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Assessment of Surface Water Quality Using Qual2k Software: A Case Study of River Yamuna, India

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ABSTRACT

In current years, water quality degradation related with rapid socio-economic development in the River Yamuna, India has attracted increasing attention from both public and Indian government. The principal sources of pollution in River Yamuna are effluent discharge from the industries and domestic sewage. The effective water environmental management strategies required to be implement in this river to upgrade the water quality and to ensure sustainable development in the region. The aim of this work was to provide a basis for water environmental management in process of making important decisions. In this study Qual2k is used as model to identify the processes that underlie river and stream water quality problems in a basin. This will be applied to predict the water quality parameters such as Temperature, Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD) and pH and the most sensitive parameter of the model that influence Yamuna River. The scope of the research is from Delhi Stretch of Wazirabad to Oklah route of the river.

Key words: Water quality, Water environmental Management, Qual2k, Biochemical Oxygen Demand, Dissolved Oxygen

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INTRODUCTION

The growing rate of the population has caused a remarkable increase of the demand for natural resources due to such processes as urbanization, agriculture and industrialization [1]. The direct consequences refer to the quantity and quality of the available freshwater to human consumption. Due to problems related to water resources it is essential to improve monitoring, research and management actions in order to ensure their effective managing. Thus, proper basin management plans should be prepared in order to solve water quality problems in the basins [6]. Many tools can be used for planning studies. One of these tools is mathematical modeling. In recent years, mathematical simulation models have been consulted to solve the water pollution problem in a basin [10]. A simulation models indicate the values of water quality variable given the flow, the quantity and quality of the waste loadings, and waste discharges or to increase the waste assimilation capacity of the receiving systems [8]. However, the applicability of models for different climate conditions needs to be tested to have accurate prediction by the model. Thus a model needs to be calibrated and validated before putting into use for accurate water quality simulation. QUAL2K is a one-dimensional river and stream water quality model that is an upgraded version of the QUAL2E model. The QUAL2K framework, which was developed by the US Environmental Protection Agency, can simulate the migration and transformation of conventional pollutants [7]. The model considers the stream as a one-dimensional channel with steady flow that is non-uniform and considers the influence of point source and non-point source pollution loads [5]. The aim of the study was to model the water quality of the polluted segment of river Yamuna, Okhla to Wazirabad by the comprehensive application of water quality model Qual2k and evaluate the performance of the model.

SOURCE OF POLLUTION

The major sources of river water pollution are classified as point sources through which the polluting substance is emitted directly into the waterway. The river stretch within Palla (Upstream of Wazirabad barrage) and Jaitpur (downstream of the Okhla Bridge) has been considered as the study area. The major drains in the first 5 km length, namely, Magazine Road, Najafgarh, Sweeper Colony and Khyber Pass, Najafgarh drain is the largest contributor of

municipal sewage [8]. In the next 5 km length, Meltcalf House, Qudusia Bagh, Mori Gate and Tonga Stand drains discharges their wastes. Other important point sources are drains from the Civil Military, Power House, Sen Nursing Home, No. 14, Barapulla and Maharani Bagh along the remaining 15 km stretch. The river gets the second largest direct load from the wastewater treatment plant located at Okhla from a diversion called Hindon Cut. Water is taken from Yamuna at two points: Wazirabad Waterworks and Agra canal in order to meet the drinking water requirements of the cities of Delhi and Agra, respectively [10].
The main sources of pollution in NCT are -

- Increasing density of human population on the bank of river
- Industrial wastewaters Immersion of idols
- Dumping of garbage into drains
- Domestic sewage
- Cattle bathing and agricultural runoffs

