Mixed Integer Programming For Pollution Control Of Indian Tropical Rivers: A Case Study

Richa Babbar
Jaypee University of Information Technology Waknaghat, Distt Solan, Himachal Pradesh, India,
E-mail: richa.babbar@gmail.com

Himanshu Joshi
Indian Institute of Technology, Roorkee, Uttarakhand, India

Abstract: *The present study was undertaken to develop an optimization model that utilized the simulating and predicting capabilities of QUAL2E water quality model. The model employed a mixed integer linear programming technique in presenting a water quality management perspective, in terms of a decision space. Constrained with effluent standards and desired water quality criteria, the model was then duly applied for its suitability to pollution impaired river stretch of River Hindon (Main River) and River Kali (a tributary).The two rivers flow through industrially developed districts of the state of Uttar Pradesh in Northern India. The execution of the model, for the study stretch, yielded a feasible solution in terms of treatment options that satisfied optimization criteria and if implemented in practice, would result in a desired water quality improvement, based upon the environmental priorities established by the government. The model is an example of developing a procedure for water quality management within the constitutional framework of pollution control in India.*

Key Words: *mixed integer programming, transfer matrix, sustainable water management, waste water treatment*

1. Introduction

The disposal of industrial waste water continues to be the most crucial environmental problem, affecting the quality of the environment where it is disposed. Providing means for its safe disposal often conflicts with the economic interests of industries needing a pollution control strategy, especially in a developing country like India.

Realizing the environmental consequences of industrialization to a river body, the Indian Government has promulgated industry specific Minimum National Standards (MINAS) for the control of pollution at source. These standards impose the mandatory treatment of all wastes to certain minimum standards, even at locations where an industry could discharge untreated waste water without altering the ambient water quality criteria (CPCB 1996).

Although the legislative framework is in place for enforcing the national minimum standards, the water quality is still deplorable because the industries are not able to provide the adequate treatment of industrial waste water to meet the standards set. Taking the help of the existing information on pollution control framework in India, an attempt is made to develop an optimization model that provides means of finding the most feasible treatment options that if adopted can improve water quality of river while also satisfying water quality criteria and effluent standards. The model has been developed for the Hindon river system which receives waste effluent from small scale industries located in its vicinity.

2. Framework Of Pollution Control In India

The problem of fresh water pollution in India came to the forefront towards the beginning of 1970's with the domestic sewage and industrial discharges being the most critical sources of pollution in Indian cities. This resulted in the promulgation of the Water (Prevention and Control of Pollution) Act, 1974 which had the the prevention and control of water pollution and maintaining or restoring the wholesomeness of water as its major objectives (CPCB 1989).

In pursuance of the above act, the Central Pollution Control Board (CPCB) was set up in the Indian Ministry to promote basin wide pollution control strategies. The CPCB liaises with State Water Pollution Control Boards (SPCB) and lays out standards for the treatment of sewage and effluents, and stipulates action in case of non-compliance.

In the Indian context, the most important and expedient approach remains the control of pollution at the source (CPCB 1995) keeping in view costs associated and the benefits assured with other options, such as instream artificial aeration, flow augmentation and waste transportation. Realizing this, the regulatory boards have developed effluent standards as mode of controlling pollution for the waste discharges entering the waters. Unlike river water quality standards, these standards are based on the determination of the required quality of effluent discharged into the receiving water and restrict the amount and concentration of pollutants to be discharged by each industry in terms of volume, permissible concentrations, and degree of treatment required for each industry. CPCB coins these effluent standards as *Mi*nimal *Na*tional *S*tandards (MINAS) and are industry specific. This approach envisages treatment of the industrial waste discharge to MINAS standards, even at locations where an industry could discharge untreated waste without altering the ambient water quality criteria. The industrial waste discharges are expressed in terms of water quality parameters such as BOD and suspended solids. In no case is the relaxation in MINAS permitted however; it may be altered on a higher end if water quality criteria in the recipient water so warrants (CPCB 1996).

While putting these regulations into practice however, several limitations are identified in controlling pollution at source. Of these, the most prominent are the discharges from small scale industries such as paper and paper board mills, edible oil, pharmaceutical, paints and varnishes that find it difficult to install appropriate treatment units. This is either due to lack of resources, space, skilled manpower or awareness (CPCB 2002), thus being insufficient to achieve the MINAS requirements.

The use of modeling techniques can be useful for providing a quantification of how much the effluent discharges can be allowed so as to yield the desired results, in terms of water quality improvement downstream of confluence of industrial discharges with the rivers. The rapid growth of computer aided modeling techniques has further evoked the interest of regulatory agencies in developing a system of pollution control within the existing framework (Subramanian 2002). In the growing era of technological advancements, an integrated approach towards water quality management is hence desired wherein a simulation model could be integrated with an optimization model. An optimization model can play a decisive role in providing the optimal solution related to the allocation of effluent to the receiving waters and when complemented with the simulation models can provide for a comprehensive water quality management. Here the formulation of optimization model is described as one of the components of an integrated modeling environment proposed in Babbar et al. (2009).

