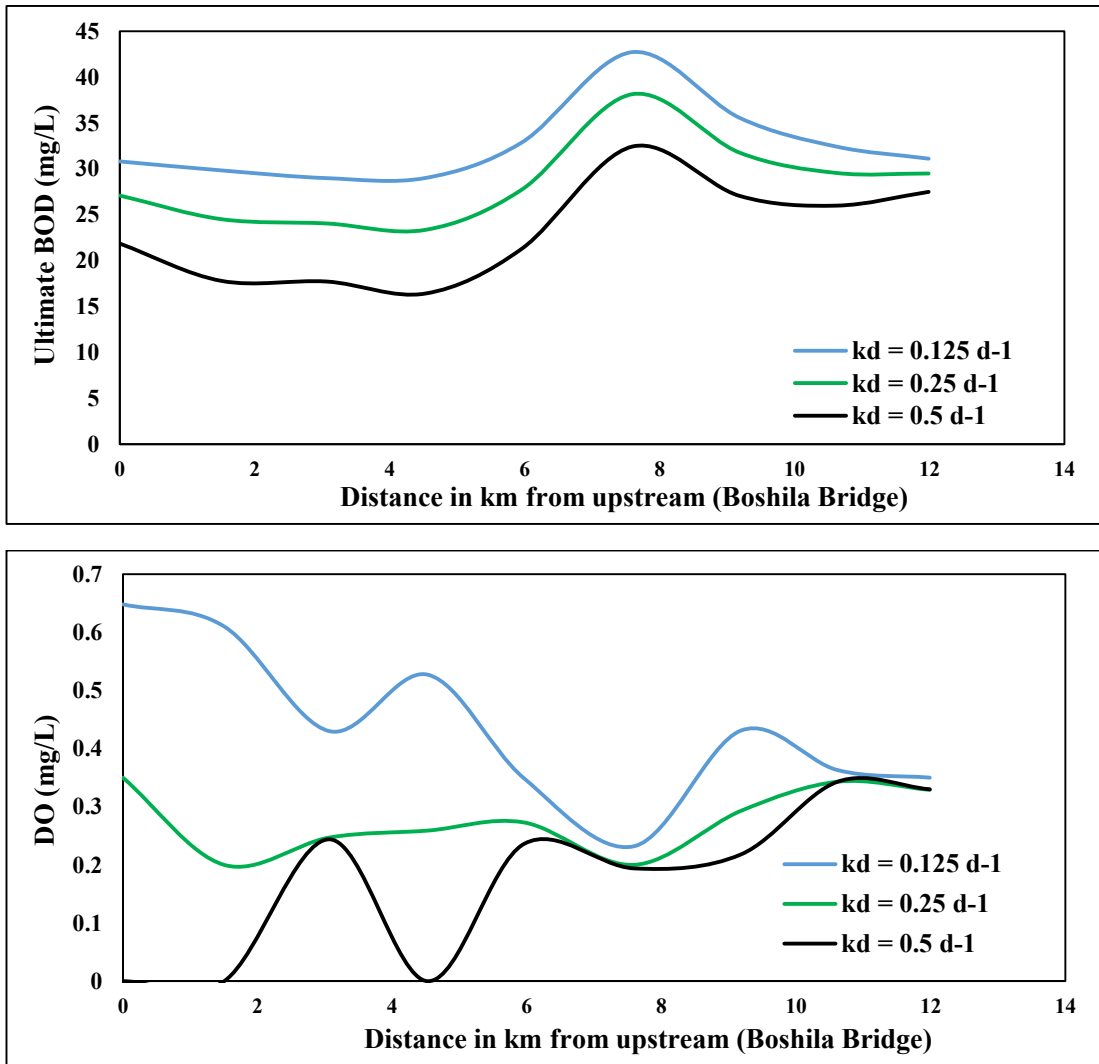


Figure 5.25: Model sensitivity analysis: Effect of BOD decay rate constant, k_d in Buriganga river on 25 March 2017.

5.7 Model Results and Discussions

In this study, a 1-D water quality model has been developed using the finite segment method on the basis of primary filed sampling and laboratory analyses data. The primary purpose of the calibration and validation process was to establish a baseline condition of the key water quality parameters of the Buriganga river for the current period. When the baseline condition is established, it can be then widely used to analyze the effect of relocation of tannery industries on the water quality of Buriganga river.

The four interactive systems in water quality modeling are phytoplankton, nitrogen, phosphorus and dissolved oxygen. The phytoplankton kinetics is closely related to dissolved oxygen as well as nitrogen and phosphorus. Dissolved oxygen is necessary to support the life functions of higher organisms and for a balanced aquatic environment.

Dissolved oxygen along the Buriganga river from Boshila Bridge to Postagola Bridge is close to anoxic level (around 0.25 mg/L) due to huge amount of pollution loads in these areas. Even the wind-induced natural aeration together with the mixing/dispersion effects of the river are not sufficient enough to raise the dissolved oxygen above a level of 2 mg/L along the major portion of its reach. However, relatively better concentration of DO has been found during March 2018 as compared to March 2017 from the model.

