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DO-BOD Modeling of River Yamuna for Delhi Segment Comparing the Actual Case of Low Water Discharge with that of the Flow Required to be Maintained to Meet Out Environmental Flow Concern of Various Stretches

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Abstract: In the perilously, polluted stretch of Yamuna river from Delhi to Chambal, there is significant fluctuations in dissolved oxygen level from Nil to well above saturation level. There are both abstractive as well as in stream uses like irrigation, domestic water supply and industrial has been served by river water. The condition deteriorates further due to significant water abstraction which reduces the dilution capacity of the river. The 22 km stretch of Delhi is the maximum polluted amongst all. It is acquired that, a large population is dependent on the river, it is of significance to preserve its water quality This paper highlights the present condition of river Yamuna in terms of its quality, flowing through the National Capital Territory of Delhi. Further it has been compared to the scenario if the flow of the river downstream of wazirabad barrage is maintained taking in account the environmental flow requirement of various stretches. MATLAB is the programming tool used here, to develop DO-BOD model of river Yamuna for predicting its quality.

Keywords: River, Water Quality Modeling, MATLAB Programming, Water Pollution

I. INTRODUCTION

As part of a timeless civilization, the river Yamuna, other than being a traditional water resource, is also a cultural icon and is worshipped as a goddess in Indian Culture. In agriculture front, the Yamuna basin, especially the areas in Haryana and Western district in Uttar Pradesh, is one of the highly fertile and high food grain yielding basin (cpcb 2005). This reflects that the River Yamuna not only flows in the hearts of Indian but also plays a significant role in the economy of the country. But due to its over exploitation, A river which notwithstanding its past glory, is today fighting a seemingly lost battle for its continued survival against powerful forces of covetousness and self-interest. Ironically, the river once pride of Indian civilization is now a dead river. Delhi sewage contributes 71 % of the pollution to River Yamuna while it only has 2% of the total length of 1376 km of the entire stretch of Yamuna (cpcb 1996). River Yamuna is also influenced by the problems imparted by industrialization, urbanization and rapid agricultural developments similar to other riverine system. Pollutant discharges originate from point and nonpoint sources. A common approach to controlling point source discharges, such as those from stormwater outfalls, municipal wastewater treatment plants or industries, is to impose standards specifying maximum allowable pollutant loads or concentrations in their effluents. Delhi has been identified with 26 industrial areas contributing their load to the river Yamuna (Paliwal and Sharma, 2007). The river has been getting a large amount of partially treated and untreated wastewater during its course especially between Wazirabad and Okhla. Inorder to estimate water quality of rivers modeling approach has been adopted. So far various models have been developed the earliest in this regard regard being of streeter and phelp (1925). The models describe the main water quality processes, and typically require the hydrological and constituent inputs (the water flows or volumes and the pollutant loadings). In this paper the modeling theory is considered for developing DO-BOD model of river Yamuna for present condition as well as for the scenario in which the flow downstream of wazirabad barrage is regulated taking in account the environmental flow requirement of various stretches between wazirabad and okhla. MATLAB is used as a programming tool which enables a developer to create a set of mathematical formulations involving differential equations, the input data is supplied in the form of matrices.

