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Assessing effect of climate change on the water quality of the Sitalakhya river using WASP model

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Abstract

The effects of increasing temperature and solar radiation due to climate change on the water quality of the Sitalakhya River were assessed using a water quality model WASP. WASP model was calibrated and verified using primary field data of 2008 and 2009. The predicted weather data of years 2030, 2050, and 2070 from a regional climate model PRECIS were used. The verified model with the existing pollutant loadings of 2009 has been used to assess the impacts of climate change on the water quality of the Sitalakhya river in the dry period of years 2030, 2050 and 2070; only the effects of changing temperature and solar radiation on water quality has been considered in the analysis. Model predicts progressive decrease of ammonia-nitrogen and BOD_5 with the increase of temperature. Predicted ammonia-nitrogen concentrations in the upstream of Kanchan are 3.00, 2.01, 1.40 and 1.37 mg/L for the years 2009, 2030, 2050 and 2070 respectively. Orthophosphate concentration is predicted to decrease due to higher uptake of orthophosphate by phyto-plankton in upper portion of the river but model predicted orthophosphate concentrations near the Saidabad WTP intake are 2.64, 2.88, 2.97 and 2.98 mg/L for the years 2009, 2030, 2050 and 2070 respectively.

Keywords: Water quality, Sitalakhya river, Ammonia, Temperature.

1. Introduction

With the development of economy and industry, greenhouse gases especially CO_2 are emitted continuously to the atmosphere, which leads to global climate change (Lenihan et al., 2008; Rundgren et al., 2005). Climate change can have far reaching consequences for water resources (Arnell, 2003), water quality (Hejzlar et al. 2003; Webb et al. 2003) and ecosystem (Beaugrand and Reid, 2003; EA, 2005; Hiscock et al., 2004; Moss et al., 2003; Sommer et al., 2004; Wilby et al., 2006). Strong climate-water quality relationship was found between air and water temperatures and nutrient concentrations (Tibby and Tiller, 2007).

Potential impacts of climate change on water quality and ecosystem, as a newly emerged problem and challenge, is of great concern by scientists and governments. However, scientific researches and practices are still facing big challenges in these issues because of their complexity and uncertainty (Jun et al., 2010).

Results of previous studies have indicated that water quality can be directly affected through several climate-related mechanisms on both short and long term (Prathumratana et al., 2008; Tu, 2009). These include impacts of air temperature increase, as well as changes in hydrological factors and others (Murdoch et al., 2000). The most immediate reaction to climate change is expected to be in river and lake water temperatures (Hammond and Pryce, 2007). Due to river and lake water temperatures are in close equilibrium with air temperature, air temperature is a key variable affecting water temperature in most biological systems, strongly influencing water chemistry, biochemical reactions and growth/death of biota (Blenckner et al., 2007; Malmaeusa et al., 2006).

The Sitalakhya river having a length of 113 km originates from the Old Brahmaputra and falls into the river Dhaleswari. It flows by the eastern side of Dhaka district. The river joins the river Balu at Demra, a small tributary flowing from the north of greater Dhaka. About 20 km downstream of Demra, the Sitalakhya river joins the Dhaleswari river. It is navigable by the country boats throughout the year. The river hardly spills over the banks and follows more or less a straight course. There are several different types of industries like textiles and dyeing, paper and pulp, jute, pharmaceuticals, fertilizers, etc of moderate to big size and several urban developments along the entire stretch of the river. These establishments contribute to the pollution load to the Sitalakhya river directly or through a number of wastewater khals (canals) like DND drainage khal, Majheepara khal, Killarpul khal, Kalibazar khal, Tanbazar khal, etc. Domestic and industrial wastewater from Dhaka city through Norai khal and from the Tongi industrial area through Tongi khal is disposed of in the river Balu. This also contributes to the pollution load to the river Sitalakhya. The water quality of this river is of particular importance not only for ecological and commercial reasons but also for concerns regarding safe drinking water supply as the largest surface water treatment plant in Bangladesh located at Saidabad draws water from it through the intake at Sarulia about 400 m downstream of its confluence with the Balu river.