3. Methodology

3,1. Study Stretch

River Hindon is a perennial river originating in the foot hills of the Shiwaliks (sub-Himalayas) of Uttar Pradesh district of India. It is a principal tributary of the mighty Yamuna River. The Hindon during its course of travel is joined by its two main tributaries; namely Kali River from the west and Krishni from the east (Figure 1).

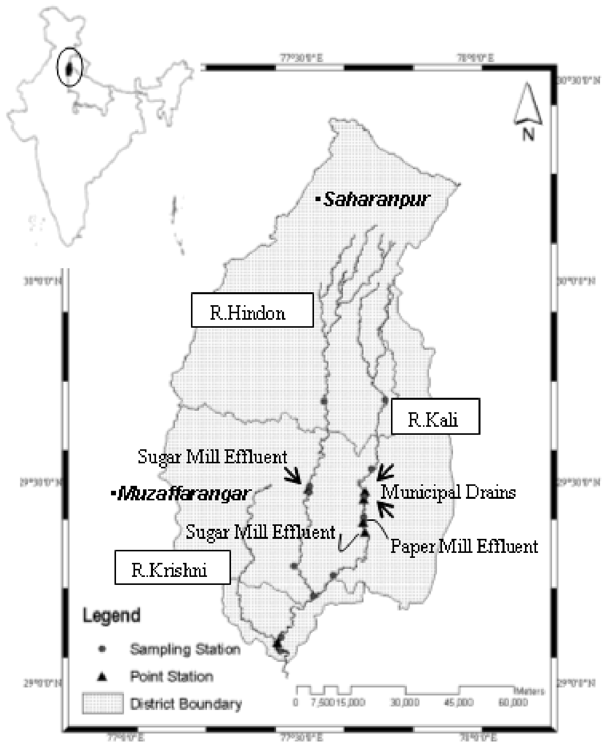

***Figure 1:** Study Area*

Several small scale industries such as sugar and paper board production are based all along the river. The impact of these industries is visible in terms both of economic growth of the region as well the water quality of the rivers, as assessed by several researchers (i.e. Lokesh 1996; Ghosh and McBean 1998; Jain and Sharma 2001). In addition to being a receiver of industrial effluents, the river waters are used for irrigation, fishing, bathing and washing clothes.

In the river stretch considered for the present study, the industries involved include a sugar refinery that empties on the west bank of Hindon River in Muzaffarangar district; a sugar refinery 26 km before River Kali joins the Hindon River and a paper board factory located in the vicinity of the junction with the Kali River (shown in Figure 1) both in Muzaffarangar district of Uttar Pradesh. In addition to these industries, two domestic waste effluents discharge into River Kali as shown in Figure 1.

Water quality assessments in the recent years have shown Biological Oxygen Demand (BOD) as the dominant parameter in the rivers. The presence of high BOD content in the river waters is indicative of large quantity of organic waste emanating from the waste outfalls An increase in BOD levels decreases the availability of Dissolved Oxygen (DO) in the water since the oxygen that is available in the water gets consumed by the aerobic bacteria in breaking down the organic waste. The depletion of oxygen in water eventually leads to death of fish and other aquatic animals, in addition to the inherent health risk of the organic organisms in the water (Lewis 2007).

3,2. Expression of Model

In terms of systems analysis, any management problem can be viewed in terms of controllable input variables and the river as an individual entity within which changes occur along the course of the river, with the result being changes in the river water quality. The model for the decision making is then formulated in order to determine the minimum treatment levels for factory and domestic effluent so that the desired water quality at given locations in the river can be achieved (Thomann 1974).

In the last three decades, significant efforts have been made by number of researchers to employ a system analysis approach and have developed various optimization models for water quality management coupled with simulation models. These include linear programming (Cho et al. 2003; Cho et al. 2004), non linear programming (Bishop and Grenney 1976), integer programming (Burn 1989; Jolma et. al. 1997); dynamic programming (Marchi et al. 1999), and fuzzy based optimization models (Sasikumar and Mujumdar 1998; Mujumdar and Sasikumar 2002; Mujumdar and Vemula 2004). These techniques have been invariably used to determine the most optimal allocation of waste loads in the form of effluent from point sources.

In the present study, a Mixed Integer Linear Programming Model (MILP) has been formulated, which can allocate the waste load reduction in proportion to the contribution made by each point source. One of the greatest strengths of the MILP model is that it allows for the creation of a decision space for a regulatory authority, from which the most feasible treatment options can be selected for a particular waste point source, and hence the model can be used as a decision support tool. Developments of such tools are being encouraged for sustainable management of polluted rivers of India (Subramanian 2002). The commitment to the decision maker in providing a decision space thus remained the objective behind formulating a MILP for study area (Babbar et. al. 2009).

