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Water quality modelling studies of river Ganga in the Kanpur stretch: estimation of non-point sources

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Abstract
The present study objectively analyzes the state of water quality (in terms of DO-BOD) in the Kanpur stretch of river Ganga and assesses the non-point sources and their impact by employing water quality modeling. The Enhanced Stream Water Quality Model (QUAL2E) of USEPA has been used in this study.

A stretch of 31-kilometer (starting from a few kilometers upstream of Kanpur) was covered and on the spot water quality sampling and analysis was carried out at various locations to generate the required database for model calibration/validation. The data on various point load discharges were collected in terms of flow and water quality characteristics.

Initially the model predicted a better water quality than the quality observed on the field. This mismatch was attributed to the undefined non-point sources of waste discharges. Efforts to calibrate the model estimated the non-point sources in terms of BOD load as about 15700 kg/day and high Sediment Oxygen Demand (SOD). It was observed during field survey that the pollution from non-point sources (e.g. small drains, solid waste disposal etc.) was wide spread along the river. Thus, as a major recommendation of this research, it was concluded that unless non-point sources are controlled, the desired water quality levels cannot be achieved.

INTRODUCTION

The river Ganga occupies a unique position in the cultural ethos of India and significant efforts are being made to improve its water quality. The focus of this study is on the Kanpur stretch of river Ganga. Kanpur is the second largest town and an Industrial city situated on the banks of river Ganga. The water quality even in upstream is not fit for water supply/treatment. This study objectively analyzes the state and causes of deterioration of water quality of the river Ganga in the Kanpur stretch and assesses the strength of non-point sources and their impacts on water quality using the water quality modeling. The scope of study can be summarized as under:

Examine water quality status and the pollution loading in terms of flow and DO-BOD parameters;
Establish a water quality model for the study area; and

Apply water quality model to understand cause-effect relationship in terms of pollution discharges and water quality.

STUDY AREA -RIVER GANGA IN KANPUR AND STUDY AREA

The river Ganga even before entering Kanpur is highly polluted. The heavy pollution is due to the pollution loads of the various cities on the upstream. At Kanpur, river Ganga bifurcates into two parts - the main river and the dredge channel (See Figure 1). The main river flows at about 2 kilometers away from the city whereas the dredge channel flows near the city. The dredge channel is a part of the river having a small flow of about 25 cumecs and confluences with the main river at the Guptar Ghat (Figure 1). The dredge channel contains the major Ghats (places of mass bathing) of the city. To meet the water supply demand during British rule, a channel was dredged near the city to bring the Ganga water and thus, the dredge channel got its name.

The study area (Figure 1) starts from Kesa Colony drain (Drain no. 1) and ends at Nazafgarh. The total length of stretch is 31 km comprising dredge channel and main river. In the delineated stretch, the details of drains are given in Table 1. For better explanation (as shown in Figure 1), the study area is divided in two parts: (i) Stretch-I (from Kesa Colony Drain to Gola Ghat) (0-5.3 km) and (ii) Stretch-II (Gptar Ghat to Najafgarh) (5.75-31 km).

WATER QUALITY MODELLING APPROACH

The USEPA model QUAL2E (Enhanced Stream Water Quality Model; Brown and Barnwell,1987; www.epa.gov) is employed in this study. The QUAL2E permits simulation of several water quality constituents in a branching stream system using a finite difference solution to the one-dimensional advective-dispersive mass transport and reaction equation.

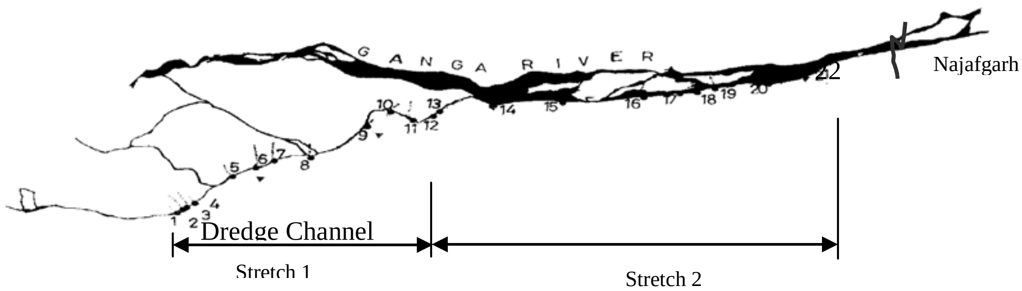


Figure 1. The Study Area (Kanpur).