To assess the impact of climate change on water quality parameters, the downstream portion of the Sitalakhya river from Ghorasal highway bridge, the total length of the Balu river from Pubail highway bridge to Demra ghat and Norai khal were selected as the study area as shown in Fig. 1. In fact all major urban and industrial establishments are located within this reach and the water quality of the river is affected by the domestic and industrial effluents generated from these establishments. The Water Quality Analysis Simulation Program (WASP7.3) (Wool et al., 2009) was used to simulate the fate and transport of water quality parameters. The water quality model was calibrated and verified using the water quality data of 2008 and 2009, respectively. The verified model with the existing pollutant loadings of 2009 has been used to assess the impacts of climate change on the water quality of the Sitalakhya river in the dry period of years 2030, 2050 and 2070; only the effects of changing temperature and solar radiation on water quality has been considered in the analysis.

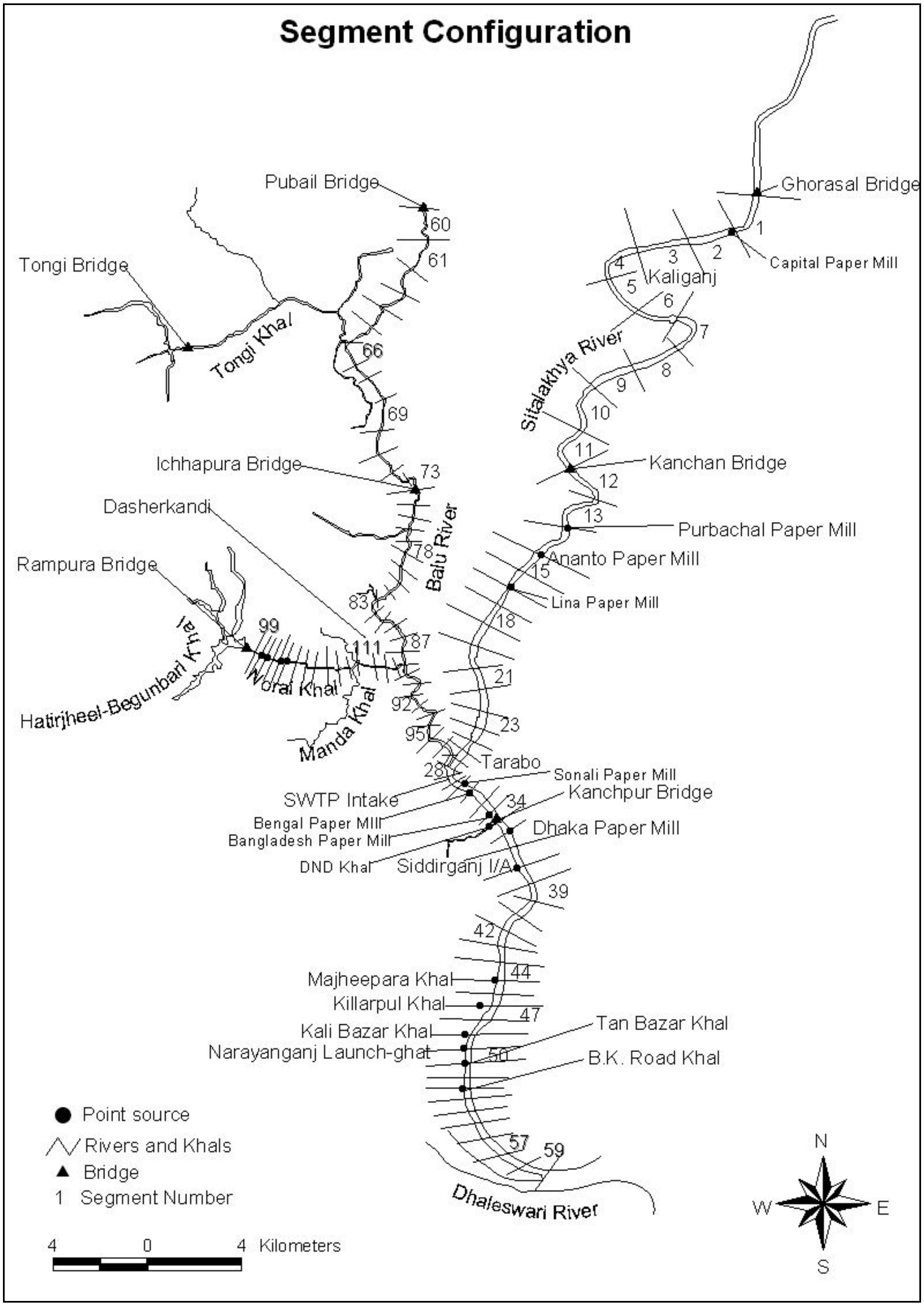

Fig. 1. Study area showing segment configuration and major point sources

2. Modelling approach

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). This model helps users to interpret and predict water quality responses to natural phenomena and man-made pollution for various pollution management decisions. EUTRO is a component of WASP7.3 that is applicable for modeling eutrophication in the water column and sediment bed. EUTRO module was used to develop the water quality model for the study area. Figure 2 presents the principal kinetic interactions for the nutrient cycles and dissolved oxygen of EUTRO module. Nine state variables: Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), Ammonia, Organic Nitrogen, Nitrate-Nitrogen, Orthophosphate, Organic Phosphorous, Total Suspended Solids (TSS) and Phytoplankton Chlorophyll-a were considered in the water quality model development. 