MATERIALS AND METHODS

Study Area and Sample Sites

River Yamuna is the largest tributary of the Ganga River in North India [4]. Its total length is around 1370 kilometers. Yamuna originates from the Yamunotri Glacier of Uttar Kashi in Uttar Pradesh. River Tons and Giri are the important tributaries of Yamuna and principle source of water in mountainous ranges. Yamuna flows through the states of Delhi, Uttar Pradesh and Haryana, before merging with the Ganges at Allahabad. The most famous cities like Delhi, Agra and Mathura lie on its banks. The study area lies between 28'28"28"'-28'54"36"'N and 77'09"-77'24"E. The River Yamuna is the primary source of drinking water for Delhi, the capital of India, also for many cities, towns and villages in the neighboring states [10]. Last few decades, there has been a serious concern over the deterioration in its water quality. The river has been receiving large around 3296 million liters per day (MLD) of sewage from drains during its course, especially between Wazirabad and Okhla, along National capital territory (NCT) of Delhi that is Central pollution control board. On the basis of hydrological and ecological conditions Yamuna has been classified into five (5) segments that are Upper Segment, Himalayan Segment, Delhi Segment, Eutrophic ate Segment and Diluted Segment. After origin Yamuna river flows through several valleys for about 200 km in lower Himalayas and emerges [10].

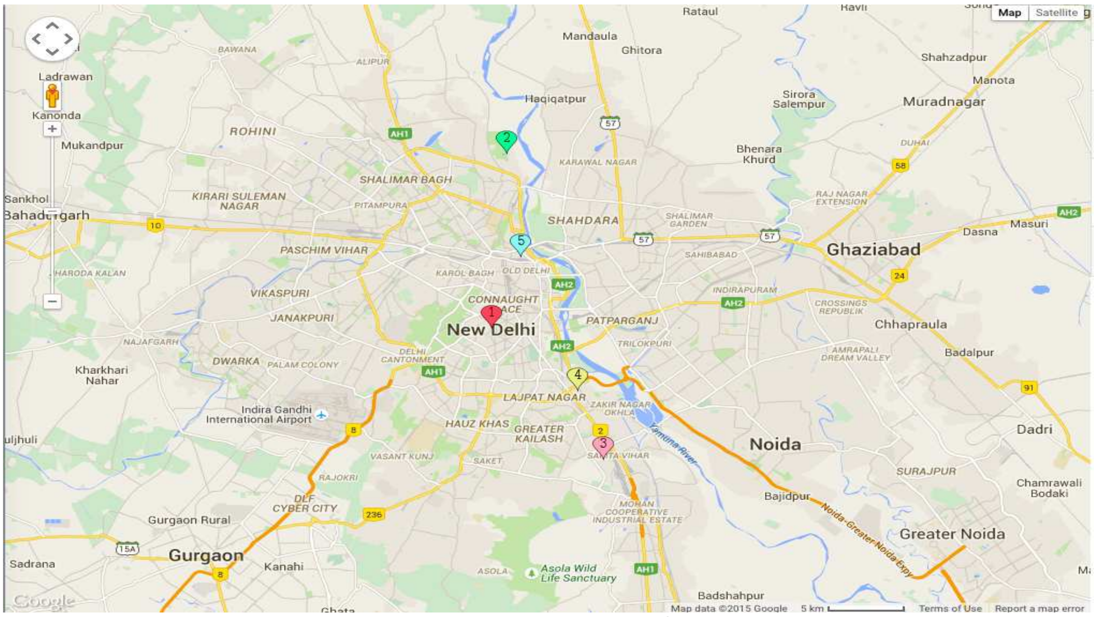


Fig. 1 Schematic illustration showing map of the study area [8]

OVERVIEW CONCEPT OF QUAL2K MODEL

Segmentation and Hydraulics

This model represents a river as a series of reaches. Also represent a stretches of river that have constant hydraulic characteristics such as a slope, bottom width, etc. Any model reaches can be further subdivided into a series of *n* equal length elements which as shown in Fig. 2.

Wazirabad barrage and Okhla barrage stretch having Fifteen drains was considered, also point sources, domestic Effluents and industrial waste were considered in the research the water quality parameters considered were BOD, Temperature flow, Total Nitrogen and DO have been considered because of lack of data of other parameter. A steady-state flow balance was implemented for each Model element as

$$Q_i = Q_i{-}1 + Q_{in,i} - Q_{out,i}$$

Where, Q_i: outflow from element *i* into the Downstream element *i*+1 cubic metre per day (m3/d),
Q_{i-1}: Inflow from the upstream element *i*-1 (m3/d),
$Q_{in,i}$:The total inflow into the element from point and Non-point sources (m3/d), and
$Q_{out,i}$: The total outflow from the element due to point and non-point withdrawals (m3/d).