The first step in using QUAL2E is to develop the spatial segmentation scheme for the system being modeled. This involves dividing the system into reaches of constant hydrogeometric characteristics. For each computational element, a hydrologic balance in terms of flow (Q), a heat balance in terms of temperature (T), and a materials balance in terms of concentration (C) is written. The 1–D advective-dispersion equation is solved for the steady flow and steady state condition. Flow and loads must be steady, but temperature, wind speed and light may vary with time. It allows for multiple waste discharges, withdrawals, tributary flow and incremental inflow and outflow.

WATER QUALITY MONITORING AND DATA COLLECTION

Water Quality Monitoring: Primary Data Collection

A field survey with spot check monitoring and sampling along the bank of the river was undertaken on two occasions covering the entire stretch of 31 kilometers of the study area (Figure1). The exercise was done using a boat. Water quality parameters such as Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), pH, Turbidity, Chloride, Temperature were considered for monitoring; DO and pH were measured *in situ*. Samples for other parameters were taken and further analyzed in the laboratories of Central Pollution Control Board (CPCB), Kanpur. At a particular cross-section samples were taken from three points one-third, middle, two-third of the width from the edge. Samples were taken from 0.6 m below the surface of the water, and the analyses were carried out as per the Standard Methods for Examination of Water and Wastewater (APHA, 1992).

Table 1. Details of Drains in Figure 1.

Number	Drain Name	Flow m^3/sec	BOD mg/l
1	Kesa	0.02	100
2	Roadways	0.008	100
3	Khewra	0.008	120
4	Jageswar	0.03	120
5	Jevra	0.013	120
6	Nawabganj	0.03	120
7	Ranighat	0.015	140
8	Sisamau	1.3	140
9	Tafco	0.01	100
10	Parmat	0.01	100
11	Muir Mill	0.03	100
12	Police Line	0.006	100
13	Gola Ghat	0.03	100
14	Guptar Ghat	0.26	120
15	Golf Club 1	0.01	100
16	Golf Club 2	0.025	100
17	Dubka	0.01	100
18	Bengali Ghat	0.01	100
19	Buriaha Ghat	0.01	100
20	Wazidpur	0.01	100
21	Jajmau TP	1.5	140
22	Shekhpur	0.15	120

The flow rate of dredge channel was determined from the surface velocity, which was measured using a float and cross-sectional area of flow. The monitoring stations selected were major ghats or well-known locations so that distance can be easily assessed. Other information such as land-use pattern along the river bank and types of non-point sources were also gathered.

Secondary Data Collection

The secondary data on flowrate of drains, river hydrodynamics, climatology, general features, water quality etc. were collected from various governmental sources such as CPCB Kanpur, Ganga Pollution Control Unit (GPCU), Kanpur, CPCB Delhi and Central Water Commission (CWC) Kanpur. The flowrates (November, 1998) in the various parts of study area were:

River: 108 Cumecs, (Source: CWC, Kanpur)
Dredge Channel: 25 Cumecs, (Source: measured in this study)
Drains: Presented in Table 1 (Source: GPCU, Kanpur)

Water Quality Parameters: BOD and DO Profiles

The water quality was measured at several locations and DO-BOD plots are shown in Figures 2 and 3. It can be seen that there is a significant variation both in DO and BOD along the river. From the DO plot, it can be inferred directly that DO level is critical in a small stretch of 3 km. Right at the outfall of Sisamau drain, the DO drops from 8.9 to 7.8 mg/l. The DO depletes further along the dredge channel to 4.4 mg/l at Gola Ghat. Sharp increase in DO takes place at Guptar Ghat due to the confluence of main river (carrying fresh water) and the dredge channel. DO depletion further starts after the Jajmau where the sewage treatments plant (STP) drain falls into the river. In the case of BOD, it increases rapidly at the outfall of drains and is very low at the confluence point with fresh water due to dilution effects (Figure 3). The measured values of DO and BOD are in agreement with the physical and biological laws governing the system.

