Impact of Climate Change on River Water Quality: A Case Study on the Yamuna River

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ABSTRACT

Global climate models have invariantly projected a significant change in future air temperature all over the world. The change in air temperature has a direct impact on water temperature, which may in turn affect the water quality. River water quality is deteriorated by the different pollution loadings from the drains which are considered as main polluters of the river water. The objectives of this study are to develop hypothetical scenarios in terms of air temperature and drain flows into the river and to explore the impacts of these scenarios on river water quality. This study used the Yamuna River at Delhi as a case study and developed the framework for investigation (area between Wazirabad barrage and Okhla barrage). First, a regression analysis of time series data of water temperature and air temperature was carried out to develop a relationship and then it was used to obtain water temperature data from the projected air temperature. The responses of water quality parameters DO and BOD to different hypothetical scenarios are simulated using the QUAL2K model. The model coefficients were calibrated and validated for Yamuna River condition using the data from literatures. The uncertainty test on water quality using water temperature was carried out (air temperature variation: -4°C to +4°C; drain flow rate variation: ±10%, ±20%, and ±100% of base case flow conditions)(base case scenario: water quality data for the March – June 2004). The changes in the water quality for the different scenarios with regards to the base scenario are quantified and the locations vulnerable to deterioration along the stretch considered due to changes in different scenarios are identified. The developed framework is being updated with the recent data for improving predicting power and for presenting information for decision-making process.

Keywords: Climate change; Hypothetical scenario; Impact; Yamuna water quality; Uncertainty

1. INTRODUCTION

Researchers worldwide are studying the impact of climate change on water availability but less attention has been given to the effect caused by climate change on water quality (Whitehead et al

2008). The most obvious effect of climate change is increased mean global temperatures, and modified precipitation distributions (Houghton et al., 1995). The change in the climate variables especially air temperature and precipitation has a direct effect on surface water variables, i.e., water temperature and stream flow (Rehana and Mujumdar, 2011).The rise in the water temperature greatly influences the reactions that take place inside the river (Hammond and Pryce, 2007). The direct impact of an increased temperature will hence be on water quality parameters such as dissolved oxygen (DO), biochemical oxygen demand (BOD), etc. (Rehana and Mujumdar, 2011).

In this study an attempt is made to assess the response of water quality parameters such as DO, BOD under different climate change scenarios on Yamuna River, India. In order to study the impact of future climate change on surface water variables future projections has to be made. Hypothetical scenarios as input to hydrologic models (Xu, 2000) have been adopted as the tool for obtaining future climate change information. Here hypothetically, increase/decrease in air temperature from the base line condition, i.e., average monthly air temperature March-June 2004, is considered. Relationship relating air and water temperature is obtained by carrying out regression analysis of the time series data available for Yamuna region. From the relationship developed, projected water temperature is obtained from the hypothetically projected air temperature and is used by the water quality simulation model (QUAL2K) for prediction of water quality. For the different climate change scenarios in terms of water temperature and drain flows, the responses of water quality parameters (DO, BOD) are obtained and compared with the base line condition (i.e. March–June 2004).

2. STUDY AREA AND METHOD

2.1 Study Area

The river Yamuna is the largest tributary of the Ganga River originating from the Yamunotri glacier near the Banderpunch peaks of the lower Himalayas at an elevation of 6320m above mean sea level, in the state of Uttaranchal of northern India (CPCB, 1999–2000). The study area covers the 21.9 km segment of River Yamuna in Delhi, flowing between Wazirabad barrage and Okhla barrage. This stretch is the most polluted stretch of any river in the country and has practically no perennial flow of its own and receives partly treated and untreated wastewater effluents from Delhi (PEACE Institute Charitable Trust, 2009).

2.2. Method

2.2.1 Model input, calibration and validation

QUAL2K is a modelling framework for simulating river and stream water quality (Chapra et al., 2006). The model represents a river as a series of reaches having constant hydraulic characteristics. The 21.9 Km stretch from Wazirabad barrage to Okhla barrage was divided into sixteen reaches with further segmentation of 0.3 km each. Sediment Oxygen Demand (SOD) was assumed to be zero for the entire course of the river (Paliwal et al., 2007). The contribution of the BOD removal by settling is not considered here since it comes only about 2% of the total BOD (Vasudevan et al., 2011).The high turbidity in the stretch diminishes the penetration of light to deeper layers, preventing the growth of phytoplankton (Kazmi, 2000). Therefore, photosynthetic oxygenation was taken as zero. QUAL2K was calibrated for average condition data of March-June 2003 representing a low flow period (Parmar and Keshari, 2011). Oxygen reaeration rate, BOD hydrolysis rate and BOD oxidation rate were considered. Obtained values of these parameter coefficients were validated with another completely different data set (i.e., February 2002 data;Parmar and Keshari, 2011).