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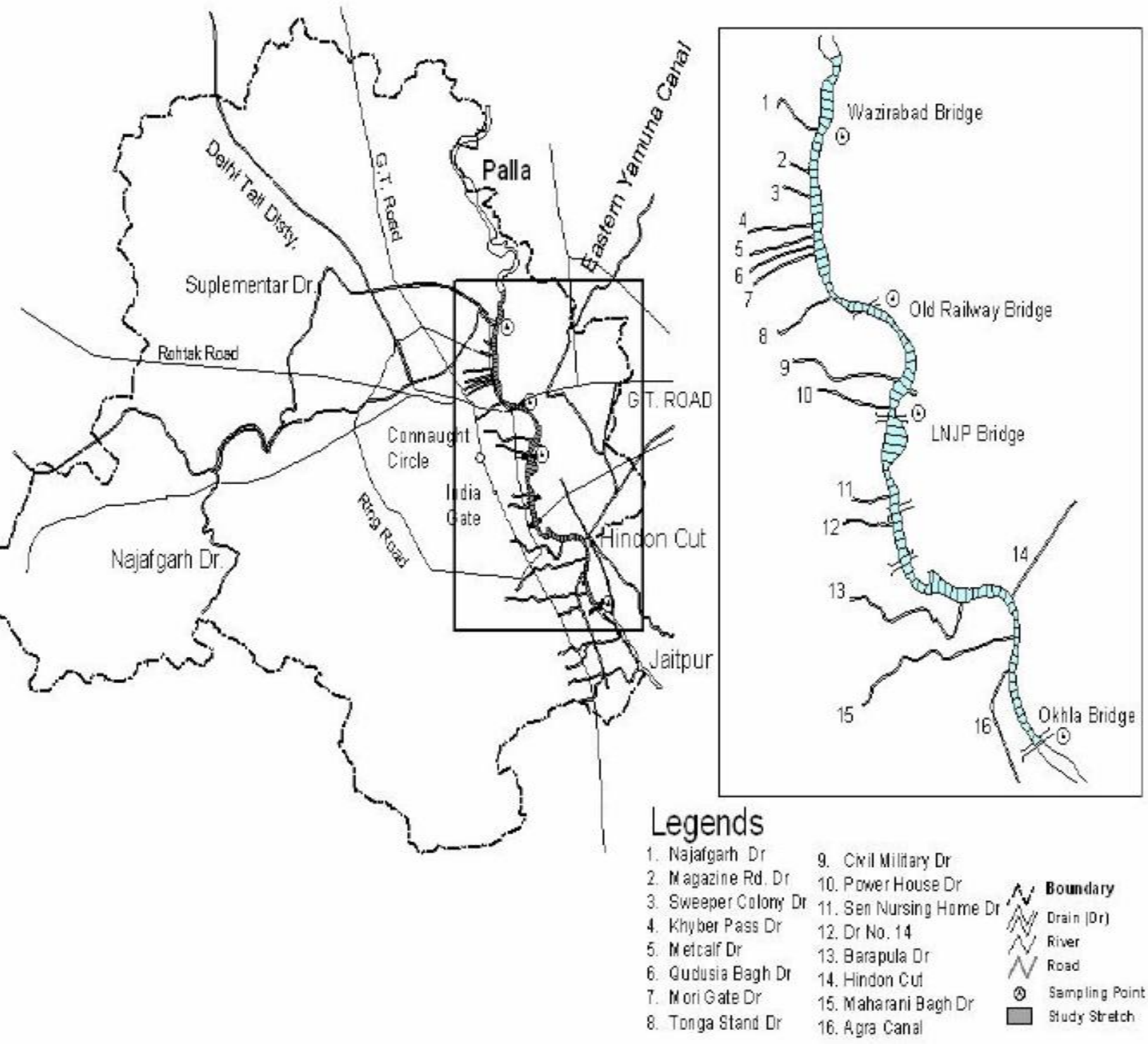

Fig. 1 Description of the study area

II. MATERIALS AND METHODOLOGY

A. Site Description

The Yamuna River being the largest tributary of River Ganga, is one of the important and sacred river of India. Originating from the Yamunotri glacier in the Mussoorie range of the lower Himalayas, it travels a length of 1,376 km and finally joins Ganga at Allahabad. During the course it flows through seven states, viz. Uttarakhand, Himachal Pradesh, Uttar Pradesh, Haryana, Delhi, Rajasthan and Madhya Pradesh and covers the drainage area of 366,220 sq km. The river enters Delhi 1.5 km above village Palla and leaves Delhi at Jaitpur downstream of the Okhla bridge after traversing around 22 km (CPCB 1999-2000). The major drains falling in the river between 22 km stretch of wazirabad and okhla include Najafgarh drain, Magzine road drain, Sweeper colony drain, Khyber pass drain, Metcalfhouse drain, ISBT + mori gate, Tonga stand, Civil mill, Drain no. 14, Power house drain, Sennursinghome drain, Barapulla drain and Maharani bagh drain (Fig 1). The diversion structures had constructed at regular intervals for regulating the flow of river in lean periods.