Observations from field survey

In addition to field sampling, a walk along the riverbank was undertaken. Some of the important observations made from field sampling are presented below.

About 20 drains falling in the river can be identified but among them barring 4, all are minor drains, but cumulatively may have significant impact.

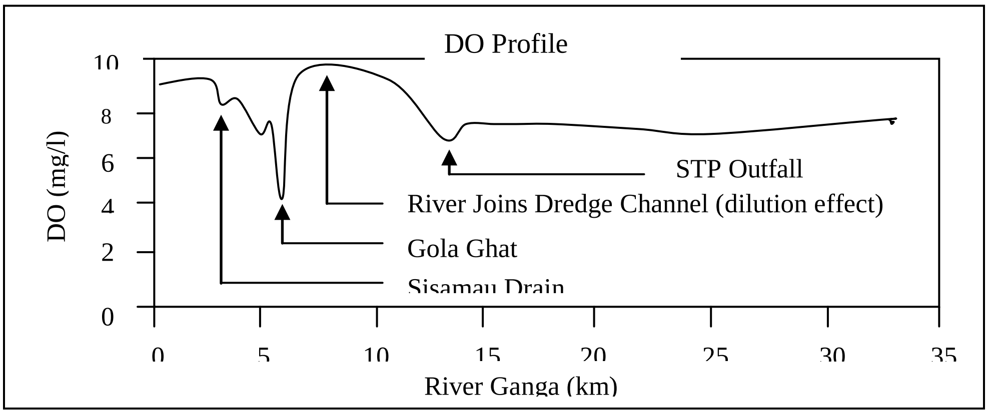
Sisamau drain has not been diverted yet, and is still discharging about 105 MLD of wastewater in the river.

The major portion of the Kanpur city lies along the dredge channel, which has small flow of about 25 cumecs (Figure 1). The area adjoining the dredge channel is densely populated. As a result, a lot of small drains with varying intensity of flow fall in this channel.

Significant amount of solid wastes was dumped along the bank of the river between Paramat and Gola Ghat.

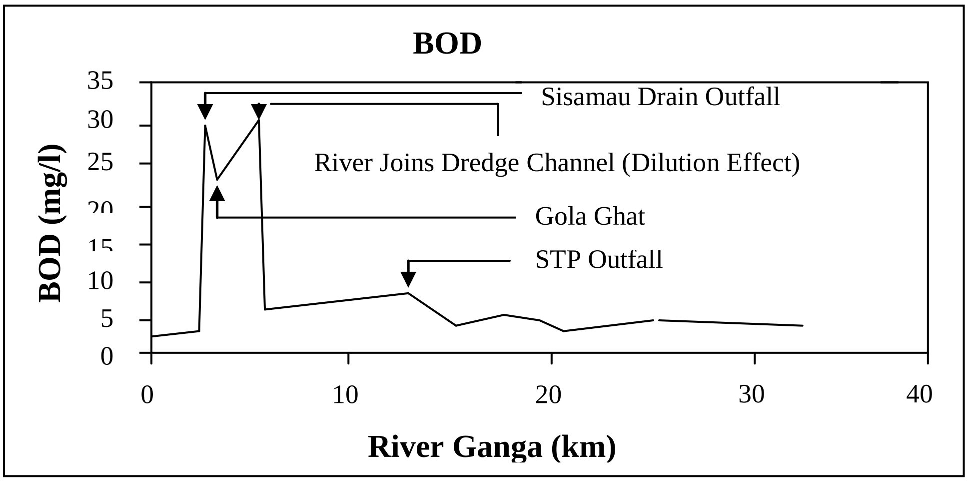
All types of activities detrimental to the quality of river water could be observed in the dredge channel. Right from washing cloths in large quantity to open solid waste disposal along the banks, dumping of flowers, mass cattle bathing could be observed.

It can be concluded that non-point sources, which are not, quantified as regular sources interms of BOD load are significant in the dredge channel. Attempts have been made to estimate these sources through water quality modeling.