The model was calibrated and validated keeping into consideration the goal of minimizing the error for DO and BOD. Various trial and error approaches were made with different combinations of rate coefficients. The performance of the model was evaluated in terms of Root Mean Square Error (RMSE), coefficient of determination (R^2), Coefficient of Correlation and Index of Agreement (IOA).

2.2.2 Relating air temperature and water temperature

A relationship between air temperature, a climate variable and water temperature a water quality variable is developed in order to obtain water temperature from hypothetically projected air temperatures. Regression analysis of the past time series data is carried out to relate air temperature to water temperature. Mean monthly water temperature data for the years 1999-2005 along the Yamuna River was obtained from CPCB record (CPCB, 2006). Based on the latitude and longitude information of the CPCB sampling locations (Palla, Nizamuddin bridge, Agra canal), the corresponding monthly air temperature data (mean, minimum and maximum) for the corresponding years 1999-2005 were obtained from the Indian Meteorological department (IMD) gridded temperature data (http://www.imdpune.gov.in/ncc_rept/RESEARCH%20%20REPORT%208.pdf). Regression analysis is carried out by fitting the data into different regression models available in Excel and SPSS software, to come out with the most reliable relationships of the above data.

2.2.3 Scenario considered for uncertainty test

Scenario combinations in terms of change in air temperature and drain flow into the river are tabulated. Air temperature is varied within the range of +4°C to -4°C, by increasing it up to 4° C and decreasing it up to -4°C from the base line condition i.e. average monthly air temperature March-June 2004). Maximum increase in air temperature up to 4° C is taken keeping into consideration that the maximum projected air temperature up to year 2100 by IPCC (IPCC, 2007). Drain flow is varied by increasing/decreasing it by ±20%, ±10% and ±100% under the base line condition (March – June 2004 drain flow characteristics). The hypothetical scenarios are taken by varying the two variables one at a time or simultaneously together. Scenarios are used to carry out uncertainty test to quantify its impact on water quality. Simulated water quality results are compared with the prescribed permissible limits for various activities in water by Central Pollution Control Board (Table 1).

Table 1 Primary water quality criteria for various uses of fresh water:

Category of water best usage	A Drinking water source without conventional treatment, but after disinfection Outdoor bathing (organized)	B Outdoor bathing (organized)	C Public water supply with approved treatment equal to coagulation, sedimentation and disinfection
Dissolved oxygen (mg/l)	Not less than 6.0	Not less than 5.0	Not less than 4.0
Biochemical oxygen demand (mg/l)	Not more than 2.0	Not more than 3.0	Not more than 3.0

(http://www.cpcb.nic.in, Accessed on 18th October 2013)

3. RESULTS AND DISCUSSION

3.1 Model calibration and validation

The calibrated results of DO and BOD, shown in Figure 3.1 and Figure 3.2 respectively, give an acceptable match of model and field data. The result showed that just downstream of Najafgarh drain discharge, DO concentration drops drastically and it tries to regain at the downstream locations. While, BOD concentration undergoes a sharp increase and falls down at the downstream locations.

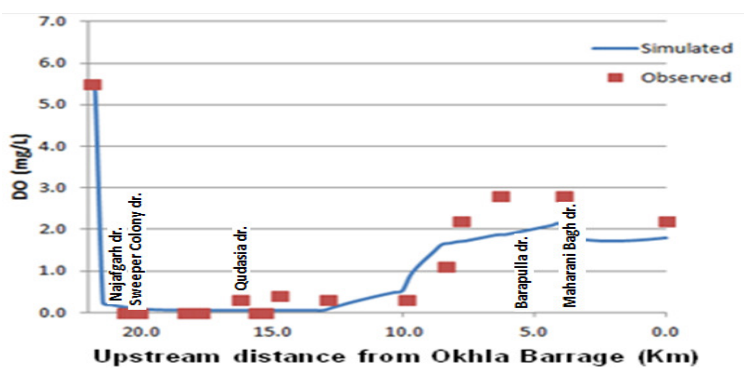

Figure 3.1 Simulated DO along the Yamuna stretch for the calibration period (March –June 2003)