The formulation of the model has been adopted from the seminal work of Loucks et al. (1981) in which states that, provided that various combinations of types of treatment and their efficiencies for particular point source are available, a model can be developed with the following two types of constraints: a policy and a water quality constraint.

The *policy constraint* is defined as:

$$W_i^C\left(1 - P_k^C Z_k\right) + W_i^N\left(1 - P_k^N Z_k\right) \le BOD_i^{\max} \qquad (1)$$

where, W_i^C and W_i^N is the raw concentration of carbonaceous form of BOD and nitrogenous form of BOD respectively produced at each waste/point source site *i* in mg/l; P_{ik}^C and P_{ik}^N is the fraction of Carbonaceous BOD (CBOD) and Nitrogenous BOD (NBOD) removal due to *k* number of feasible treatment options; Z_{ik} is an integer representing a value of either 1 or 0 depending whether a particular treatment option gives feasible result or not; $BOD_i^{\max}$ is the maximum concentration of BOD (sum total of CBOD and NBOD) to which each point source discharge *i* should reduce by means of *k* treatment options.

This constraint defines the water pollution control policy, in the form of effluent standards, derived by a regulatory authority and monitored by the appropriate governmental agency. The control is exercised on point source discharges which produce waste that is nitrogenous and carbonaceous in nature. Given the various waste treatment options (*k*), the one treatment option that reduces the raw concentration to the extent of effluent standards for BOD ($BOD_i^{\max}$), for a particular waste site *i*, is defined as a feasible solution of Eq. 1 and the value of Z_{ik} is then 1.

The *water quality constraint* is defined as:

$$\sum_i C_{ji}\left(P_k^C + P_k^N\right) \ge \Delta c_j \qquad (2a)$$

and $\Delta c_j = c_{\min} - c_{\alpha}$ (2b)

Such that,

$$\Delta c_j \ge 0 \qquad (3)$$

Where C_{ji} is the coefficient of a steady state transfer matrix, derived from water quality modeling of the river under consideration; $c_{\min}$ is the minimum DO required for river reach *j*; and c_{α} is the present DO level in the same reach such that Δc_j is the increment of DO which must be provided to meet $c_{\min}$.

The objective function is defined as a function that minimizes the sum of the treatment options, assuming minimum treatment efficiency is related to the minimum cost of treatment. This is given as,

$$\text{Minimize } \sum_k \left(P_{ik}^C + P_k^N\right) Z_k \qquad (4)$$

The above formulated optimization problem can be easily executed with any commercially available optimization package such as LINDO (LINDO Systems, 2002).

3.3. Model Application

The above model was configured for the two rivers under study. The determination of the values used for including the treatment options (*k*) and their efficiencies in terms of CBOD fraction removal (P_{ik}), effluent standards ($BOD_i^{\max}$), minimum DO required for river reach ($c_{\min}$) and a steady state transfer matrix is described in the following section.

A general approach to managing water quality may take various forms depending upon the feasibility of the type of the management option in terms of source of pollution, time variability, social and economic factors. The options may include treatment and/or control of the effluent at the source, transportation of the effluent either prior to or following some treatment through an isolated channel or pipeline, to a more advantageous place on the stream, in-stream treatment (such as artificial aeration of the river) or flow augmentation (further diluting the concentration of the effluent). Since in the Indian context, the expedient approach to managing water quality remains the control of pollution at its source, a collection of the most prevalent secondary treatment options (*k*) in India was made, and provided in Table 1. The efficiencies of these options in terms of CBOD reduction (P_{ik}) are different for different point source discharges and were directly used as one of the model variable. These values are based on performance of each treatment options in Indian conditions, and are likely to vary for other places.

Effluent standards represent the upper limit of the policy constraint defined in Eq. 1. These standards impose a limit to the maximum allowable constituent concentrations (here CBOD) in the waste discharge of the industrial sources of pollution. The MINAS levels for selective industries including those operating in the study area are included as constraints and are given in Table 2. The upper limit for CBOD waste load reduction of domestic waste water effluent, was taken as 30 mg/l as per Indian Standards.

The decision on the water quality criteria as a constraint required specification of both the existing water quality class and desired water quality class. This would then define the water quality criterion, in terms of DO that should always be met by controlling the point source discharges into the river as given in Eq. 2 a & 2b. In this study it was adopted

Table 1: *BOD (%) Reduction for commonly adopted waste treatment options in India*

Level of Treatment	Treatment Options (k)	Type of point sources in the study area		
		Municipal Drain	Sugar Mill Waste	Paper Mill Waste
Secondary Treatment	Activated Sludge Process	80- 90	93-98	93- 96
	Upflow anaerobic Sludge Blanket Process (UASB)	85- 90 (with lagoons) 90- 95 (with Fluidized Anaerobic Bio Reactor (FABR))	95-98 (with extended aeration) 96- 99 (with FABR)	95- 96 (with extended aeration) 96- 97 (with FABR)
	Bio Filtration	91- 92	96 - 99	96- 97
Tertiary Treatment	Clari-Flocculation	90- 95	90 - 95	90- 95
	Tube/Plate Settler	90- 95	90- 95	90- 95