Distance measured from Kesa colony drain

Figure 2. DO profile along the river.



Distance measured from Kesa Colony Drain

Figure 3. BOD profile along the river.

APPLICATION OF QUAL2E MODEL

The Qual2e model was applied to the river along the Kanpur stretch. In the entire modeling process the main aim was to simulate the DO and BOD conditions for the river. For this purpose, the nitrogen, algae and phosphorous contents have been assumed to be the same as in the upstream of the river. The model was applied for three conditions (referred to as Runs 1 through 3).

Run 1: The model was first applied to the Stretch-II (i.e. from Guptar Ghat to Nazafgarh). A stretch of about 25.5 km (Figure 1).

Run 2: Stretch-I from Kesa colony drain to Gola Ghat (dredge channel), a stretch of about 5.5 km, was simulated with rate coefficients and constants as calibrated in Run 1.

Run 3: Stretch-I (the same stretch as taken in Run 2) was simulated separately with varied coefficients and constants so as to match the simulated and observed water quality in the dredge channel.

The rationale behind dividing the entire modeling process into three runs was to incorporate the impact of non-point sources like small drains, solid waste disposal etc. along the banks. In the Stretch-II (i.e. from Guptar Ghat to Nazafgarh; Figure 1) the density of population along the banks is much less than that along the dredge channel and so is the contribution of non-point sources. As a result, the situation in Stretch-II can be assumed to be much simpler than that of dredge channel. Thus, the model can be calibrated with greater level of confidence, as the numbers of variables to be varied are much less in this stretch.

In Run 1, the model was calibrated for DO and BOD by varying parameters like BOD decay rate (0.40 d-1); BOD settling rate (0.5 m/d); Sediment Oxygen Demand (1.5 $g/m^2/d$); incremental inflow (0.05 m^3/s); and BOD content of incremental inflow (50 mg/l). The flow rates for the main river and for the drains (Table 1) were obtained from CWC, Kanpur and GPCU, Kanpur.

In Run 2, the model was applied to Stretch-I without varying the model parameters (those obtained from Run 1). This was done so as to assess the impact of non-point sources. In other words, if non-point sources are insignificant, the model should perform well in the stretch of dredge channel.

Since for Run 2, the model predicted higher DO than measured (results discussed later), in Run 3 the coefficients and input BOD loads were varied so to match simulated and measured DO levels in Stretch-1. It implies that the additional BOD load considered in Run 3 is a measure of non-point sources in the Stretch-I (i.e. dredge channel).

Input parameters for Run 3 (Stretch-I)

The same stretch as taken in Run 2 was simulated in Run 3 with varied rate coefficients and constants. The coefficients and constants varied in this run include:

- Incremental inflow for subreaches 4 and 5: 0.15 m^3/s with BOD of 1000 mg/l.
- BOD decay rate: 0.5 day^{-1}
- BOD settling rate: 0.6 m/day
- SOD: 10 $gm/m^2/day$ (for subreaches 4 and 5)
- Sisamau drain flow: increased to 2 m^3/s with BOD of 220 mg/l.

Other parameters were kept the same as that for Run 2.