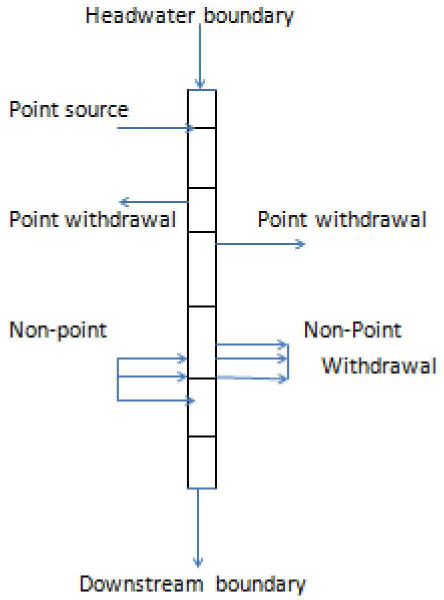


Fig. 2 QUAL2K Segmentation Scheme for a River with No Tributaries

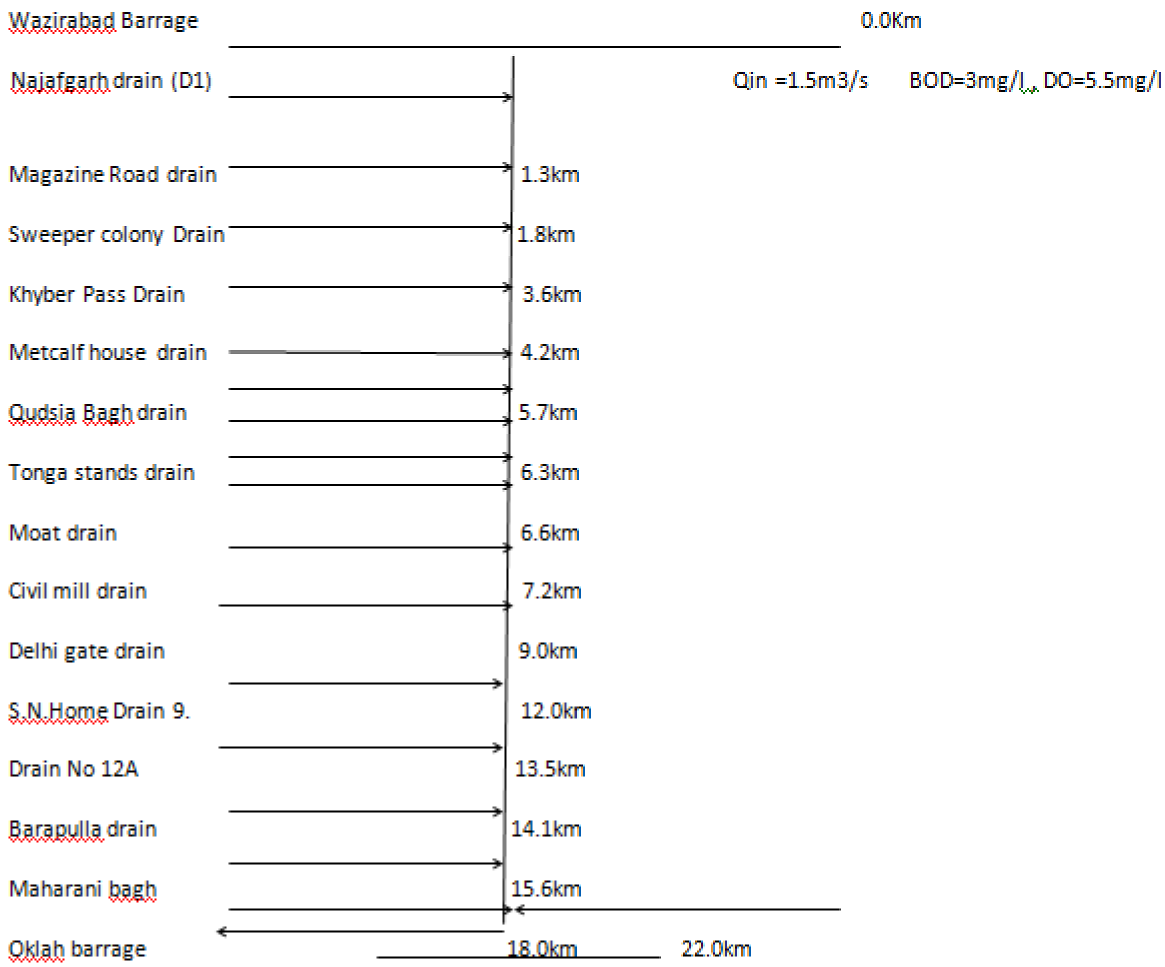


Fig. 3 Diagram showing the sketch of 15 drains of Delhi stretch of River Yamuna

METHODOLOGY

Model Calibration

The calibration of the process compartment of the model was carried out sequentially by using transformation kinetic parameters. The order of calibration is DO, temperature, Alkalinity, Total Nitrogen, and pH related. While calibrating water quality process part of the model, estimated parameters are fixed, few parameters are extracted from standard modeling literature, remaining parameters are obtained by tuning them till the observed and predicted results matched. For the DO, it was considered based on the concept that it can grow due to plant photosynthesis and lost via Carbonaceous Biochemical Oxygen Demand (CBOD) oxidation, nitrification and plant respiration. Depending on whether the water is under-saturated or oversaturated the DO is gained or lost via re-aeration.

IMPLEMENTATION OF THE MODEL