The area under consideration for the purpose of this study is between wazirabad and okhla barrage Considering 14 node points where the drain meets the river and 13 reaches (the interval between stretches).The utilization of river water is done for irrigation, drinking and industries as well as for mass bathing, laundry, cattle bathing, and secretion of the cremation ash. The inflow of wastewater either treated or partially treated in the river further enhance the water quality problem of the river. Withdrawals of water from the river takes place at two points Wazirabad Waterworks and Agra canal. Drinking water is supplied to the cities of Delhi and Agra, respectively, from these withdrawals.

B. Modeling Tool

MATLAB is used as a programming tool for the purpose of development of model. MATLAB (matrix laboratory) is a numerical computing environment and fourth-generation programming language. Developed by MathWorks, it is a high-level language and offers interactive environment for numerical computation, visualization, and programming.
Matlab is designed to solve problems numerically, that is, in finite-precision arithmetic. Therefore it produces approximate rather than exact solutions.

C. Model Calibration

The model was calibrated using yearly average of monitored data for the year 2011considering two scenarios (1) The discharge through Wazirbad barrage to the downstream path is taken after subtracting the withdrawal of water for wazirabad water works. This case represents the actual condition. (2) In this case the discharge is taken keeping in consideration the environmental flow requirement of various stretches for maintaining a healthy surrounding. Environmental flow is an important issue for the river Yamuna, various hydrology based methodology was investigated to estimate it for different stretches. A hydraulic method which accounts for seepage and evaporation losses, ecological requirement and water requirement for pollution assimilation was used to estimate the stretch-wise environmental flow requirement (Rai et al. 2011).

1- *Input Parameters:* The simulation of model require certain parameters as input constants to set initial condition which has been divided into different classes as (a) hydraulic constants, (b) reactions rate constants. For carrying out the simulation only point sources of pollutant load has been considered.

(a) Hydraulic constants
The hydraulic constants comprises depth of river and flow velocity along various stretches, which can be calculated by following empirical equation. (CPCB 1982-83, Ghosh 1996, Chapra 1997) (Table 1)

$$V = a\,Q^{b} \qquad (1)$$
$$H = c\,Q^{d} \qquad (2)$$

Where,
V = average cross-sectional velocity,
H = average cross-sectional depth,
Q = flow rate,
a, c = coefficients for flow on velocity and depth respectively,
b, d = exponents for flow on velocity and depth respectively.

Table 1
Range of Discharge Coefficients and Exponents

S. No.	**Input Variables**	**Value (ranges)**
1.	Coefficient on flow for velocity	0.032-0.08
2.	Exponent on flow for velocity	0.300-0.425
3.	Coefficient on flow for depth	0.126-0.33
4.	Exponent on flow for depth	0.245-0.475

Source: CPCB 1982-83, Ghosh 1996, Chapra 1997

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(b) Reaction rate constant
The value of the reaeration coefficient K_2 depends, eventually, on the hydraulic parameters of the stream and a large number of experimental formulae have been presented in various literatures (Gromiec 1983, Jolánkai 1979, 1992). Reaeration rate coefficient is the rate at which oxygen enters the water from the atmosphere. For the purpose, the value of K_2 as a function of flow velocity V and stream depth H, is calculated by the following equation.

$$K_2 = 2.148\ (V^{0.878} \times H^{-1.48}) \qquad (3)$$

Another reaction rate coefficient is K_1, which is decomposition rate coefficient and whose value can be taken from table 2 (Jolánkai, 1979).The settling rate and Sediment Oxygen Demand (SOD) were assumed to be zero for the entire course of the river. CPCB (1982 – 83) reported that only 25 % of the total BOD reaching Yamuna was settleable for the considered stretch and a part of this settled material decomposes anaerobically because the river generally has low DO levels (CPCB, 1982 - 83 and Kazmi, 2000). Thus the settling process removes only a small part of the total BOD without disturbing the DO profile of the river. Whatever BOD was removed through settling was assumed to get balanced by the loads contributed by non-quantified non-point sources such as bathing, washing, cattle wading and religious offerings of flowers, sweets and milk (CPCB, 1999-2000). 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.