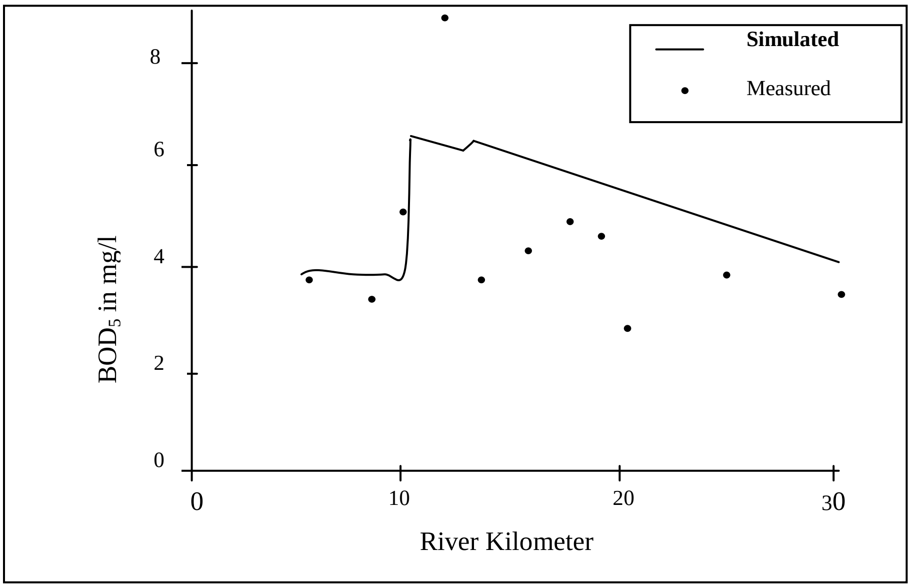


Figure 4. Profile for Run 1 (Guptar Ghat – Nazafgarh).

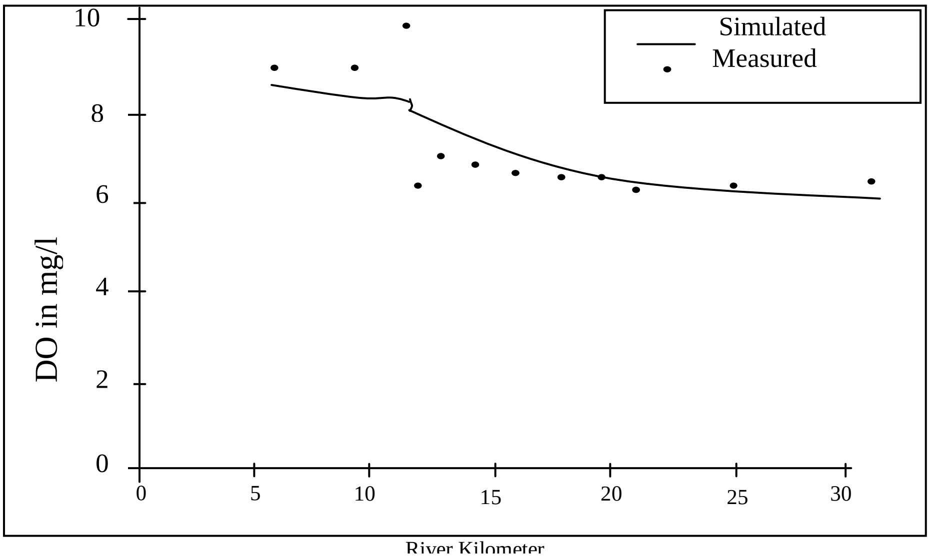


Figure 5. DO Profile for Run 1 (Guptar Ghat – Nazafgarh).

RESULTS AND DISCUSSION

Run 1

Run 1 from Guptar Ghat to Nazafgarh (Stretch-II) behaves quite ideally (Figures 4 and 5). The simulated DO and BOD values match reasonably well with the measured data, largely because of the fact that system was simple to model.

The increase in BOD from 4 mg/l to 6.5 mg/l along the stretch is mainly due to the outflall from sewage treatment plant at Jajmau. The DO depleted in this region can be mainly attributed to following factors:

- Increase in BOD level of the river due to outfall from Jajmau treatment plant;
- High inflow of BOD from dredge channel; and
- High N and P content due to outflow from drains in dredge channel