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 rivers and the water level during the study period. The water quality model was calibrated and verified using the water quality and the hydrodynamic data of the rivers during the dry period of 2008 and 2009, respectively. Several runs were made by varying the kinetic constants and coefficients within the range given in the literature to minimize the difference between the computed and the observed profiles.

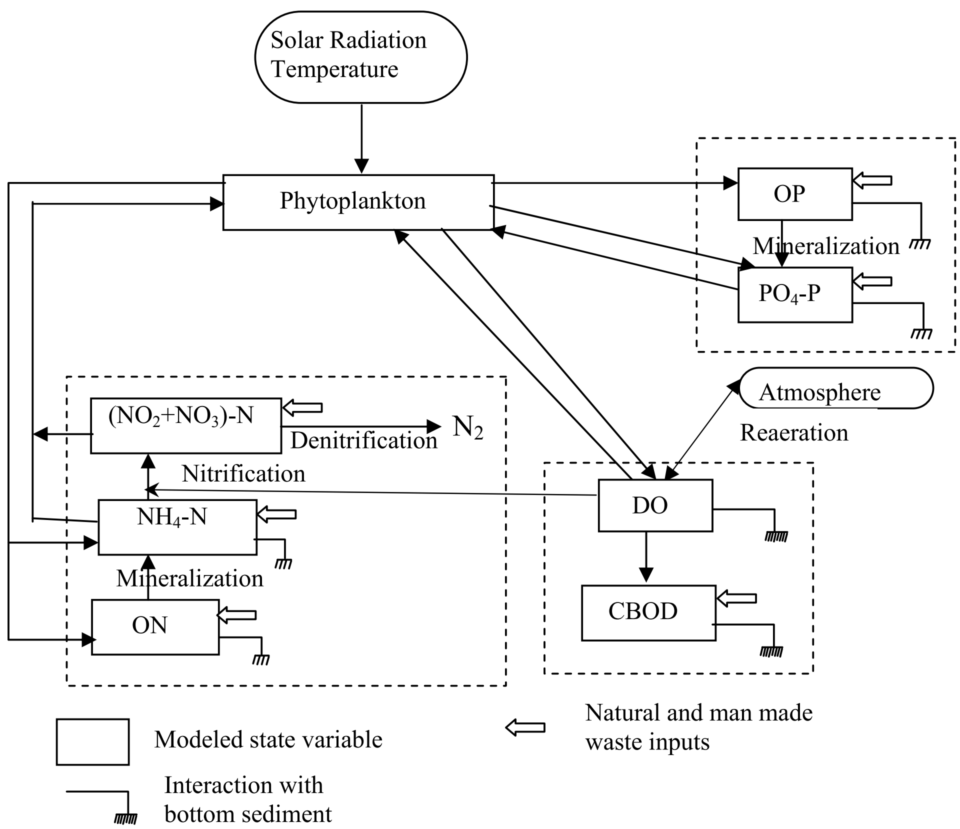

Fig. 2. EUTRO state variables interactions

3. Model segmentation

For streams and rivers, the principal morphological factors of importance include depth, width and cross-sectional area as a function of distance and for a specific period of time. Variations of such parameters with river distance forms an important part of the water quality analysis. Nineteen cross-sections in the Sitalakhya river were surveyed in the year 2006 by the Bangladesh Water Development Board (BWDB), 28 cross-sections in the Balu river were surveyed in the year 2003 by the Institute of Water Modeling (IWM) and 5 cross-sections in the Norai khal were surveyed in the year 2009 as a part of the present study. These cross-sectional profile data were used in the water quality model. For water quality modeling, the study reach of Sitalakhya river, Balu river and Norai khal were divided into 59, 39 and 16 longitudinal segments of various lengths, respectively. The segment configuration of the study area and major point source discharges are shown in Fig. 1. As per the basic concept of the 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 directions only. The geometry (volume) of these segments was determined from the channel morphological data of the rivers and mean water levels for the study period.