Table 2: *MINAS levels for some typical effluents discharging into water bodies*

Type of Industry	MINAS level in terms of effluents standards for BOD(mg/l)
*Sugar Industry	30
*Small Paper and Pulp Industry	50
Distilleries	100
Synthetic Fiber Industries	30
Oil Refineries	15

**Operative industries discharging into the study stretch*
(Source: Mahajan, 2002)

from the concept of designated water use described by Central Pollution Control Board (CPCB 1989) under Water (Prevention and Control of Pollution) Act, 1974 for the purpose of managing river water quality in India. According to this concept, out of several uses a water body is put to, the use which demands highest quality of water is termed as *designated best use*. The rivers in India are then assigned classes from A to E, with class A river being the best water quality and governed by the most stringent water quality criterion. Class E describes a river having the worst water quality that can be upgraded to Class D only if certain parameters such as pH, DO and free Ammonia, are controlled within limits 6.5-8.5, 4 mg/l or more and 1.2 mg/l respectively (CPCB, 2002). In the same classification system of Indian rivers, the two rivers examined in the present study fall in Class E category. Any attempt to manage the water quality of the two rivers, therefore, would require improving existing DO levels to values equal to 4 mg/l or higher. Hence the water quality goal as defined in Eq. 2 is an expression of minimum treatment levels for CBOD reductions so as to obtain desired levels of DO improvements at various downstream locations, if only CBOD is considered as the controlling parameter to manage resulting DO. Therefore, with a desired value of DO level defined as say 4 mg/l or higher, it will be possible to find out what is the maximum possible reduction in CBOD that would solve the inequality defined in the Eq.2.

The coefficients of transfer matrix were developed from a modeling study done on the two rivers. QUAL2E, a steady state water quality model was calibrated and validated for the Hindon (105 km length) and Kali (86 km length) rivers under study. The model is a popular model in the stream of water quality management, its applications are varied and manifold both as a simulation and planning model and are very well suited to slow moving rivers as the two rivers under study. As a pre requisite to running the QUAL2E model, the river(s) were divided into reaches of hydraulic homogeneity (Brown and Barnwell, 1989). In addition to this, a division was made such that every waste point outfall, if any, was situated at the beginning of the reach. This way it was possible to relate the potential of every waste outfall in terms of CBOD with the resulting DO downstream of the respected reach whenever simulation of the reaches was done using the QUAL2E software.

While conducting the modeling study, due care was taken to configure the model for study area. The major point sources to the Hindon River include: a sugar factory industrial effluent and an un-simulated tributary while two domestic discharges and two industrial discharges, a sugar factory and paper board factory discharges into Kali. These were monitored at various monitoring stations shown in Fig 1 and pollution and hydraulic loads were estimated. Two different sets of field data were collected for the purpose of calibration and validation process. The water quality constituents modeled included DO, BOD and nitrogen components (such as ammonical nitrogen and nitrates). The calibration process included fine tuning of the model with various computed coefficient values. These coefficients defined mathematical relationships? for modeled constituents such as the deoxygenation rate coefficient, reaeration coefficient, sediment oxygen demand for finding net available DO at each computational element of the reach. The model was said to be calibrated when a good agreement was obtained between the predicted and field observed concentration values, at various monitoring stations on the river reaches, of the modeled constituents. The coefficients that gave good agreement statistically were used for validation of the model. The statistical tests included correlation coefficient, RMSE and measure of model agreement, W Index. The values obtained for DO parameter were 0.98, 1.16, 0.93 mg/l and 0.98, 0.86, 0.98 mg/l for Hindon and Kali respectively. Similarly for the BOD parameter, the values obtained were 1, 0.81, 1 mg/l and 1, 0.5, 1 mg/l for Hindon and Kali respectively. The data set chosen for the purpose of validation was collected during the minimum low periods so that extreme water quality conditions were accounted for while testing the robustness of the model. Successful model run was indicated from the visual interpretations of the validation plots for the two rivers as shown in Figure 2. A good match was found between the observed and the predicted values, although DO tended to be overestimated in the model for both rivers when lower BOD conditions prevailed in the river (Figure. 2).