Progressive increase in the dissolved oxygen concentrations measured in the upper portion of the Buriganga river have been obtained by the model results. At the downstream end, also there is a slight increase in DO value, this might be due to the dilution effects of the river with no significant existence of tannery industries further downstream of this model boundary.

This model predicts present Ammonia-Nitrogen concentrations along the river most accurately. During March 2018, along the river, $\text{NH}_3\text{-N}$ varied from 10.8 to 13.75 mg/L. From the model, it was found that the $\text{NH}_3\text{-N}$ concentrations varied from 11.3 to 13.5 mg/L. During March 2017, $\text{NH}_3\text{-N}$ concentration variation limit was 13.8 to 16.4 mg/L. From the model this limit was found to be 14.4 to 16.32 mg/L. So, the decrease in $\text{NH}_3\text{-N}$ concentration as compared to 2017 was captured by the model.

Along the river, ultimate BOD varied from 20 to 29 mg/L in March 2018. The model predicted limit was 19.6 to 24 mg/L. The spatial trend predicted by the model for orthophosphate matched reasonably well with the observed data. Orthophosphate concentrations varied from 2.67 to 3.56 mg/L along the Buriganga river in March 2018. Besides, from the model, along the river orthophosphate concentration varied from 2.92 to 3.55 mg/L. Although the upper prediction limit is very close to the observed one but slightly higher orthophosphate concentrations were predicted by the

model at the monitoring locations. Spatial and temporal variations of NO₃-N was found similar to ammonia and ultimate BOD.

Simulation results from the model for the water quality parameters match reasonably well with the observed or measured field data. Although, some differences are noted between the measured and the simulated values, but the model followed the trend of field measured data very well, specially the change in concentration of water quality parameters before and after the relocation of majority of tannery industries. The overall behavior of system can be represented sensibly by the model.

5.8 Application of WQ Model: Effects of Relocation of Tannery Industries on Water Quality of the River

A calibrated and verified water quality model can be used in developing water quality management alternatives and subsequently policy decisions. One of the main objectives of this research was to analyze the effects of relocation of tannery industries on the water quality of Buriganga river. In this study, the verified model with the pollutant loadings on 20, March of 2018 was considered as the ‘base condition’. Then this model has been used to assess the impact of tannery relocations on the water quality of the river by introducing a number of load reduction scenarios on the point source loadings (loadings through Rayer Bazar khal and Kamrangir Char khal). Table 5.5 shows the base condition and the scenario details that has been considered while applying this water quality model to assess the impacts of tannery shifting on the water quality of the river.

Table 5.5 Base condition and scenario details for the application of the WQ model

Scenario Name	Conditions
Base condition	Considering full loadings through the point sources on 20, March 2018
Scenario 1	75% of loadings has been considered through the point sources
Scenario 2	50% of loadings has been considered through the point sources
Scenario 3	25 % of loadings has been considered through the point sources
Scenario 4	0% of loadings has been considered through the point sources

As mentioned earlier in this chapter, seven state variables: DO, ultimate BOD, $\text{NH}_3\text{-N}$, $\text{NO}_3\text{-N}$, ortho- PO_4 , TSS and phytoplankton chlorophyll-a have been considered while developing the model. In this application, part of the water quality model, the variation of these parameters in different scenarios have been analyzed.

Dissolved Oxygen (DO)

Only a small variation is found between the baseline condition and the scenarios. Although no BOD loading has been considered through the point sources during March in scenario no 4, but according to the model, the improvement in DO concentrations was very small (around 0.2 mg/L). It indicates that, with less discharge along the river during dry season, relocation of Hazaribagh tannery industries alone may not improve the DO levels of the Buriganga river to a large extent. For this, non-point source pollution and legacy pollution along the river need to be analyzed in details. However, during the monsoon season, with high fresh water flow along the river, DO of the river would improve. Figure 5.26 shows the spatial variation of DO along the Buriganga river for different load reductions scenarios.