4. Water quality data and environmental parameters

The data available from previous studies are inadequate for spatial analysis of the water quality model. Thus, an extensive field measurement and sampling program followed by laboratory analyses were conducted during the period of March and April of 2008 and February, March and April of 2009. The planning of the monitoring program was guided by the requirement of the water quality model. River water samples were collected from twelve sampling locations on the Sitalakhya river, seven sampling locations on the Balu river and three sampling locations on the Norai khal. Laboratory analysis of the water samples was conducted to determine BOD_{5}, Ammonia, Nitrate, Orthophosphate, Organic-P, Organic-N and Phytoplankton Chlorophyll-a concentrations. Key environmental parameters associated with the water quality model include total daily solar radiation, fraction of daylight (photoperiod), wind speed, water temperature and air temperature. Of these parameters DO, Secchi depth and water temperature data were collected from field measurements during sampling. The rest of the parameters were collected from Bangladesh Meteorological Department. Temporal variations of these environmental parameters were used in the model. The time variable light extinction functions were incorporated in the model on a spatial basis. Light extinction coefficient (K) was estimated from $K = 1.7/d$ per m, where, d = Secchi depth in meter (Thomann and Mueller, 1987).

5. Initial and boundary conditions

A longitudinal profile of all the state variables is required at the commencement of model simulation. Initial concentrations for all the discretized segments were linearly interpolated between the sampling stations. The most upstream segment of the Sitalakhya river at Ghorasal bridge (segment #1), the Balu river at Pubail bridge (segment #60) and Norai khal at Rampura bridge (segment #99) were used as the upstream boundaries. Tongi khal contributes to segment #66, Manda khal contributes to segment #110 and Sarulia SWTP intake point at segment #29 were also taken as boundaries; and the most downstream segment #59 of Sitalakhya river before meeting Dhaleswari river was taken as the downstream boundary. The water quality parameters measured at the above mentioned locations were taken as the boundary concentrations. Time variable boundary conditions were provided for the time steps March 01 and April 16 of 2008 for model calibration and February 08, March 25 and April 30 of 2009 for model verification.

6. Pollution loads

The pollution loads from the Norai khal, Manda khal and Tongi khal are major inputs to the model, and these have been incorporated into the model via the boundary condition group option of the WASP 7.3. Loads from other khals and industrial discharges have been included in the model as point source loading. These pollution loads were calculated from the flows and parameter concentrations measured during the study period.

7. Flows and exchanges

The hydrodynamic characteristic is closely related with the advective mass transport of the water quality model. Discharge parameter of the river at a reference section for a definite period is needed to compute the water quality parameters along the time series. Bangladesh Water Development Board (BWDB) is responsible for discharge measurement of the rivers of Bangladesh at all the important locations. The BWDB does not take any discharge measurements during the dry period; they take discharge measurements only during the wet period as part of flood monitoring. Therefore, a calibrated model using MIKE11 (DHI, 2003) modeling system was applied on the Sitalakhya river network to compute the water level and discharge during the study period of the Sitalakhya river, Balu river and Tongi khal. The discharges of Norai khal and Manda khal were measured during the study period. The flow of Shitalakhya river is highly fluctuating during this period due to tidal influence and average daily flow varies from 56 m^3/sec to zero. The average daily flow of Balu river is about zero as there is no fresh water flow from upstream during the dry period. The average daily flow of Tongi khal, Norai khal and Manda khal are about 3 m^3/sec, 4.34 m^3/sec and 1.95 m^3/sec respectively. Calibrated dispersion coefficients of 150 m^2/sec, 100 m^2/sec and 50 m^2/sec were used in the study for Sitalakhya river, Balu river and Norai khal, respectively (Bowie et al., 1985; Ghosh and Mcbean, 1998; Karim et al., 2000).