A transfer matrix was then constituted as a column wise array of water quality responses for the data observed during validation process. The water quality response was in terms of DO in all reaches downstream due to an effluent discharge (loading) at the beginning of each reach. An important interpreta-

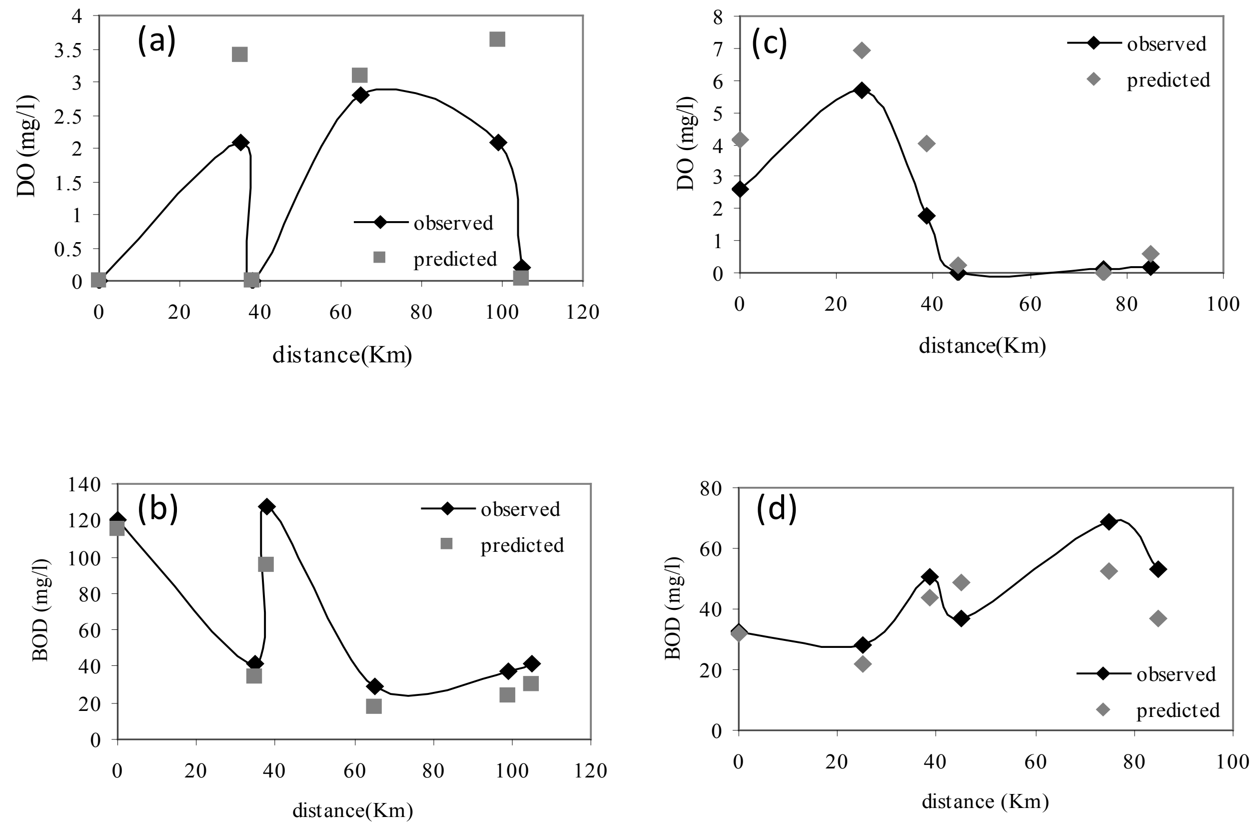

Figure 2: *Validation plots for (a) to (b) Hindon and (c) to(d) Kali river*

tion of transfer matrix was that the array indicated DO increases due to removal of point source loads; hence was useful in evaluating the control limit on waste input for desired water DO response.

The optimization model in itself is, however, not validated for the study river reaches but derives information from a validated QUAL2E model. Since the variables describing the optimization model are defined by water quality criteria, effluent standards and the transfer matrix coefficients derived from the QUAL2E model, different management scenarios can be developed using MILP optimization model from which the user can use to make a decision towards choosing the best alternative in terms of treatment of the effluent.

4. Result And Discussions

Various scenarios of water quality improvement in the river system under study were performed to identify and determine the best treatment options, which satisfy the optimization parameters described above. The predictive capabilities of QUAL2E model were utilized in simulating each of these optimal treatment options, and visualizing the impact of the decision.

In the availability of present water quality status of the two rivers under study; the CPCB categorizes the two rivers into Class E, meaning thereby that the water quality of the river is suitable only for purposes like industrial cooling and controlled waste water disposal. Not many years back, the same stretch under consideration was designated as Class D suitable for propagation of fisheries (Singhal 2003).

The scenarios were thus developed for two cases that showed a need for regulating effluent into the two rivers for (1) maintaining minimum water quality such that the present water use is not impaired, and (2) fulfilling the water quality criteria so that the two rivers can be re-classified to higher class (Class D in this case), assuming that no treatment has been given to any point source.