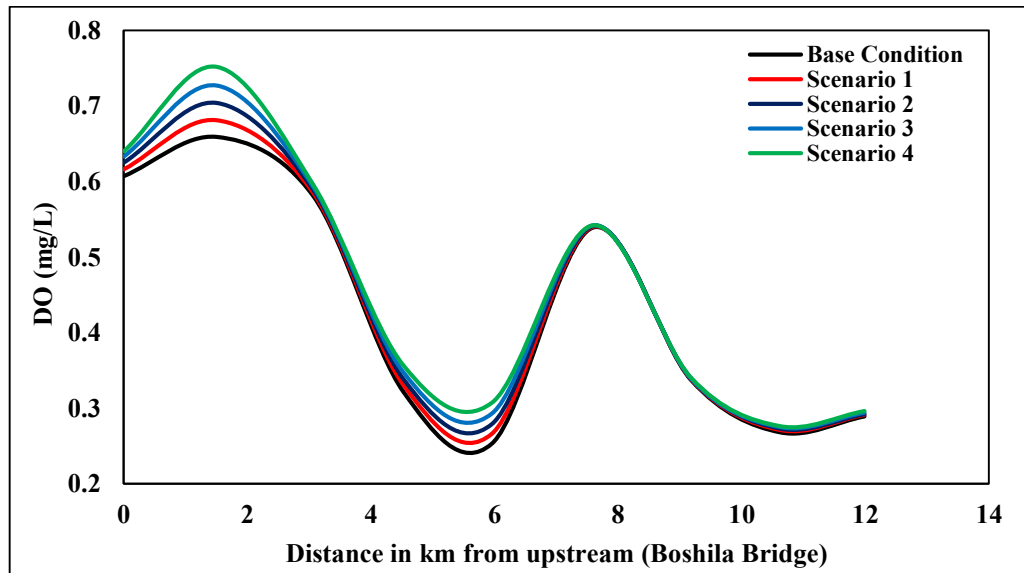


Figure 5.26: Spatial variation of DO along the Buriganga river for different load reductions scenarios

Ultimate Biochemical Oxygen Demand (ultimate BOD)

Significant difference in BOD values has been found while comparing base condition and the scenarios. The main point source that released tannery loadings into the river is Kamrangir Char khal, which is approximately 7 km downstream from the upper most monitoring location, Boshila Bridge. From Figure 5.27, it can be said that, with the reduced amount of BOD loadings towards this point source, ultimate BOD values decrease in reasonable amount and the BOD peak at the Showari Ghat (7.5 km downstream of Boshila Bridge) diminishes with load reductions. So, with the total relocation of tannery industries from Hazaribagh, this model predicts that, ultimate BOD values will drop by an amount of 5 to 6 mg/L.

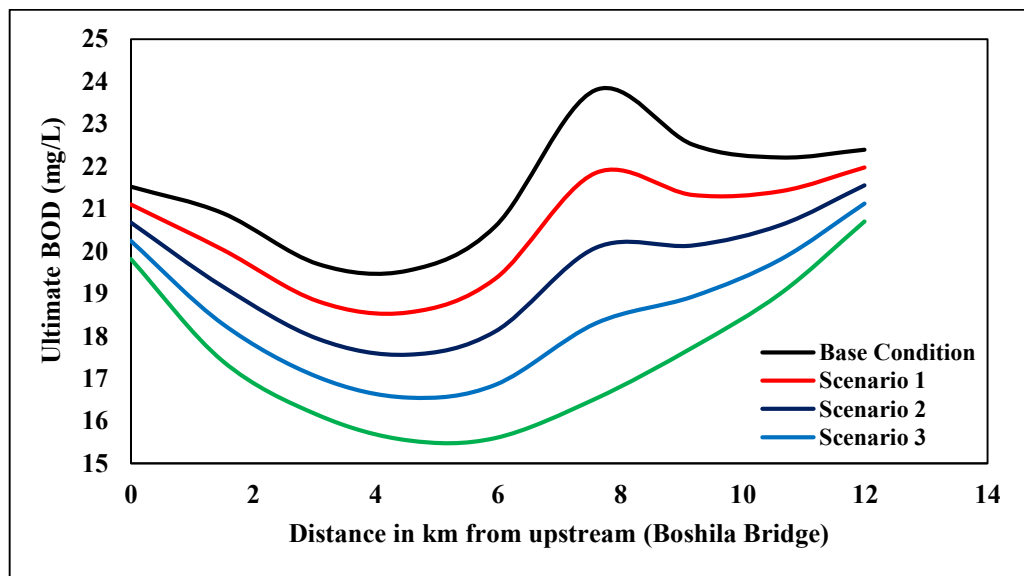


Figure 5.27: Spatial variation of ultimate BOD along the Buriganga river for different load reductions scenarios

Ammonia Concentrations (NH₃-N)

This model predicts the ammonia concentration very reasonably. From primary field measurement, in March 2017, maximum ammonia concentration was found 16.4 mg/L near Showari Ghat. In 2018, at Showari Ghat, the concentration was observed 13.75 mg/L. This model predicts this trend of lowering of ammonia concentrations with the reduction of loadings due to the relocation of tannery industries. From the model, while considering no BOD loadings at the point sources (scenario 4), the ammonia concentration at the Showari Ghat was found around 11.25 mg/L. Figure 5.28 shows

spatial variation of ammonia concentration along the Buriganga river for different load reductions scenarios.