8. Effects of climate change on the water quality of the river

The verified model with the existing pollutant loadings of 2009 has been used to assess the impacts of climate change on the water quality of the Sitalakhya river in the dry period of years 2030, 2050 and 2070; only the effects of changing temperature and solar radiation on water quality has been considered in the analysis. In this study, the predictions made with a regional climate model named Providing REgional Climate for Impacts Studies (PRECIS) have been used to generate daily weather data needed for running the WASP model. The model domain was selected 65–103°E and 6–35°N to cover Bangladesh and its surroundings. PRECIS run was completed for the year 2030, 2050 and 2070 using ECHAM 4 SRES A2 as the model input (Basak et al., 2010). The PRECIS outputs that were used in the WASP model include daily maximum air temperature and daily incoming solar radiation. The stream temperature (T_s) has been estimated from the following equation:

$$T_s = \mu + \frac{\alpha - \mu}{1 + e^{\gamma(\beta - T_a)}}$$

where T_a is the air temperature, the coefficient μ is the estimated minimum stream temperature, α is the estimated maximum stream temperature, γ is a measure of steepest slope function, and β represents the air temperature at the inflection point (Mohseni et al., 1998). Observed (2009) and predicted monthly average stream temperature and solar radiation are shown in Fig. 3 and 4. Following each run, model output of 25 March on spatial basis has been compared with the verified model results as it has been observed that during the last week of March water quality of the Sitalakhya river becomes worst.

Model results for ammonia-nitrogen, BOD_5, DO, nitrate-nitrogen, orthophosphate, and phyto-plankton chlorophyll-a are presented in Fig. 5. Model predicts progressive decrease of ammonia-nitrogen and BOD_5 with the increase of temperature. Predicted ammonia-nitrogen concentrations in the upstream of Kanchan are 3.00, 2.01, 1.40 and 1.37 mg/L for the years 2009, 2030, 2050 and 2070 respectively. The increase of the nitrification and BOD decay rate is likely to occur due to rise in temperature. Model predicts progressive decrease of nitrate (NO_3-N) due to higher uptake of nitrate by phyto-plankton as growth rate of phyto-plankton increases with the increase of temperature and solar radiation. According to the model output, DO concentrations are expected to increase due to higher algal photosynthetic production of DO as the phytoplankton chlorophyll-a concentration is increased. Predicted phytoplankton chlorophyll-a concentrations in the upstream of Kanchan are 34, 83, 119 and 121 μg/L for the years 2009, 2030, 2050 and 2070 respectively. These changes are significant in upper portion of the river from Ghorasal to Kanchan where water quality is expected to be relatively better than downstream portion. Orthophosphate concentration is predicted to decrease due to higher uptake of orthophosphate by phyto-plankton in upper portion of the river but model predicted orthophosphate concentrations near the Saidabad WTP intake are 2.64, 2.88, 2.97 and 2.98 mg/L for the years 2009, 2030, 2050 and 2070 respectively. Rise in orthophosphate levels may be attributed to increased mineralization rate. This change is more pronounced near and downstream of Saidabad WTP intake where a large amount of organic phosphorous is converted to orthophosphate.