For scenario 1, it was desired that minimum DO available everywhere in the rivers was at least 2 mg/l. This minimum value is desired for propagation of certain species of fish that are a source of livelihood in the area. With this water quality criterion, the optimization model was run with the prevalent secondary level treatment options in India (Table 1) as integer variables. It was observed that Upflow Anaerobic Sludge Blanket Process (UASB) followed with lagoons for municipal effluent and UASB followed by extended aeration for industrial effluent remained the minimum treatment levels satisfying the optimal criteria as worked out in Table 3. For the corresponding reductions in the BOD parameter at source, an improvement in DO is observed as shown in Figure 3. The foreseen reduction values improve the anoxic conditions of the river in an overall effect. The technology of UASB is well adapted to the tropical climate of India and if adopted can increase the DO shown in Figure 3 without the need of going for advanced treatment methods such as biofiltration.

In scenario 2, it was desired that minimum DO available everywhere in the rivers was atleast 4 mg/l. This minimum value is the water quality criteria for a river to be classified as Class D category. For this criterion, variations in the feasible treatment options were used for wastewater effluent, while the same treatment as in scenario 1, considered for industrial effluent (Table 3). Given economic considerations, this is a compromise between the benefits and capital cost for this set of treatment technologies, which can put the river into Class D. Using this scenario, the model predicts that the goal will be achieved using these treatment solutions (Fig. 4). However, it was observed that the CBOD and hence DO available at reaches upstream of point outfalls remain unattended as shown in Figure 5. This is also shown in the model for the available BOD, which is seen to decrease consistently downstream under the chosen treatment conditions (Fig. 5). This is because the QUAL2E model assumes a steady input of BOD from headwaters and point source outfalls assigned for the present study only. In the event of new industries and their effluents, the QUAL2E model will have to be re-run for the new point source inputs. This will further create new conditions for available DO in rivers and determine the need of managing the waste inputs (existing and newly added now) for fulfilling the optimality criteria as defined in the optimization model.

Paucity of field data needed for running a data intensive water quality model such as QUAL2E is often one of the reasons as to why a rational choice using optimization is not made between the available treatment options for an industry, although effluent standards are all well documented. The description of the optimization model above is only a procedure for evaluating available treatment options constrained with the effluent standards, given the QUAL2E model inputs that are water quality and flow data of the river headwaters and point sources at various locations on the two rivers.

Table 3: *The optimal % BOD reductions for different point sources*

River	Type of Point Source (in distance from headwaters)	Obs. CBOD mg/l)	Scenario 1			Scenario 2		
Hindon			Choice 1	Choice 2	Choice 3	Choice 1	Choice 2	Choice 3
	Sugar Mill (37 km)	423	21.1	21.1	16.9	21.1	16.9	12.7
Kali	Municipal Drain (38 km)	200	30.0	20.0	10.0	10	10	10
	Municipal Drain (40 km)	197	29.6	19.7	9.85	9.85	9.85	9.85
	Paper Board (48 km)	540	27.0	27.0	21.6	27	21.6	16.2
	Sugar Mill (52 km)	601	24.0	24.0	24.0	24.0	24.0	18.0

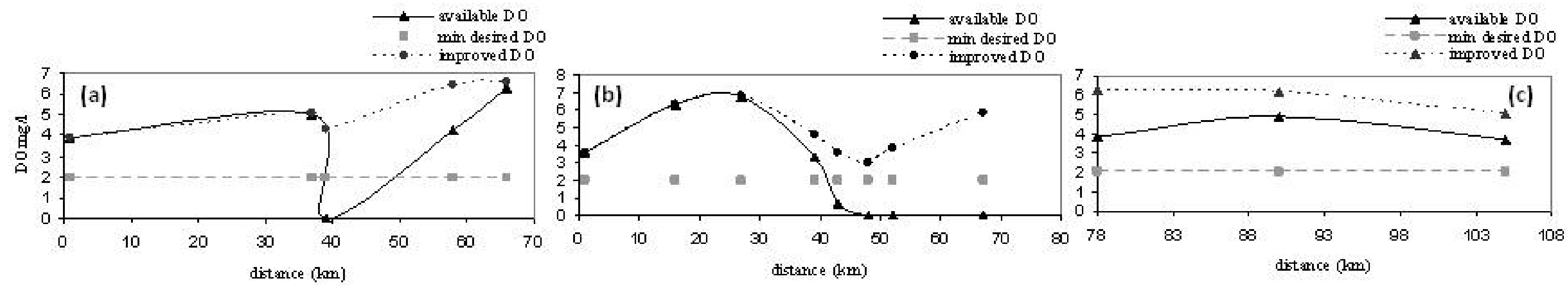

Figure 3: Scenario 1: Improvement in DO along the rivers profile (a) Hindon (b) Kali and (c) Hindon after confluence