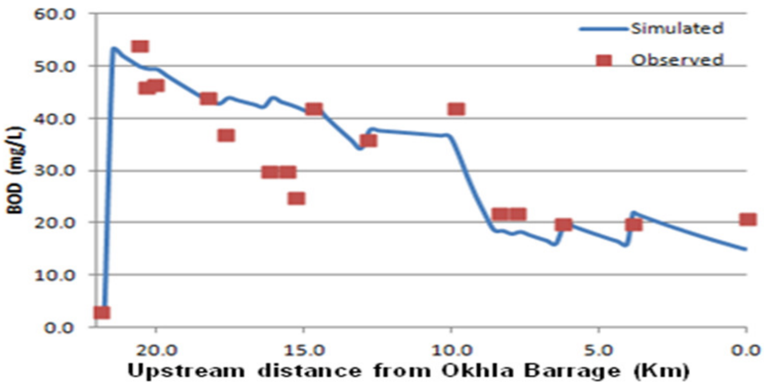

Figure 3.2 Simulated BOD along the Yamuna stretch for the calibration period (March –June 2003)

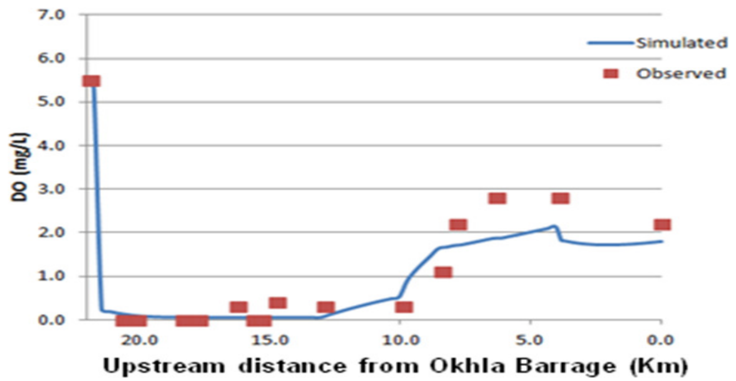

Figure 3.3 Simulated DO along the Yamuna stretch for the validation period (February 2002)

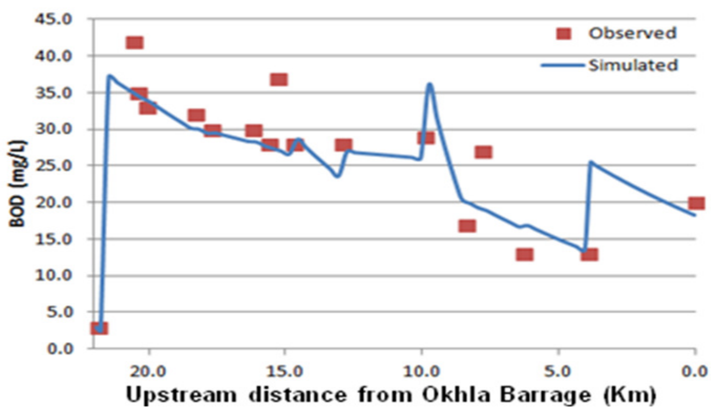

Fig 3.4 Simulated DO along the Yamuna stretch for the validation period (February 2002)

The validation results of DO and BOD, shown in Figure 3.3 and Figure 3.4 respectively, too showed a reasonably good match with measured data. Same as calibration, an abrupt reduction in DO concentration happened just downstream of Najafgarh drain and BOD concentration undergoes a sharp increase. The performance measures obtained for DO and BOD using the obtained calibrated reaction rate coefficients are listed in Table 2.

Table 2 Model performance results of the calibrated and validated model parameters

Model performance measurement tools	Model Calibration Values		Model Validation Values	
	DO	BOD	DO	BOD
Root Mean Square Error (RMSE)	0.309	7.089	0.362	4.443
Index of Agreement (IOA)	0.999	0.842	0.996	0.876
Correlation coefficient (R)	0.975	0.887	0.976	0.919
Coefficient of Determination (R^2)	0.951	0.779	0.932	0.733

Differences between the observed and predicted values of DO and BOD were insignificant and showed a good fit. Thus, the model was utilized in the future simulation to carry out uncertainty test.