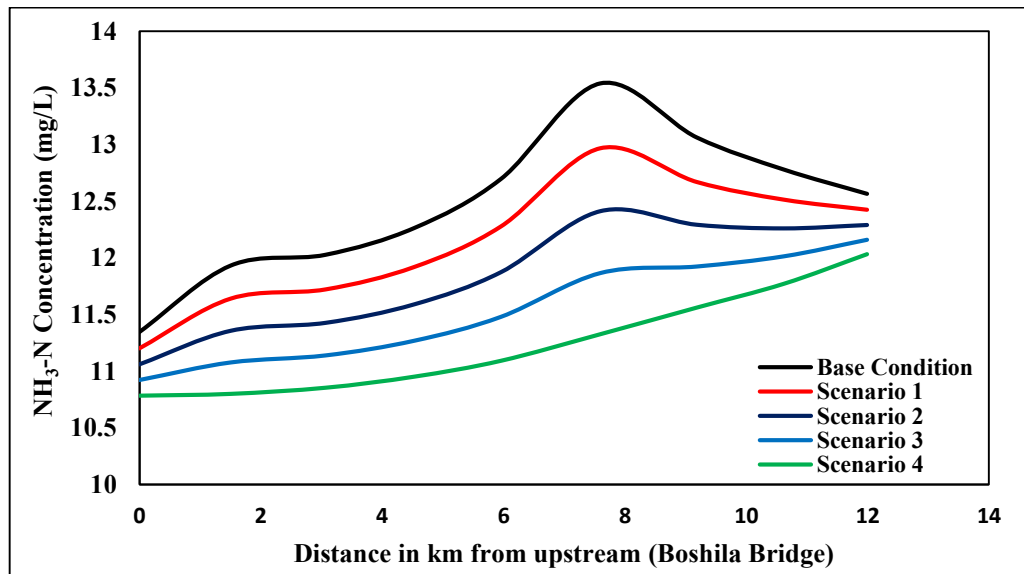


Figure 5.28: Spatial variation of ultimate BOD along the Buriganga river for different load reductions scenarios

Nitrate ($\text{NO}_3\text{-N}$) and orthophosphate (PO_4^{3-}) Concentration

Reduced concentrations of nitrate and orthophosphate are predicted by the model with the reduced loadings through the point sources. As compared to base condition with scenario 4, the model predicts almost similar trends for both nitrate and orthophosphate concentration during dry season. In case of orthophosphate, relatively lower concentrations are predicted by the model at the downstream of the river reach i.e. near Postagola Bridge. The spatial variation of nitrate and orthophosphate concentration along the Buriganga river for different load reductions scenarios have been shown in Figure 5.29 and 5.30, respectively.

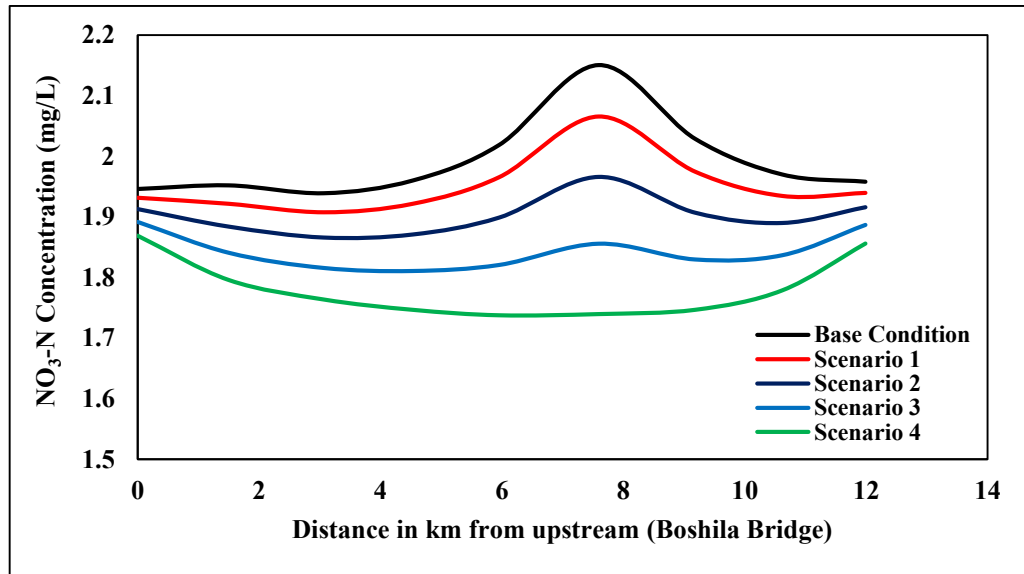


Figure 5.29: Spatial variation of nitrate concentration along the Buriganga river for different load reductions scenarios