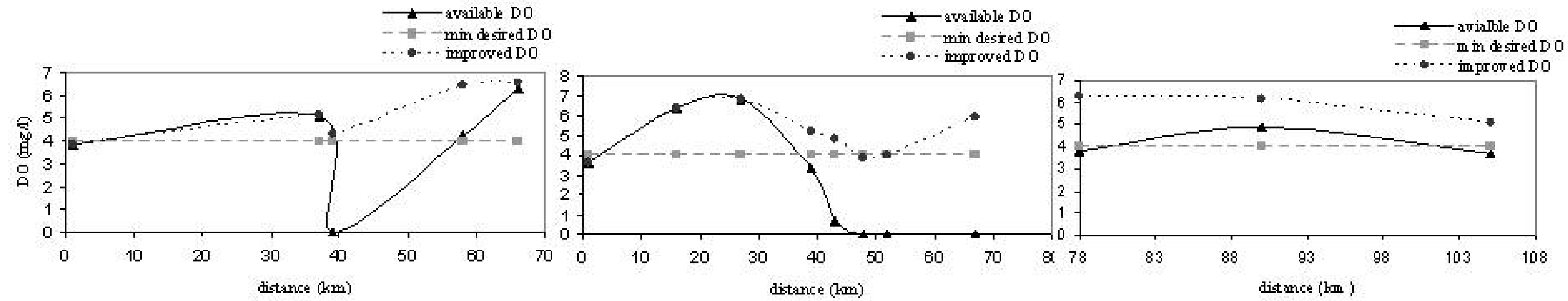

Figure 4: Scenario 2: Improvement of DO along the rivers profile (a) Hindon (b) Kali and (c) Hindon after confluence

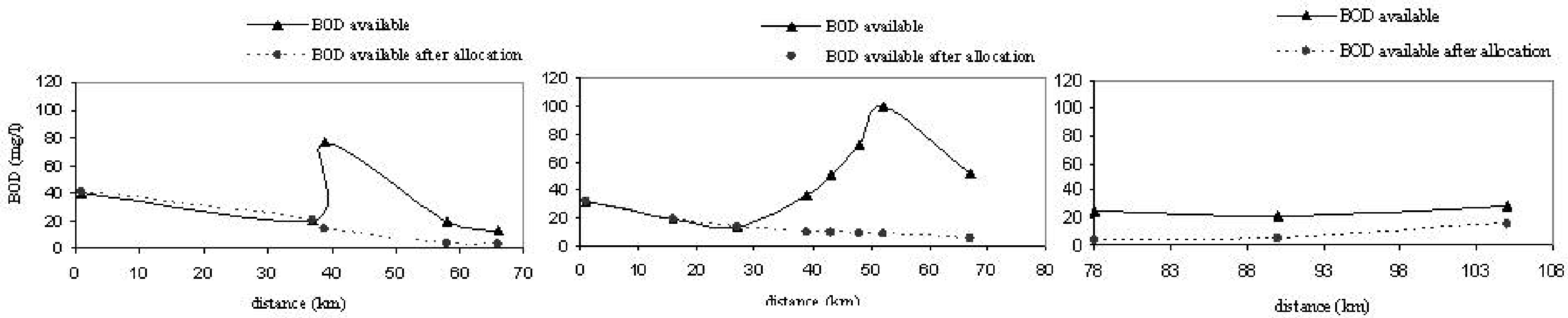

Figure 5: Scenario 2: BOD reduction along the rivers profile (a) Hindon (b) Kali and (c) Hindon after confluence

5. Conclusions

Selection of wastewater treatment methods for maintaining water quality downstream of point outfalls suffers limitations in terms of realistic requirements of water quality improvement. Treatment at source, as a viable pollution control measure, may not always be advocated. This may be due to a simple lack of awareness or mere economics. Industries remain unaffected by the prevailing legislative norms of pollution control, thus seriously impairing the river water use.

In India, where treatment at source is considered to be the most important and expedient approach to pollution control, there is a need of formulating a procedure for identifying only those treatment options that are able to achieve MINAS for a particular industry. With MINAS being an effluent standard, it is mandatory for every industry to treat their waste up to a minimum level in terms of water quality parameters before disposal into the rivers. If every industry is able to achieve these standards, the rivers in India will be able to sustain its quality given the continued growth of industries in India.

In the present attempt, an approach to water quality management in India was suggested. A mixed integer linear programming optimization technique was formulated for Indian conditions, it allowed the inclusion of effluent treatment options as a decision variable satisfying minimum treatment level, desired water quality criteria and effluent standards. The model was exemplified for pollution impaired Hindon river system in Uttar Pradesh district of India. In its present form the optimization model has not been validated for the study reach but derives information from a QUAL2E model that has been configured and verified for the worst water quality conditions that are likely to occur in the study area and hence the decision space created by the MILP model can be assumed to corroborate with the actual field conditions.

The optimization criteria apportioned the treatment levels to different point sources in proportion to their contribution in the available DO levels and maximum allowable BOD reduction at the source. In an overall sense, the model was able to indicate whether chosen treatment method for various point source discharges could help the river achieve a minimum water quality standard with respect to BOD and DO.