The total study length of 22 km of Yamuna Delhi stretch River was discretized into 16 reaches of 0.3 km each. The reaches were further subdivided into different element. The head water data discribes the upstream boundary condition. The steady state data measured on February 2003 in pre-monsoon season and the data from July 2009 were used in assessing the water quality. The sketch of the reach is shown below in Fig. 3.

INPUT DATA

Hydraulic Characteristics

The outflow for each element and reach was computed and the depth and velocity were calculated by rating curve. The table shows the data in Table -1.

Table -1 Geometric and hydraulic data of the Delhi stretch of the river Yamuna [8]

Name of reach	Length (km)	Width (km)	Depth (km)	Flow(Q in m3/s)	Velocity (m/sec)
R1	0.3	60	0.4	1.0	0.032
R2	1.2	83	1.1	22.97	0.25
R3	0.3	110	1.1	23.027	0.19
R4	1.8	110	1.1	23.131	0.21
R5	0.6	110	1.3	23.245	0.178
R6	1.5	100	1.3	24.187	0.186
R7	0.6	130	1.4	24.682	0.13
R8	0.3	120	1.3	24.759	0.158
R9	0.6	125	1.2	24.7591	0.165
R10	1.8	185	1.2	25.436	0.13
R11	3.0	170	1.2	27.335	0.14
R12	1.5	115	6.0	28.329	0.1
R13	0.6	120	1.8	28.519	0.132
R14	1.5	130	2.1	28.709	0.105
R15	2.4	272	3.0	30.585	0.075
R16	3.9	200	2.5	30.80	0.117

Water Quality and Flow Data

The water quality and flow data measured for assessing the water quality of the river for both 2002 and 2009 are given in Tables -2.