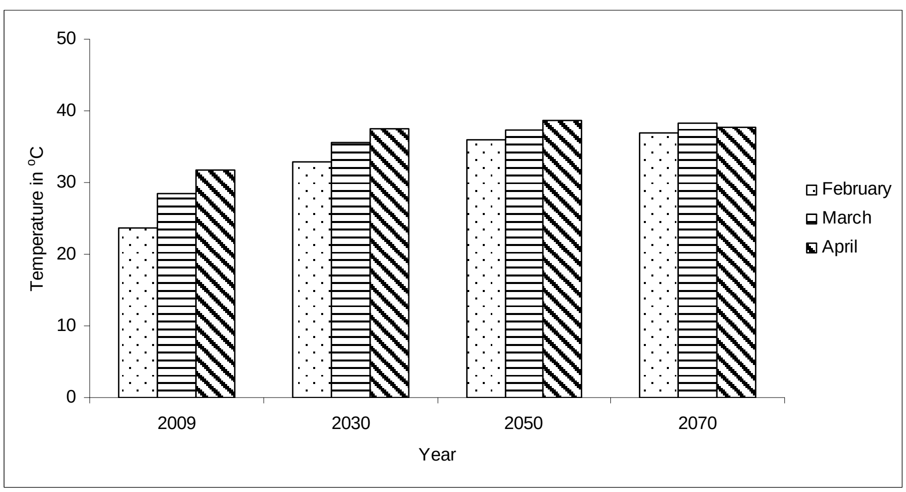

Fig. 3. Observed (2009) and predicted monthly average stream temperature in ºC

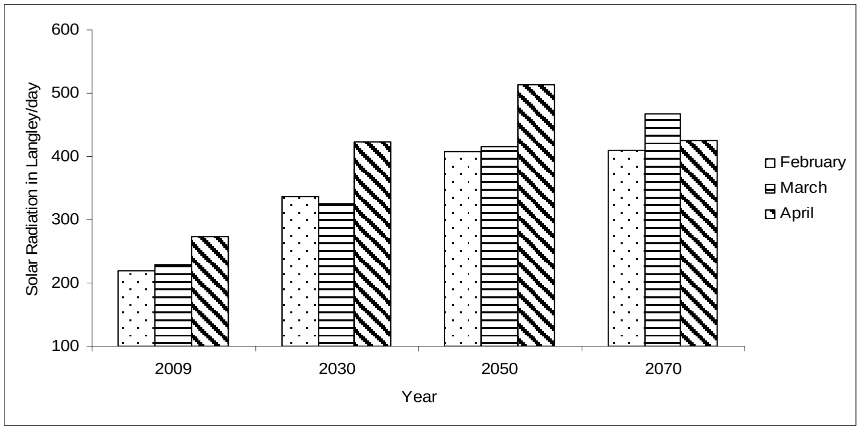

Fig. 4. Observed (2009) and predicted monthly average solar radiation in Langley/day

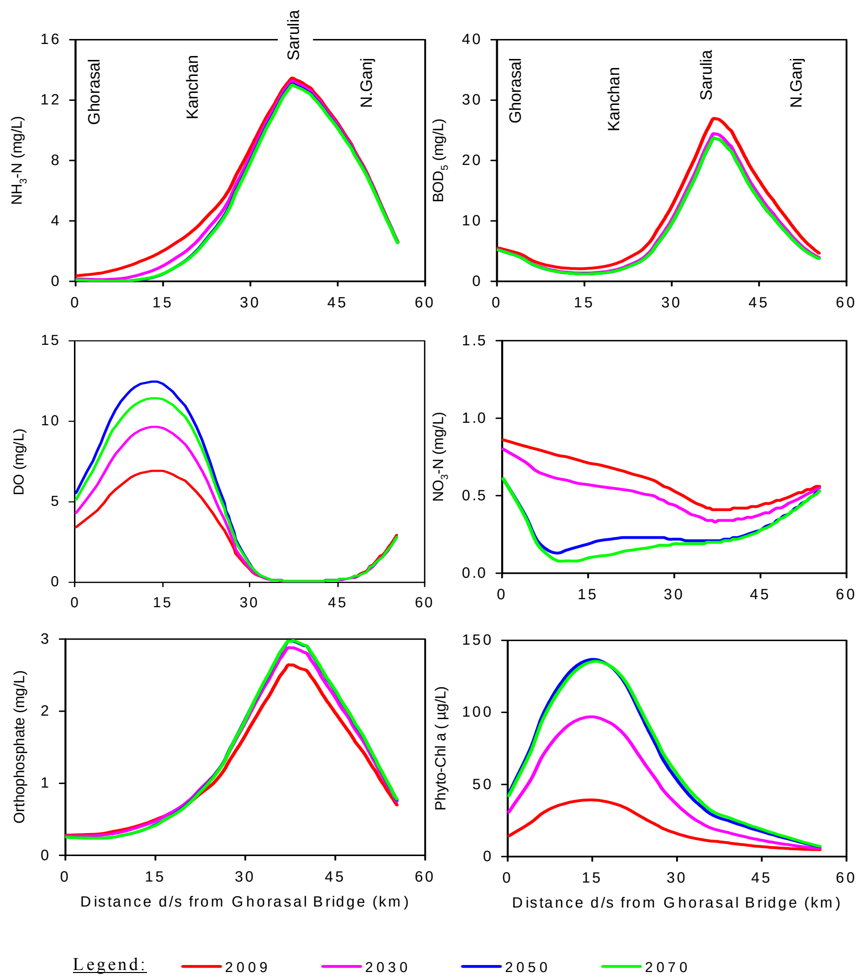

Fig. 5. Variation of water quality along the Sitalakhya river on 25 March for years 2009, 2030, 2050, and 2070

9. Conclusions

Model predicts progressive decrease of ammonia-nitrogen and BOD_5 with the increase of temperature predicted for future years due to climate change as nitrification and BOD decay rates increases. Model predicts progressive decrease of nitrate (NO_3-N) due to higher uptake of nitrate by phytoplankton as growth rate of phytoplankton increases with the increase of temperature and solar radiation. DO concentrations have been predicted to increase to some extent due to higher algal photosynthetic DO production. Orthophosphate concentration is predicted to decrease due to higher uptake of orthophosphate by phyto-plankton in upper portion of the river but rise in concentrations near the Saidabad WTP intake, where a large amount of organic phosphorous is converted to orthophosphate with the increase of temperature.

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