3.2 Relationship between Air temperature and Water temperature

It is inferred that cubic polynomial regression model gives better fit between monthly air temperature and water temperature series. Also, among the three air temperature series available, i.e., minimum, mean and maximum monthly air temperatures, the relationship with mean monthly water temperature and minimum air temperature was found to be holding a significant relation. The regression equation with best " R^2 " value obtained are as follows: $y= -0.002x^3 + 0.0x^2 + 4.331x - 46.411$ with $R^2 = 0.627$ for Yamuna river where "y " is the mean monthly water temperature in ° C and " x " is the minimum monthly air temperature in ° C. To check the relationship accuracy, validation using mean monthly water temperature of year 2011 (source: CPCB, 2013) and mean minimum monthly air temperature of year 2011 (Source: www.wunderground.com) is carried out and the details are given in Table 3. The predicted water temperature is very close to the observed one with a difference of 1°C. Hence, this relationship is used to obtain water temperature from projected hypothetical air temperature for water quality simulation in QUAL2K model.

Table 3 Validation of the developed cubic regression relationship between water and air temperatures

Observed averaged Minimum monthly Air temperature (°C) in year 2011 (Source : http://www.wunderground.com)	Observed average mean water temperature in year 2011 (°C), (Source : CPCB, 2011)	Relationship predicted average mean water temperature on year 2011 (°C)
19.4	24	23

3.3 Impact of Scenarios on Water quality

When the discharge of drain under the baseline condition was varied by -10, -20% and -100% the DO was found to increase whereas the BOD decreased. When the discharge of drain was varied by +10, +20% and +100% the DO was found to decrease whereas the BOD increased. The variation in air temperature has very minimal effect on DO and BOD as well. The best scenarios showing improvement on water quality was found when the drain flows were decreased by 100% from the baseline condition irrespective of climate change effect. The worst scenarios deteriorating the water quality was observed when the drain flows were increased 100% irrespective of climate change effect. The variation in DO and BOD based on scenarios when stream flow of the river is constant with the base scenario and change in air temperature (ΔAT) of -4°C and +4°C and change in drain flows (ΔDF) to the river as ±100% with regards to base drain flow condition is shown in Figure 3.5 and Figure 3.6 respectively. It can be seen from the figures that the minimum requirement of DO and maximum permissible limit of BOD in water bodies as per CPCB, India (Table 1) is met only when the drain flows into the river is reduced to 100% with regard to base drain flow conditions.

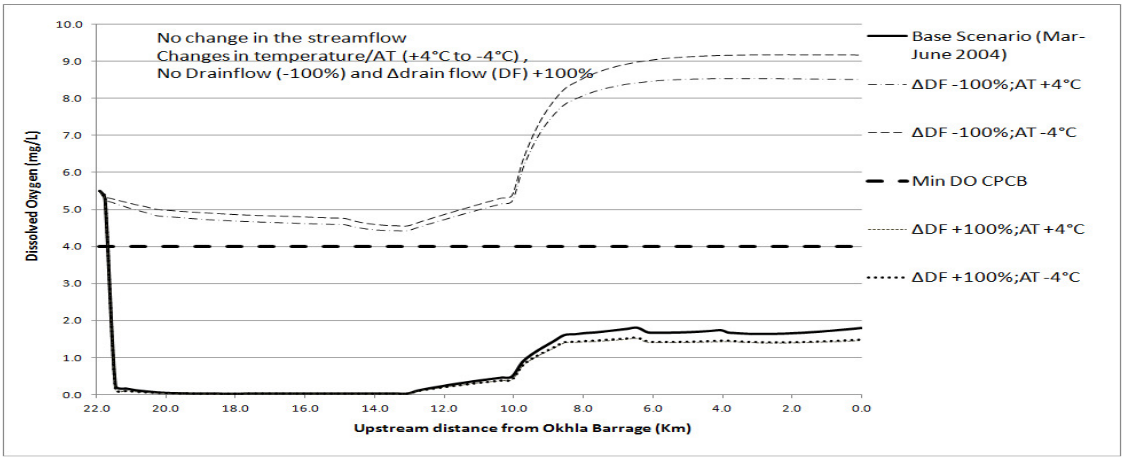

Figure 3.5 Variation in DO keeping stream flow constant, change in temperature ±4°C and change in Drain flows ±100% with regards to base line condition.