Table 2
Ratio $f=K_2/K_1$ as a Function of the Hydraulic Condition of the Stream

S.No.	Description of the water body	Range of $f=K_2/K_1$
1.	Small reservoir or lake	0.5 - 1.0
2.	Slow sluggish stream, large lake	1.0 - 2.0
3.	Large slow river	1.5 - 2.0
4.	Large river of medium flow velocity	2.0 - 3.0
5.	Fast-flowing stream	3.0 - 5.0
6.	Rapids and water falls	5.0 - and above

Source: Jolánkai 1979.

Note: For the purpose of model evaluation River Yamuna has been categorized as a large river with medium flow velocity.

2-*Assumptions*:In case of inadequacy of data certain assumption has to be followed for proper simulation of the model. A large number of assumption will lead to miscrepancy of results which deviate more from the actual value. But some assumptions is seems to be necessary to predict the actual results.

1. The terms accounting for dispersion phenomenon has been neglected from the basic equation of water quality modeling.
2. With this we assume that the system is fully mixed, which means that any external material input (load) to the river or lake will be instantaneously and fully mixed with the water.
3. The only velocity component, which remains in the basic equation, is then v_x, the average longitudinal flow velocity.
4. The model is considered to be Steady-state model i.e., $\partial S/\partial t = 0$
5. Within the each reach, all model parameters like K_1, K_2, velocity, depth, etc., remains the same.

3- *Mathematical Formulation:*

$$\frac{\partial C}{\partial t} + V_x \frac{\partial C}{\partial x} + V_y \frac{\partial C}{\partial y} + V_z \frac{\partial C}{\partial z} = \frac{\partial}{\partial x}\left(D_x \frac{\partial C}{\partial x}\right) + \frac{\partial}{\partial y}\left(D_y \frac{\partial C}{\partial y}\right) + \frac{\partial}{\partial z}\left(D_z \frac{\partial C}{\partial z}\right) + S(x,y,z,t) \pm S_{internal} \qquad (4)$$

Where,

C = concentration, the mass of the quality constituent in a unit volume of water,
D_x, D_y, D_z = coefficients of dispersion in the direction of spatial co-ordinates x, y, and z,
V_x, V_y, V_z = components of the flow velocity in spatial directions x, y, and z,
t = time,
S(x,y,z,t) = external sources and sinks of the substance in concern that may vary in both time and space,

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$S_{internal}$ = internal sources and sinks of the substance.

This equation forms the basis of all the water quality models. It depends on the mass inflow-outflow phenomenon through an elementary box. Practically all water quality model equations, used in the everyday practice, can be derived in a similar way: by adding one or more dispersion and advection terms and by coupling the reaction processes, when more than one interacting water quality constituents (pollutants) are concerned.

From this equation the most simple river model equation can be obtained a

$$V_x \frac{dC}{dx} = -KC \quad (5)$$

The main process that affect the oxygen content of water is the oxygen consumption of micro-organisms, living in the water, while they decompose biodegradable organic matter, In the models biodegradable organic matter is taken into consideration by a parameter termed Biochemical oxygen demand. The BOD decay model describes the decomposition of biodegradable organic matter (termed here L) in function of the time (which is the time of travel along the stream, $t = X / V$).

$$L = L_0 \times \exp(-K_1 t) \quad (6)$$

L_0 = initial BOD in the stream (below waste water discharge).