Table -2 Point Loads and Withdrawals 2002 [8]

Name of drain	Flow (m3/s)	BOD (mg/l)	DO (mg/l)	Temperature (Celsius)
Najafgarh drain	21.97	58	0	28
Magazine drain	0.057	448	0	28
Sweeper colony	0.104	286	0	28
Khyber pass	0.114	92	0	28
Metcalf house	0.942	84	0	28
Mori gate	0.495	174	0	28
Tonga stand	0.077	84	0	28
Moat drain	0.0001	78	0	28
Civil drain	0.677	134	0	28
Delhi gate	1.899	88	0	28
Sen nursing	0.994	74	0	31
Drain No. 12A	0.19	92	0	31

Table -3 Calibrated Points and Withdrawal Sources

Name of drain	Flow m3/s	BOD (mg/l)	DO (mg/l)	Temperature (Celsius)
Najafgarh drain	20.68	56	0.0	28
Magazine drain	0.07	333	0.0	28
Sweeper colony	0.13	236	0.0	28
Khyber pass	0.13	136	0.0	28
Metcalf house	0.09	73	0.0	28
Mori gate	0.39	134	0.2	28
Tonga stand	0.09	96	0.2	28
Moat drain	0.001	62	0.4	28
Civil drain	0.52	171	0.3	28

Adding Point Source Data

Data collected was used to understand the distinct minimum and maximum of DO at which the point waste water effluent enters the system. It was observed that the slow and fast CBOD decrease at different rates as we progress downstream of their different decay rate. Overall, the model concept was grabbed by repeatedly trial and error techniques using different set of data. The Schematic representation shows the illustrations of the reaches of the Yamuna River and their sources of pollution is shown in Fig. 4.

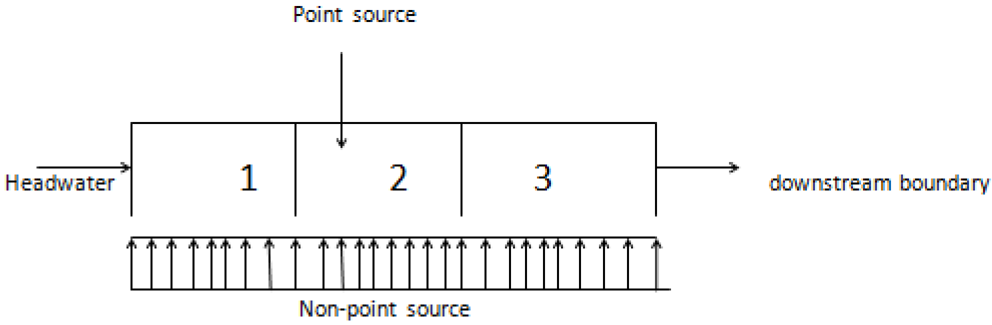
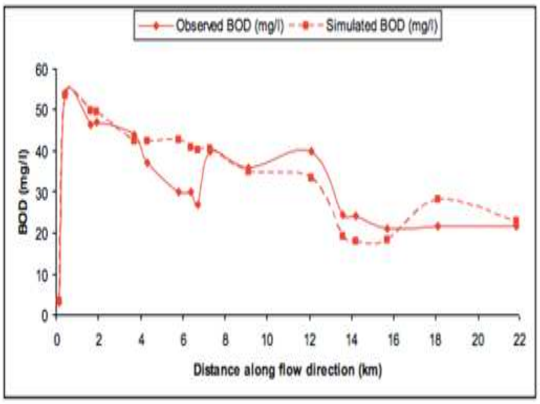


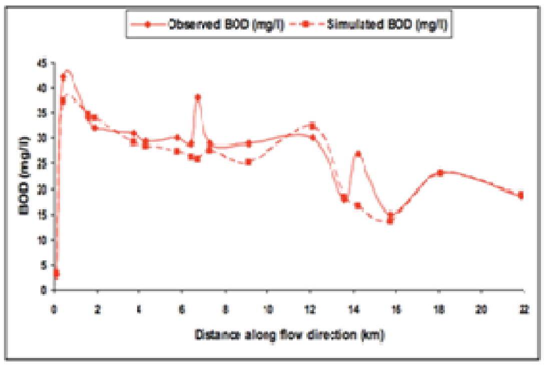
Fig. 4 Schematic representation showing illustrations of the t reaches of the Yamuna River & their sources of pollution