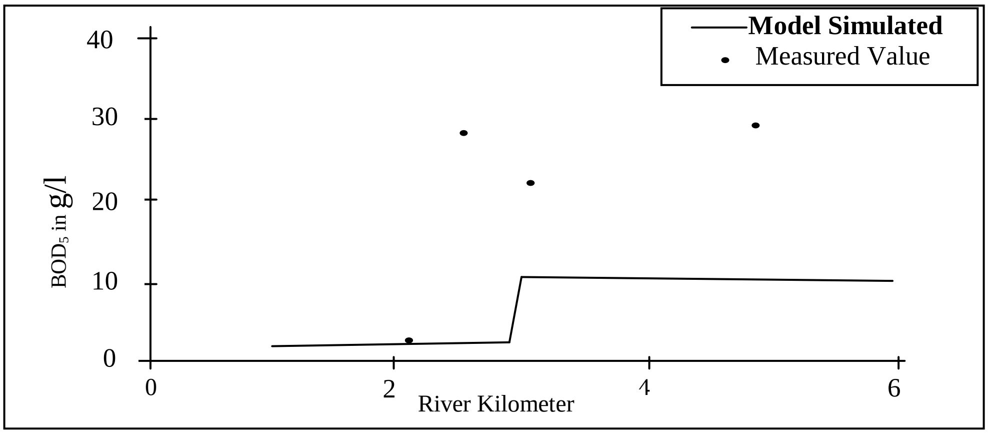


Figure 6. Profile for Run 2 (Guptar Ghat – Nazafgarh) without calibration.

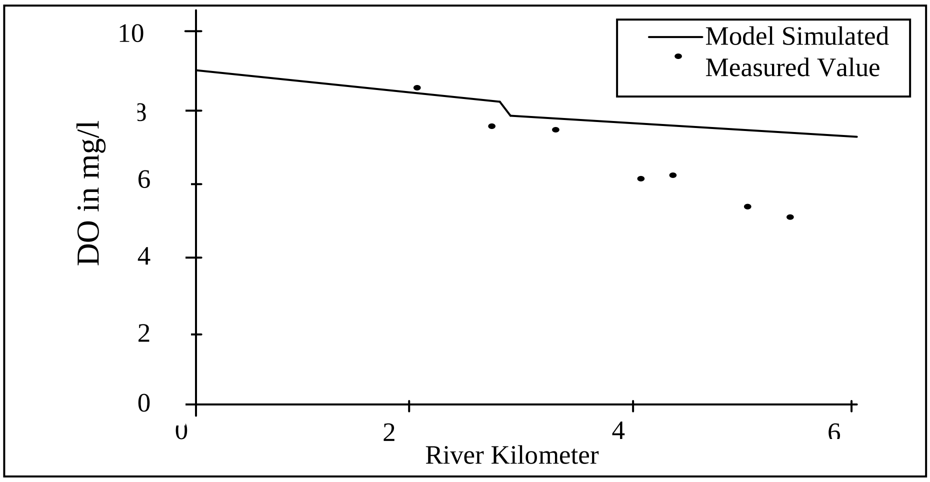


Figure 7. DO Profile for Run 2 (Guptar Ghat – Nazafgarh).

Run 2

The main aim of this run was to show the situation in dredge channel if the non-point sources are removed or fully controlled The stretch of 5.5 km from Kesa colony drain to Gola Ghat was divided into 5 subreaches. The simulated and measured levels for this run for BOD and DO are presented in Figures 6 and 7. It can be seen from the figures that neither the simulation DO nor the BOD levels match the measured data. The maximum BOD assessed by the model is 13 mg/l, whereas the measured value was 30 mg/l; and the minimum DO assessed by the model is 7.5 mg/l, whereas the measured value is 4.5 mg/l. This clearly indicates that unless non-point sources are considered, the model cannot perform. It is, therefore, important to consider the non-point sources, which is done in Run3.

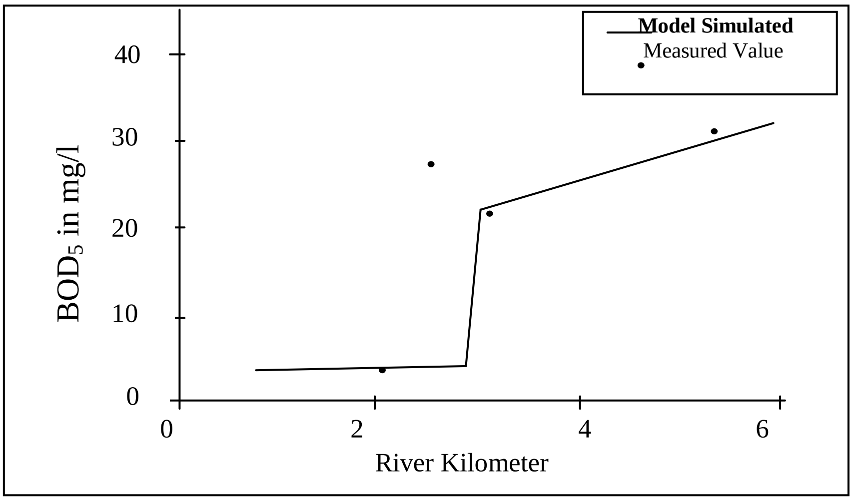


Figure 8. BOD Profile for Run 3 (Guptar Ghat – Nazafgarh).