The traditional dissolved oxygen model describes the fate, the sag, of the dissolved oxygen in the river as influenced by the decay of biodegradable organic matter and the reaeration process (across the water surface).

$$\frac{dD}{dt} = K_1 L - K_2 D \quad (7)$$

Where,
D = oxygen deficit of water (mg/l),
L = BOD in the water (mg/l),
K_1 = rate coefficient of biochemical decomposition of organic matter (day^{-1}),
K_2 = reaeration rate coefficient (day^{-1})

D. Modeling Simulation

The simulation is done for the year 2011 taking in account the yearly average of input parameters. The model is made to run two times over the same stretch between wazirabad to okhla for two different conditions. At first the discharge of river downstream wazirabad barrage is taken after subtracting the withdrawal for wazirabad waterworks, this represent the actual scenario (table 3). In the other scenario the discharge is maintained fulfilling the environmental flow concern for the various stretches (table 3). The two scenes have been compared and the results obtained are discussed in the subsequent section. There are 13 drains which joins the river between Wazirabad and Okhla stretch. The point of confluence of drain with river is considered as a node and the distance between two consecutive nodes is considered as a stretch (Fig 2). The simulation is done for each stretch independently. For each independent stretch the initial point is taken as 0 and the subsequent length is divided into equal intervals upto the specified distance from the initial node to the next node. The concentration of DO and BOD is obtained at each interval point and finally the concentration obtained just upstream and downstream of node is plotted for complete stretch of 22 km between wazirabad and okhla taking in account every node. Along with the predicted concentration the observed dataset from central pollution control board for the year 2011 at two locations, viz. Nizamuddin (mid-stream, 15 km D/s of wazirabad barrage) and Agra canal (24 km D/s of wazirabad barrage) were also plotted.

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Table 3
Characteristics of Various Pollution Loads and Withdrawals

Case 1 Low water discharge downstream of wazirabad barrage

S. No.	Discharge / Withdrawal	Flow (m^3/s)	D O (mg/l)	BOD (mg/l)
1.	Head water	15.0	7.87	2.25
2.	Wazirabad waterworks**	-11.1	-	-
3.	Najafgarh drain	22.5	0	53.58
4.	Magazine Road drain	0.1225	0	238
5.	Sweeper Colony drain	0.058	0	57.58
6.	Khyber Pass drain	0.041	0	8.58
7.	Metcalf House drain	0.075	0	30.33
8.	ISBT + Mori Gate drain	0.495	0	76,42
9.	Tonga Stand drain	0.073	0	158.58
10.	Civil Mill drain	0.215	0	64.75
11.	Power House drain	1.998	0	209.5
12.	Sen Nursing Home drain	0.763	0	99.33
13.	Drain No. 14	0.1375	0	18.67
14.	Barapulla drain	1.66	0	62.33
15.	Maharani Bagh drain	0.409	0	122.17

Source: (CPCB , 2003-2012)
** NEERI, 1996

Case 2 Sufficient water discharge downstream of wazirabad barrage to meet out environmental flow concern of various stretches

S. No.	Discharge / Withdrawal	Flow (m^3/s)	D O (mg/l)	BOD (mg/l)
1.	Head water**	49.55	7.87	2.25
2.	Najafgarh drain	22.5	0	53.58
3.	Magazine Road drain	0.1225	0	238
4.	Sweeper Colony drain	0.058	0	57.58
5.	Khyber Pass drain	0.041	0	8.58
5.	Metcalf House drain	0.075	0	30.33
6.	ISBT + Mori Gate drain	0.495	0	76,42
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11.	Drain No. 14	0.1375	0	18.67
12.	Barapulla drain	1.66	0	62.33
13.	Maharani Bagh drain	0.409	0	122.17

** Rai et al. 2011

III. RESULTS AND DISCUSSION

The variation of BOD is illustrated in Fig 3 for case 1. The figure shows that there is significance increase in BOD concentration downstream of wazirabad barrage where the Najafgarh drain joins the river. Thus Najafgarh drain here is considered to be the main contributer of organic pollutant into the river. In the further length the concentration of BOD is gradually decreasing. The other drains also contribute considerable amount of BOD which is depicted in the figure where the upstream concentration fall short of downstream concentration but not enough to exceed that added by Najafgarh drain. The variation from the observed concentration is because of the inadequacy of data and the other meteorological factors. In the second case (Fig 4), also Najafgarh drain remains the main accused but the concentration of BOD is reduced considerably as the flow downstream is regulated to meet out the environmental concern. The decrement along the stretch follow almost a linear pattern. Thus a uniform condition is maintained throughout the stretch.