RESULTS AND DISCUSSION

With reference to table 6 Yamuna river belongs to class “E”. The graphs show the deterioration of the river at various locations. The BOD is a measure of the amount oxygen that bacteria will consume while decomposing organic matter under aerobic conditions. The BOD level in the studied area was found to exceed the permissible limits of 2mg/l (table 5) across the 22km stretch. The result indicates that point sources, effluent from industrial wastes and domestic waste have a wide range of flows and concentrations which influence Yamuna River with different magnitudes of change in relation to the water quality constituent. The BOD level starts increasing due to falling out of drains and domestic effluent along Najafgarh drain. The BOD level was found to be highest at magazine drain 448, 333mg/l for 2002 and 2009 respectively shown in Fig. 5a and Fig. 6a.



(a)



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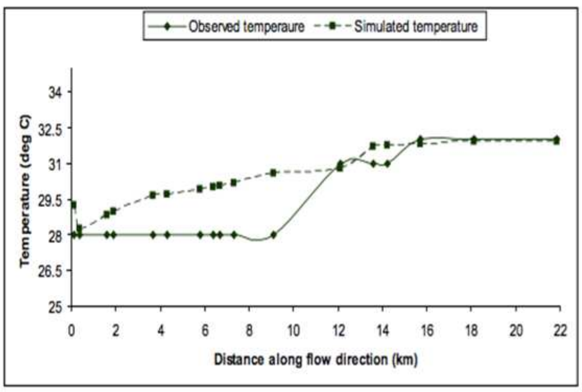

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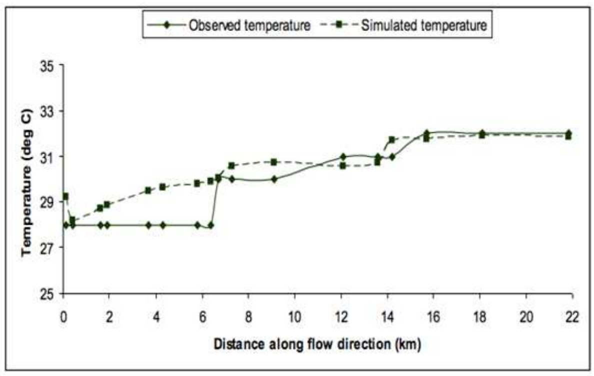

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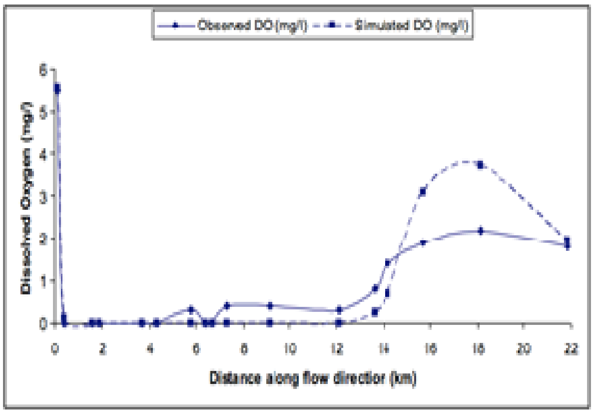
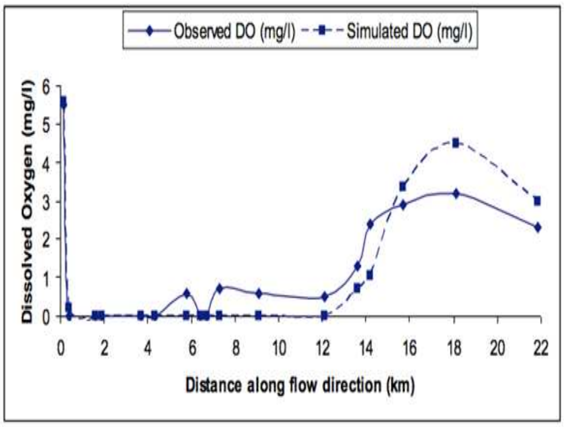


(c)
Fig. 5 Simulation results for River Yamuna, Delhi stretch 2002 [4]