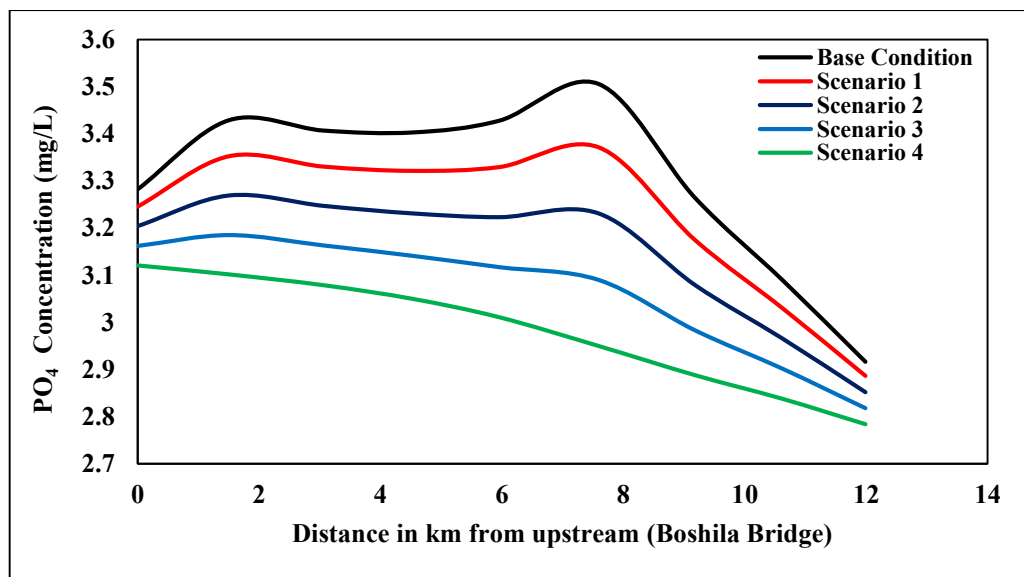


Figure 5.30: Spatial variation of orthophosphate concentration along the Buriganga river for different load reductions scenarios

Total Suspended Solids (TSS)

Like base condition, relatively lower TSS values are predicted by the model at the downstream of the river in different load reduction scenarios indicating reduction in suspended solids along the river with the less pollutant loadings through the point sources due to relocation of tannery industries. Figure 5.31 shows the spatial variation of TSS along the Buriganga river for different load reductions scenarios.

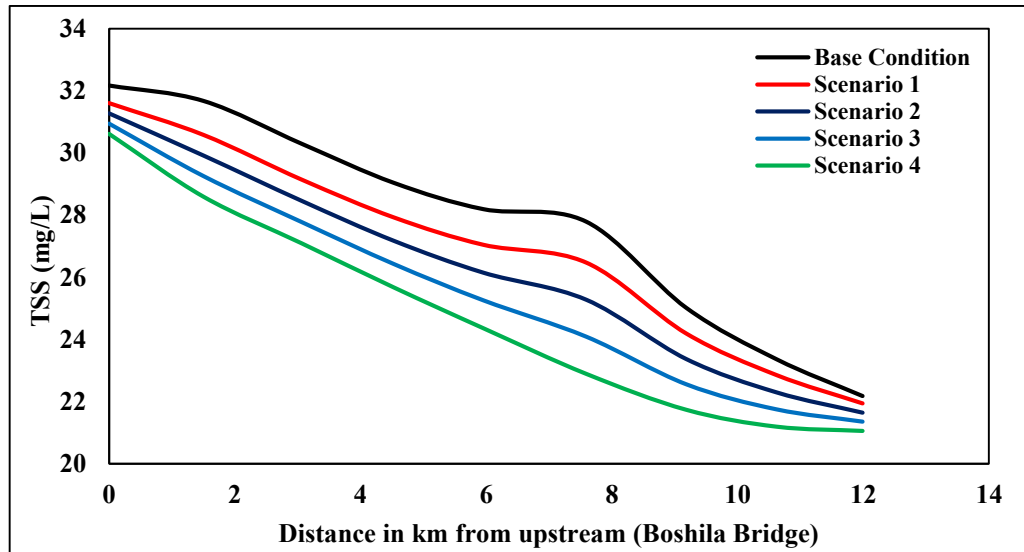


Figure 5.31: Spatial variation of TSS along the Buriganga river for different load reductions scenarios

Phytoplankton Chlorophyll-a

There is no variation found by model in the case of phytoplankton chlorophyll-a concentration for base condition and different load reduction scenarios. According to this model prediction, relocation of tannery industries from Hazaribagh will not be a driving factor in affecting the phytoplankton chlorophyll-a concentrations along the river. The spatial variation of chlorophyll-a concentration along the Buriganga river for different load reductions scenarios has been shown in Figure 5.32.

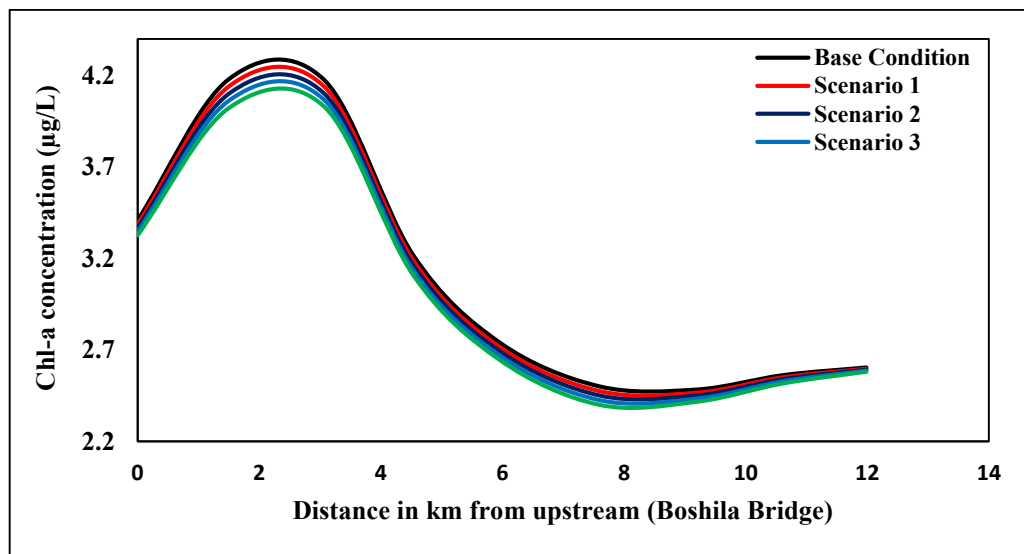


Figure 5.32: Spatial variation of chlorophyll-a along the Buriganga river for different load reductions scenarios