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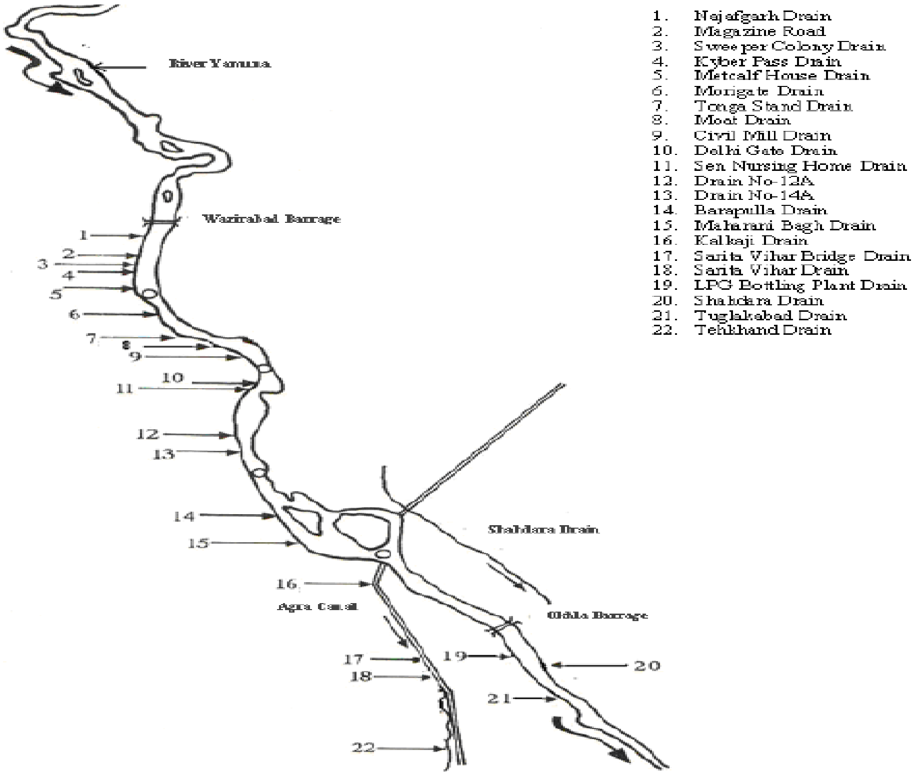