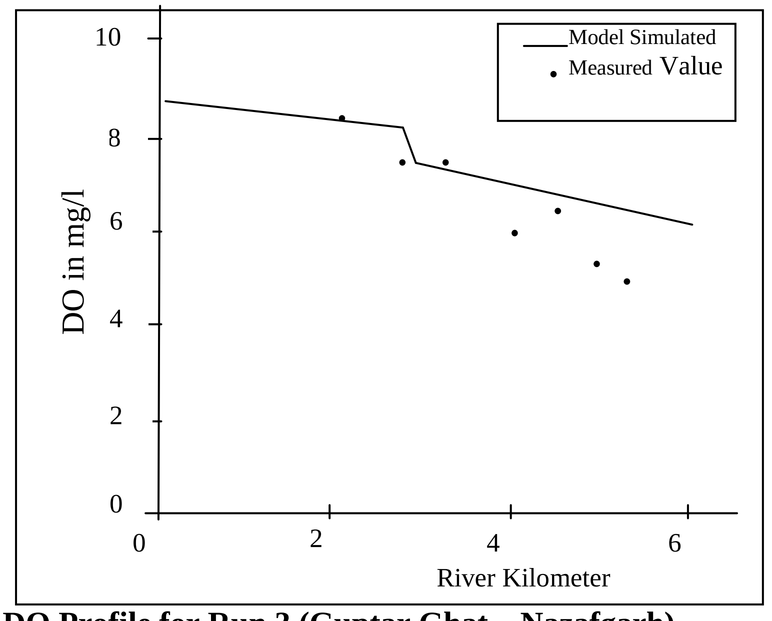


Figure 9. DO Profile for Run 3 (Guptar Ghat – Nazafgarh).

Run 3

The main aim of this run was to reduce the difference in measured and predicted DO and BOD values by incorporating the non-point sources. Salient features of this run are:

The BOD decay rate increased to $0.5d^{-1}$;

The BOD settling rate was taken as 0.6m/d

For subreaches 4 and 5 in which DO deficit was largest, SOD value was taken as 10 $gm/m^2/d$ (the maximum permissible value in the model);

To assess the contribution of non-point sources the incremental inflow was increased from 0.05 to 0.15 m^3/s and BOD load was increased from 50 to 1000 mg/l;

To match the BOD profile, the BOD load of Sisamau Drain was increased from 150 mg/l to 220 mg/l and the flow was increased from 1.5 to 2 m^3/s.

This additional incremental flow and BOD correspond to a BOD load of 15700 kg/d. Finally with the above variations the BOD profile was matching with the monitored data and to some extent the DO profile (Figures 8 and 9).

CONCLUSION AND FINDINGS

The QUAL2E model has been applied for DO-BOD and attempts have been made to calibrate the model to a simple stretch (with a few waste inputs) and to a complicated stretch which had several small waste inputs through small drains and disposal of solid waste into the river. The overall findings drawn from this study are presented below:

The actual BOD load, particularly in middle part of dredge cChannel is much higher than the values simulated considering BOD contributions of major drains only;

The above DO-BOD mismatch of simulated and measured values can be attributed to the presence of non-point sources like solid wastes disposal along the banks and to some extent to the small drains which are still falling in the river; and

The BOD load of non-point sources are estimated to be 15700 kg/day into the dredge channel from sources as small drains, disposal of unorganized municipal solid wastes, discarded flower offerings etc.

The other possible reasons for high BOD/low DO can be attributed to SOD being exerted by the active biological materials, such as sludge and slimes at the bottom of the dredge channel. The growth and accumulation of these materials might have resulted from deposition of suspended organic matter over years.

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www.epa.gov The Website of USEPA.