In a summary, in response to the relocation of tannery industries from Hazaribagh, according to the model prediction, the DO level of the Buriganga river may not improve in a considerable amount. But considerable reduction of BOD, ammonia, nitrate and phosphate are expected as a result of the relocation.

CHAPTER SIX

CONCLUSIONS AND SUGGESTIONS

6.1 Introduction

The main focus of this study was to assess the impacts of tannery relocations from Hazaribagh on the water quality of Buriganga river. Many of the tannery industries have been shifted from Hazaribagh to Savar during the dry season of the year 2017. In order to explore the variation in water quality of Buriganga river during and after these relocations, water samples were collected from different monitoring locations along the river during the dry season of the year 2017 (January, February and March) and 2018 (February and March). Wastewater from these tannery industries are discharged into the river through Rayer Bazar khal and Kamrangir Char khal. The average pollution loading rates from these major point sources were estimated by measuring flows and concentrations of selected parameters during the study period.

A one-dimensional modeling tool named Water Quality Analysis and Simulation Program (WASP) was applied to a selected reach of the Buriganga river to assess the impact of tannery relocation on the river water quality. The water quality model was calibrated and verified using water quality data of 2017 and 2018, respectively. Then a number of load reduction scenarios (through the point sources) were assumed to assess the tannery shifting impacts on the river water quality.

In this Chapter, major conclusions based on the results of this study have been summarized and some suggestions have been made for future studies.

6.2 Conclusions

Major conclusions from this study may be summarized as follows:

1. Lower dissolved oxygen level along the river has been found during the dry seasons of the year 2017 and 2018. During 2017, DO ranged from 0.21 to 0.33 mg/L along the river, whereas during 2018, DO ranged from 0.23 to 0.39 mg/L. It indicates that DO level has not improved to a large extent in 2018, even after

relocation of many tannery industries from Hazaribagh. The water quality model also predicted only minor increase (about 0.2 mg/L) in DO, even if all the BOD load from tannery industries are removed. This is due to the significant waste load that the river carries from upstream (i.e., upstream of tannery industries) locations.

2. Electrical conductivity along the river ranged from 1180 to 1200 $\mu\text{S}/\text{cm}$ in March 2017, while in March 2018, most of the EC values were below 1000 $\mu\text{S}/\text{cm}$, indicating a reduction of around 15-20%. Total solids concentration also decreased by about 15 to 20% during the dry season of 2018 as compared to 2017.
3. COD along the Buriganga river ranged from 65 to 140 mg/L during the dry season of 2017, while it ranged from 55 to 85 mg/ L during the dry season of 2018, indicating a reduction of approximately 30 to 35% during 2018.
4. BOD₅ varied from 14 to 36 mg/L during the dry season of 2017, and it reduced by about 25 to 30% during the dry season of 2018. These results are consistent with the trend of EC and COD in the Buriganga River water. Considering no other major changes along the stretch of the Buriganga River studied, the reduction of EC, COD and BOD₅ in the year 2018 compared to 2017 could be attributed to the shifting of tannery industries from Hazaribagh.
5. Maximum ammonia (NH₃-N) concentrations were recorded along the river in March 2017, which varied from 13.8 to 16.4 mg/L; highest concentration was found at Showari Ghat. In March 2018, ammonia concentration decreased by around 15 to 20%. This reduction in NH₃-N concentration is also likely to be due to the shifting of large number tannery industries from Hazaribagh.
6. Relatively lower nitrate (NO₃-N) and orthophosphate (PO₄³⁻) concentrations were found during the dry season of 2018 as compared to 2017. The reductions of these concentrations are consistent with the trend of ammonia concentration along the river.

7. A water quality model was calibrated and validated with the primary field data of dry season of the year 2017 and 2018, respectively. It was observed that the model simulation reasonably reproduced the spatial trends for $\text{NH}_3\text{-N}$, $\text{NO}_3\text{-N}$, orthophosphate, TSS and phytoplankton chlorophyll-a concentrations along the river.
8. Model predicts considerable reduction in BOD, ammonia, nitrate and orthophosphate concentrations in Buriganga river water with the reduced pollutant loadings through the two main point sources related to tannery industries. However, reduction in waste load from other upstream locations would be needed in order to achieve substantial improvement in the water quality of the River.