Fig. 2 Simplified diagram showing location across the study area

CASE-1

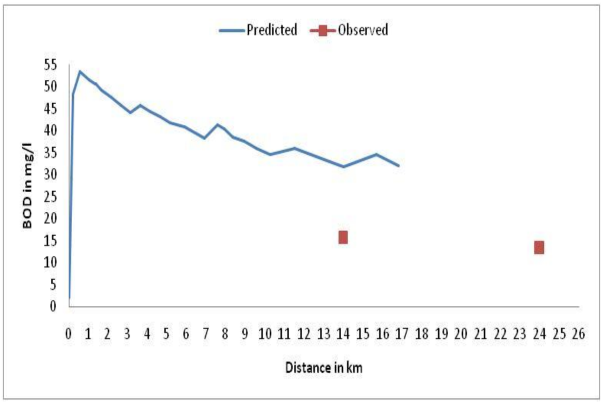

Fig. 3 Predicted and Observed BOD concentration for 2011

CASE-2

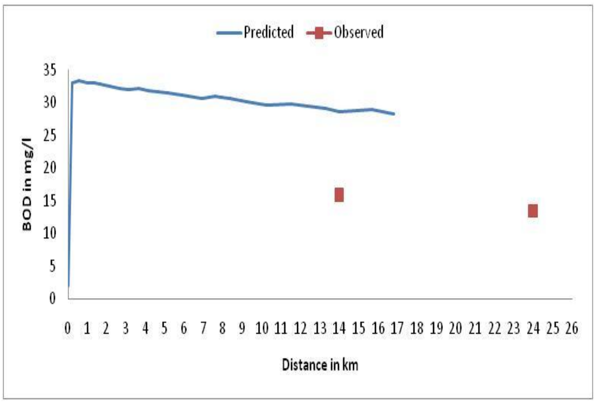

Fig. 4 Predicted and Observed BOD concentration for 2011

The variation of DO is illustrated in Fig 5 and Fig 6 for the case 1 and 2 respectively. In the case 1 the DO concentration remain nil throughout the stretch indicating dreadful condition of the river where the standard level of DO in the river should be 4 mg/l according to classification given by CPCB. This indicate the zero self purifying capacity of river. While according to case 2 the DO level for the initial stretch remain above the standard level and then it start decreasing due to low self purifying capacity. But the level remain above zero for whole of the stretch.

CASE-1

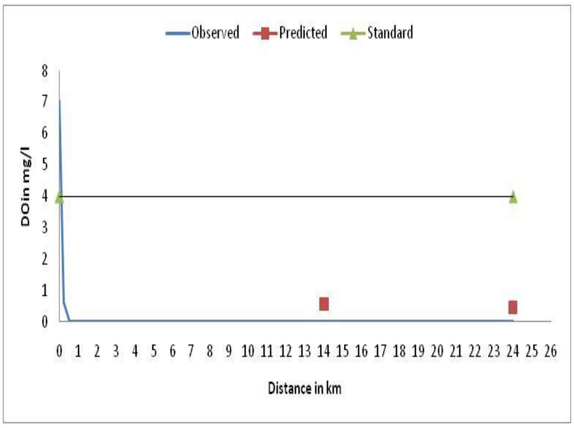

Fig. 5 Predicted and Observed DO concentration for 2011

CASE-2

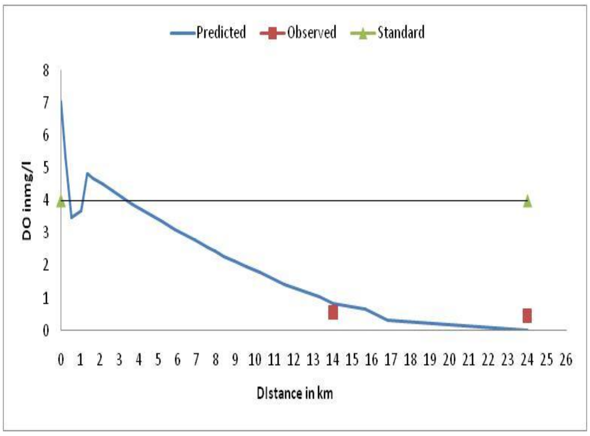

Fig.6 Predicted and Observed DO concentration for 2011

IV. Conclusion

The study presented in this paper briefly describes that MATLAB can be used as a programming tool for simulation of a model. It can be made to perform as many iteration as required for the simulation. The performance of model could have been significantly enhanced if more ground observations were available. The statistical variation of calculated DO and BOD are also due to variation of hydrological and meteorological parameters. If these variations had been taken into account, the results would have been considerably changed. Further Study leads us to the conclusion that once recognised as a holy mightiest river, is now facing a dreadful situation with almost zero level of DO and significant level of BOD concentration. The self purifying capacity of river also become nil due to its over exploitation. Now the time for taking precautions has been long gone but certain measures can still be adopted for saving the river before it has declared been dead. One of the measure has been shown in the paper which accounts for maintain a considerable amount of flow in the river which can balance the over populated load from point sources to some extent. Though the study conducted is primarily focussed on the pollution from the point sources but if we consider the other non-point sources as well as the natural phenomenon the results obtained will be quite precise, if there will be sufficiency of data. Another measure which can be adopted is to decrease the considerable pollution load from the drains. This can be achieved by constructing parallel drains along the river to prevent entry of waste into the river. Programmes should be needed to collect flood water for recharging ground water and filling water bodies. Encroachment on Yamuna bed need to be removed so that recharging of river can take place. Treated water must not be mixed with untreated water. Artificial reaeration can also be accommodated as a substantial solution.

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