The maximum reduction in DO from the analysed scenarios was observed at location d/s of Najafgarh drain (21.15 Km upstream of Okhla barrage) with DO value reducing from 0.234mg/L to 0.09 mg/L. It gave maximum percentage reduction in DO as 39.79%. this type of reduction is observed when the air temperature is increased by +4°C and 100% increase in drain flows under the base line condition. The maximum improvement in DO is observed at location d/s of Sweeper colony drain (17.85 km u/s of Okhla Barrage) with DO value increasing from 0.029 mg/L to 4.85 mg/L giving out the max percentage increment in DO to be 16727.94 %. Such reduction is observed when the air temperature is decreased by -4°C and 100% decrease in drain flows under the base line condition.

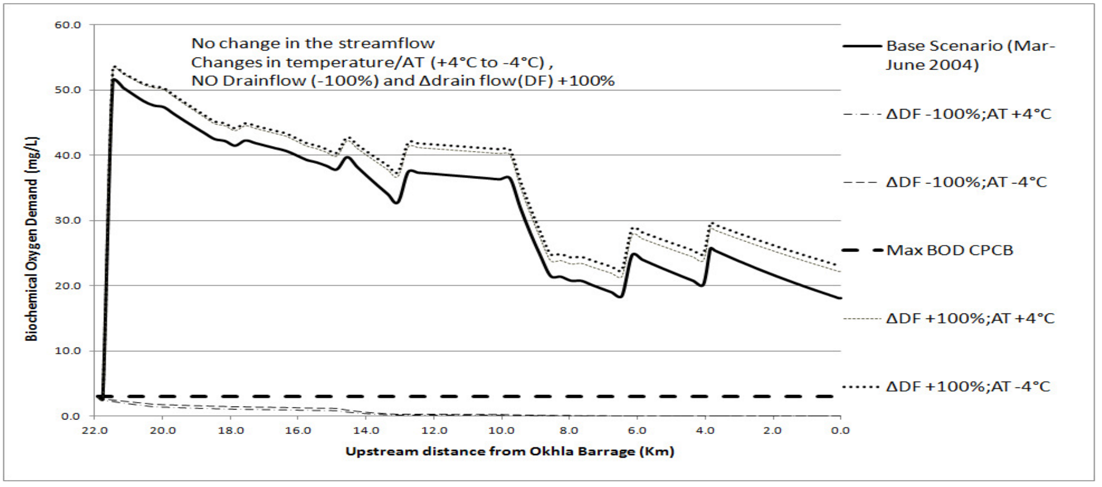

Figure 3.6 Variation in BOD keeping stream flow constant, change in temperature ±4°C and change in drain flows ±100% with regards to base line condition

In BOD, maximum deterioration in percentage was observed at location d/s Maharani Bagh drain (entry to Okhla barrage) with BOD value increasing from 18.03mg/L to 23.01 mg/L giving out the maximum percentage increment in BOD to be 27.64%. It is observed when the air temperature is decreased by -4°C and 100% increase in drain flows under the base line condition. Maximum improvement in BOD is observed d/s of Barapulla drain (3.84 km u/s of Okhla Barrage) with BOD value decreasing from 25.65 mg/L to 0.015 mg/L giving out the maximum percentage reduction in BOD to be 99.94 % and such increase is observed when the air temperature is increased by +4°C and 100% decrease in drain flows under the base line condition

4. CONCLUSIONS

Impact of Climate change and change in drain flows scenarios on water quality of Yamuna River, India was carried out. QUAL2K model was used to simulate DO and BOD concentration.

Calibration and validation of the model gave reasonably good fit to the simulated and observed field data. The locations vulnerable to the impact of the climate change and drain flow scenarios are locations d/s of Najafgarh drain and location d/s of Maharani Bagh drain. The effect of climate change in terms of change in air temperature on water quality is very minimal. Variation in drain flows proved to be more sensitive on water quality. DO showed to be more prone to climate change effect whereas BOD was vulnerable to drain flow fluctuations. The best scenario in terms of water quality meeting the standards was observed when there is 100% reduction in drain flows irrespective of any climate change scenarios. Water quality results depicted an extreme deterioration of the Yamuna River even before the application of the uncertainty test of the various scenarios. The developed framework is being updated with the recent data for improving predicting power and for presenting information for decision-making process.

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