6.3 Suggestions for Future Studies

The following suggestions can be made from the present study:

1. In this study, all the analyses and modeling activities were done based on dry season data only. Field sampling and laboratory analysis can be done for wet season also. It will provide a comparative study of the water quality parameters along the Buriganga river for dry season and wet season. The impacts of relocation of tannery industries on river water quality during wet season could then be estimated.
2. Discharge data along the river for the year 2017 and 2018 have been prepared from the rating curve equation generated from the dry season discharge data of the year 2006. This is due to unavailability of the actual flow of the river during dry season. No organization including Bangladesh Water Development Board (BWDB) measures the river flow in the dry period. But the dry period is critical time for water quality in a river. Also, low flow information is very important for the development of appropriate management practice. Therefore, a continuous measurement of the river flow in the dry period should be undertaken for the rivers which receive significant pollution load. In addition, these data should be made available for research works specially those related to water quality modelling.

- 3.** Developing a water quality model needs adequate amount of water quality data as well as hydrodynamic characteristics of the river. In this study, five field samplings were done and those data were incorporated in the model. More water quality data would improve the accuracy of the model.
- 4.** Average values of the water quality parameters at different locations of the river were predicted by this model. But concentrations of the parameters may vary with depth as well as in the lateral direction. Therefore, a 2-Dimensional multilayer water quality model can be developed to simulate the variation of water quality parameters both in longitudinal and transverse direction.
- 5.** A sediment water interaction model can be formulated under the present modelling framework to better understand the temporal and spatial variations of nutrients and other water quality parameters. However, it will require considerable amount of field data on sediment kinetics and concentration of water quality parameters in overlying water column and the bottom sediment.
- 6.** Only two point sources that contribute pollutant loadings from tannery industries to the river water were considered in order to investigate the impacts of tannery shifting on Buriganga river water quality. For better understanding of the river water pollution, all the point and non-point sources need to be considered.

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APPENDICES

Table A 1: Water level (m, PWD) during January, February and March month of the year of 2006, 2017 and 2018 at SW 42 Station.

Date	WL (m, PWD)		
	Year 2006	Year 2017	Year 2018
1-Jan	2.1	1.89	2.09
2-Jan	2.05	1.98	2.06
3-Jan	2.03	1.69	2.08
4-Jan	2.05	1.58	1.91
5-Jan	1.85	1.48	1.88
6-Jan	1.75	1.43	1.88
7-Jan	1.72	1.37	1.84
8-Jan	1.7	1.26	1.74
9-Jan	1.75	1.33	1.67
10-Jan	1.65	1.4	1.55
11-Jan	1.65	1.37	1.36
12-Jan	1.55	1.37	1.36
13-Jan	1.65	1.48	1.45
14-Jan	1.75	1.51	1.46
15-Jan	1.8	1.52	1.46
16-Jan	1.7	1.71	1.55
17-Jan	1.7	1.68	1.63
18-Jan	1.75	1.61	1.63
19-Jan	1.68	1.5	1.66
20-Jan	1.45	1.39	1.76
21-Jan	1.55	1.22	1.77
22-Jan	1.55	1.23	1.81
23-Jan	1.3	1.35	1.68
24-Jan	1.08	1.32	1.61
25-Jan	1	1.21	1.67
26-Jan	1.05	1.6	1.62
27-Jan	1.35	1.639	1.63
28-Jan	1.42	1.58	1.61
29-Jan	1.75	1.61	1.57
30-Jan	1.78	1.53	1.56
31-Jan	1.79	1.61	1.53
1-Feb	1.88	1.33	1.64
2-Feb	1.9	1.34	1.78
3-Feb	1.78	1.38	1.84
4-Feb	1.6	1.4	1.71
5-Feb	1.5	1.46	1.65
6-Feb	1.45	1.35	1.62
7-Feb	1.2	1.34	1.55
8-Feb	1.25	1.37	1.53
9-Feb	1.3	1.4	1.49
10-Feb	1.33	1.53	1.44
11-Feb	1.35	1.58	1.25

12-Feb	1.49	1.6	1.21
13-Feb	1.53	1.68	1.27
14-Feb	1.58	1.54	1.22
15-Feb	1.65	1.48	1.14
16-Feb	1.73	1.34	1.36
17-Feb	1.85	1.38	1.47
18-Feb	1.78	1.33	1.51
19-Feb	1.68	1.38	1.55
20-Feb	1.45	1.3	1.5
21-Feb	1.38	1.35	1.55
22-Feb	1.33	1.37	1.56
23-Feb	1.25	1.43	1.5
24-Feb	1.4	1.42	1.41
25-Feb	1.5	1.48	1.36
26-Feb	1.58	1.56	1.34
27-Feb	1.78	1.58	1.49
28-Feb	2.05	1.68	1.52
1-Mar	2.1	1.75	1.53
2-Mar	1.95	1.78	1.58
3-Mar	1.9	1.82	1.62
4-Mar	1.75	1.82	1.62
5-Mar	1.65	1.92	1.66
6-Mar	1.48	1.89	1.68
7-Mar	1.25	1.87	1.72
8-Mar	1.2	1.82	1.73
9-Mar	1.2	1.84	1.78
10-Mar	1.28	1.76	1.71
11-Mar	1.4	1.72	1.65
12-Mar	1.3	1.69	1.63
13-Mar	1.63	1.69	1.58
14-Mar	1.68	1.63	1.52
15-Mar	1.72	1.56	1.48
16-Mar	1.68	1.51	1.37
17-Mar	1.63	1.56	1.33
18-Mar	1.6	1.44	1.31
19-Mar	1.5	1.47	1.3
20-Mar	1.42	1.42	1.34
21-Mar	1.44	1.39	1.36
22-Mar	1.38	1.35	1.38
23-Mar	1.2	1.25	1.48
24-Mar	1.2	1.13	1.52
25-Mar	1.25	1.24	1.57
26-Mar	1.35	1.64	1.63
27-Mar	1.65	1.74	1.65
28-Mar	1.82	1.78	1.73
29-Mar	1.92	1.95	1.78
30-Mar	2.04	2.09	1.84
31-Mar	2.07	2.07	1.91