(c)
Fig. 6 Simulation results for River Yamuna, Delhi stretch 2009 [4]

The Dissolved Oxygen concentrations were predicted and it was observed to have exceeded the permissible limit as the DO concentration was found to be 0-0.5mg/l along the stretch, expect along barapulah and maharani drain which range from 3-5 mg/l, due to insignificant point sources effluent and domestic sewage. With reference to central pollution control board the water along the stretch is best use for irrigation, industrial cooling and controlled waste disposal as shown in Fig. 5b and Fig. 6b pH is very important parameter as rise in it increases the solubility of toxic chemical which can prove harmful to aquatic habitat, consequently low pH can also result in fish kills. The pH limits to exceed the permissible limit of both year 2002 and 2009. The temperature along the 22km stretch was found to have exceeds the permissible limit criteria ranging from 28-32 degree Celsius, which will adversely affect the water quality due to high increase in metabolic activities by organisms due to the high temperature. The highest temperature was predicted to be 32 and 31 degree Celsius for 2002 and 2009 respectively along hindon cut and oklah barrage. As shown in Fig. 5c and Fig. 6c respectively.

SENSITIVITY ANALYSIS

To identify the parameters of the QUAL2K water quality model that have the highest influence on model predictions, a simple sensitivity analysis was performed with respect to DO estimates. The analysis was performed for the five model parameters and forcing by increasing and decreasing each parameter by 10% of its calibrated value and keeping the remaining parameters constant. The impacts on these changes in DO estimates were then assessed. It was found that in table 5 and 6, the model was rather highly sensitive to river flow and point source discharges and moderately sensitive to fast CBOD and nitrification rate as shown from Fig 7 and Fig 8.

Table -4 Indian River Water Qualities (Central Pollution Control Board)

Designated –best-use	Class of water	criteria
Drinking water source without conventional treatment but after disinfection	A	Total coliforns organism MPN/100ml shall be 0 or less PH between 6.5 and 8.5 Dissolved oxygen: 6mg/l or more Biological oxygen demand 5 days 20c mg/l or less
Outdoor bathing	B	Total coliforns organism MPN/100ml shall be 00 or less PH between 6.5 and 8.5 Dissolved oxygen: 5mg/l or more Biochemical oxygen demand 5days 20c 3mg/l or less
Drinking water source after conventional treatment and disinfection	C	Total coliforns organism MPN/100ml shall be 00 or less PH between 6 to 9 Dissolved oxygen : 4mg/l or more Biochemical oxygen demand 5days 20c mg/l or less
Propagation of wild life and fisheries	D	PH between 6.5 to 8.5 Dissolved oxygen : 4mg/l or more Free ammonia (as N): 1.2mg/l
Irrigation, industrial cooling, controlled waste disposal	E	PH between 6.0 to 8.5 Electrical conductivity at 25c micro mhos/cm max.2250 Sodium absorption ratio max 26 Boron max 2mg/l Below E- Not meeting A,B,C,D,and E criteria

Table -5 Sensitivity analysis for the Qual2k model on River Yamuna based on February 2009 data

Parameters	Description	*DO* change (%)	
		+10% parameter	-10% parameter
Q	*River flow*	1.795	-2.04
q	*Point source flow*	-1.17	1.27
Kdc	Fast CBOD oxidation rate	-0.31	0.745
Kna	Nitrification rate	-0.52	0.625
n	Manning coefficient	-0.215	0.415
CBOD	Point sources CBOD	-0.365	0.37
Kdn	Denitrification rate	0.36	-0.35

Table -6 Sensitivity analysis for the Qual2k model on River Yamuna based on July, 2009 data

Parameters	Description	*DO* change (%)	
		+10% parameter	-10% parameter
Q	*River flow*	3.782	-1.24
q	*Point source flow*	-0.87	1.12
Kdc	Fast CBOD oxidation rate	-0.24	1.46
Kna	Nitrification rate	-0.46	0.825
n	Manning coefficient	-0.136	0..666
CBOD	Point sources CBOD	-0.291	0.822
Kdn	Denitrification rate	0.52	-0.264