Table A 2: Measured discharge during January, February and March of the year 2006, 2017 and 2018 along the Buriganga river.

Date	Discharge (m ³ /s)		
	Year 2006	Year 2017	Year 2018
1-Jan	168.4	122.12	161.85
2-Jan	172.1	139.18	155.47
3-Jan	143.4	88.83	159.70
4-Jan	143.2	73.13	125.80
5-Jan	136.3	60.40	120.31
6-Jan	104.2	54.56	120.31
7-Jan	88.7	48.02	113.21
8-Jan	80.8	37.28	96.57
9-Jan	98.0	43.93	85.84
10-Jan	102.8	51.23	69.16
11-Jan	110.1	48.02	46.98
12-Jan	108.7	48.02	46.98
13-Jan	102.9	60.40	56.85
14-Jan	98.8	64.06	58.02
15-Jan	104.3	65.32	58.02
16-Jan	96.4	91.88	69.16
17-Jan	99.5	87.33	80.04
18-Jan	99.8	77.23	80.04
19-Jan	89.0	62.83	84.37
20-Jan	58.4	50.15	99.77
21-Jan	55.3	33.77	101.40
22-Jan	56.9	34.63	108.05
23-Jan	37.8	45.95	87.33
24-Jan	23.7	42.94	77.23
25-Jan	16.6	32.93	85.84
26-Jan	24.1	75.85	78.63
27-Jan	31.6	81.33	80.04
28-Jan	47.8	73.13	77.23
29-Jan	89.6	77.23	71.79
30-Jan	96.5	66.58	70.47
31-Jan	92.7	77.23	66.58
1-Feb	108.8	43.93	81.47
2-Feb	106.7	44.93	103.04
3-Feb	88.4	49.08	113.21
4-Feb	74.9	51.23	91.88
5-Feb	60.8	58.02	82.91
6-Feb	49.4	45.95	78.63
7-Feb	33.3	44.93	69.16
8-Feb	32.1	48.02	66.58
9-Feb	35.7	51.23	61.60
10-Feb	40.3	66.58	55.70
11-Feb	42.1	73.13	36.39
12-Feb	50.9	75.85	32.93

13-Feb	59.2	87.33	38.19
14-Feb	66.2	67.86	33.77
15-Feb	83.5	60.40	27.36
16-Feb	90.9	44.93	46.98
17-Feb	105.7	49.08	59.20
18-Feb	87.2	43.93	64.06
19-Feb	73.4	49.08	69.16
20-Feb	57.3	41.00	62.83
21-Feb	48.9	45.95	69.16
22-Feb	46.0	48.02	70.47
23-Feb	43.9	54.56	62.83
24-Feb	47.7	53.44	52.33
25-Feb	70.4	60.40	46.98
26-Feb	77.6	70.47	44.93
27-Feb	90.3	73.13	61.60
28-Feb	124.8	87.33	65.32
1-Mar	158.3	98.16	66.58
2-Mar	146.1	103.04	73.13
3-Mar	105.6	109.76	78.63
4-Mar	79.4	109.76	78.63
5-Mar	67.2	127.66	84.37
6-Mar	55.3	122.12	87.33
7-Mar	42.6	118.51	93.43
8-Mar	37.3	109.76	94.99
9-Mar	39.4	113.21	103.04
10-Mar	36.7	99.77	91.88
11-Mar	45.5	93.43	82.91
12-Mar	32.7	88.83	80.04
13-Mar	61.5	88.83	73.13
14-Mar	70.6	80.04	65.32
15-Mar	85.0	70.47	60.40
16-Mar	76.6	64.06	48.02
17-Mar	75.6	70.47	43.93
18-Mar	77.9	55.70	41.97
19-Mar	51.1	59.20	41.00
20-Mar	43.0	53.44	44.93
21-Mar	41.9	50.15	46.98
22-Mar	42.8	45.95	49.08
23-Mar	40.3	36.39	60.40
24-Mar	44.8	26.61	65.32
25-Mar	41.8	35.50	71.79
26-Mar	49.8	81.47	80.04
27-Mar	89.2	96.57	82.91
28-Mar	113.5	103.04	94.99
29-Mar	118.4	133.35	103.04
30-Mar	135.6	161.85	113.21
31-Mar	133.9	157.58	125.80