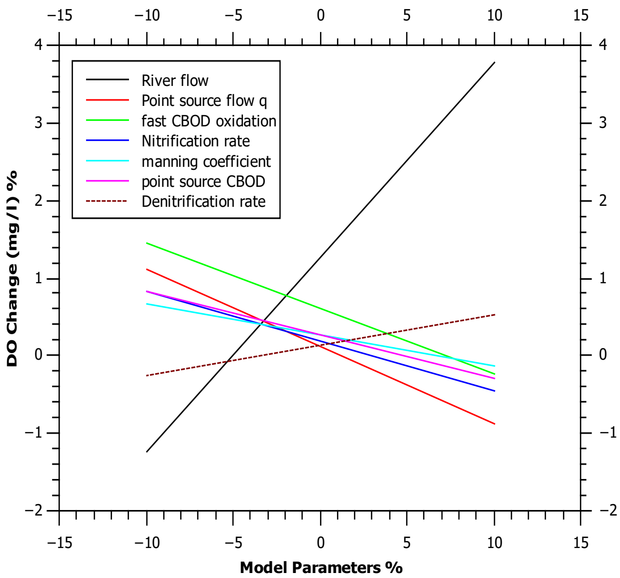


Fig. 7 Graph Showing Sensitivity of Model Parameter July 2009

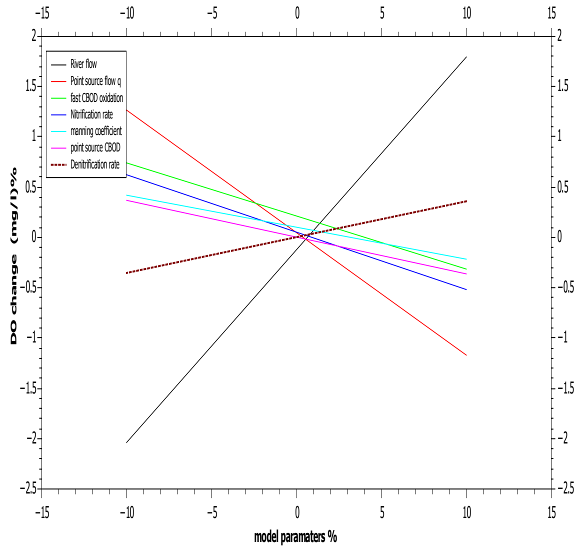


Fig. 8 Graph Showing Sensitivity Of Model Parameter February 2009

Performance Evaluation of the Model

The results model predictions were fairly good and performance of the model was confirmed through evaluation of the results. Also the analysis of the model results indicates that simulated results were relatively in best agreement with the measured value. Model predictions of water temperature and DO fall within the measured bound of the February data and very close to the in-stream July data median for all measurement locations. For all constituents, the mean of differences between model predictions and the median of data is small, model predictions for all constituents falls within the expected range of data onto nearly all measurement locations.

CONCLUSION

The current study characterized the quality of wastewater discharge into River Yamuna. 10 drains were investigated along the river and their flow by analyzing the water quality characteristics. In the data analysis at 16 reaches along the river, water quality parameters such as BOD and DO varied between 25mg/l and 55 mg/L and between 0.1 and 5.5 mg/L, respectively for 2009. Results obtained will be very useful to the decision makers by implementing policies and solutions for improving the water quality in the river Yamuna up to the required level. The existing study found that the model was most sensitive to point sources flow, river flow, fast CBOD oxidation rate and nitrification rate compared with the other model input parameters, QUAL2K clearly has potential for assessing water quality along the river and could be implemented as a valuable tool to inform Yamuna River management strategies. For example, based on the observations provided for this study it appears that Dissolved Oxygen may be manipulated using well-defined management strategies to keep DO concentrate on minimum allowable levels. The QUAL2K model can be used to simulate the amount of DO required and the potential impacts on such management on other water quality factors of the entire river. As such, the implementation of QUAL2K with regard to optimization techniques and accuracy assessments under various conditions warrants further consideration.

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