Presently, the water quality status of the Hindon river falls in the Class E category of Indian river classification based on water quality. This classification describes the river as unsuitable for any use except controlled industrial and municipal effluent, irrigation and industrial cooling. Therefore water quality criteria meant to be protected under this class include only those parameters that are crucial for maintaining irrigation water quality viz., Electrical Conductivity, Boron, and Sodium Absorption Ratio (SAR). Hence in absence of any information on the desired water quality criteria for DO as a parameter, the optimization model, described here, could be utilized to analyze for desired improvement in terms of DO as an output parameter and CBOD and NBOD as controlling parameter. This would help improve the decision making for managing the water quality of the river for additional water uses such as human consumption and fish. It may be pointed out that fish catch is one of the means of livelihood of the local villagers that has been seriously affected by the increasing pollution in the river. On the other hand, high loading of biodegradable waste has resulted into serious source of vectors such as fecal pathogens and mosquitoes jeopardizing with the health of local community.

Hence it may be concluded that exercising control on the waste water discharges, subject to MINAS effluent standards, will help in desired improvement of water quality for the sustainability of water uses that are directly related to the well being of local community. Treatment at source is one option of water quality management of rivers and MINAS manages this option, exercising control on industrial discharges subject to techno-economic feasibility of the extent of maximum control defined for each industry. If, in any case, the situation warrants improvement in rivers beyond what is possible through the control of effluent only, then other options such as instream aeration or flow augmentation will also have to be considered. Since the present condition of Indian rivers shows major deterioration in quality due to partially or untreated waste waters hence enforcing effluent standards seem to be one of the most viable solutions.

References

Babbar, R., Arya, D.S., and Joshi, H. (2009). A Proposed Decision Support System for River Water Quality Management in India. *Journal of Decision Support Systems*, Vol. 18(4), pp. 411-427.

Bishop, A. B., and Grenny, W.J. (1976). Coupled optimization-simulation water quality model. *Journal of Environmental Engineering Division*, Vol. 102(5), pp. 1071-1086.

Brown, L. C. and Barnwell, T.O., Jr. (1987). The Enhanced Stream Water Quality Models QUAL2E and QUAL2E-UNCAS Documentation and Users Manual, U.S.EPA /600/3-87/007. U.S. Environmental Protection Agency, Athens 1987.

Burn, H. D. (1989). Water-quality management through combined simulation-optimization approach. *Journal of Environmental Engineerin,* Vol. 115(5), pp. 1011-1024.

Cho, J .H., Ahn, K. H., Chung, W. J., and Gwon, E.M. (2003). Waste Load Allocation for water quality management of a heavily polluted river using linear programming. *Water Science and Technology*, Vol. 48(10), pp.185-190.

Cho, J. H., Sung, K. S., Ha, S. R. (2004). A river water quality management model for optimizing regional wastewater treatment using genetic algorithm. *Journal of Environmental Management,* Vol. 73, pp. 229-242.

CPCB (Central Pollution Control Board) (1989). Pollution Control Acts and Rules with Amendments. Pollution Control Law Series (PCLS): PCL/1/1989, New Delhi.

CPCB (Central Pollution Control Board) (1995). An Inventory of Major Polluting Industries in the Ganga Basin and their Pollution Control Status. Programme Objective Series: PROBES/65/1995-1996, New Delhi, India.

CPCB (Central Pollution Control Board) (1996). Rationale in Evolution of Standards for Industrial Effluents and Emissions. Programme Objective Series: PROBES/67/1996-97, New Delhi.

CPCB (Central Pollution Control Board) (2002). Assessment of Industrial Pollution Programme Objective Series: PROBES/92/2002-2003, New Delhi, India.

Ghosh, N. C., and McBean, E. A. (1998). Water quality modeling of the Kali River. *Water, Air, and Soil Pollution*, Vol. 102, pp. 91-103.

Jain, C.K. and Sharma, M.K. (2001). Distribution of trace metals in the Hindon River system, India. *Journal of Hydrology,* Vol. 253, pp.81-90.

Jolma A., De Marchi, C., Smith, M., Perera, B. J. C., and Somlyody, L. (1997). STREAMPLAN: A support system for water quality management on a river basin scale. *Environmental Modelling &Software*, Vol. 12(4), pp. 275-284.

Lewis, H. (2007). Hindon River: Gasping for Breath. *Janhit Foundation Publications*, Meerut, Uttar Pradesh, India.

LINDO System, Inc. Optimization Software (version 6.1) (2002): Integer Programming, Linear Programming, Nonlinear Programming, Stochastic Programming, Global Optimization. Lindo Systems, Chicago, Illinois.

Lokesh, K.S. (1996). Studies of Heavy Metals in water and sediment of Hindon River, PhD Thesis, Department of Civil Engineering, University of Roorkee, Roorkee, India.

Loucks, D.P., Stedinger, J.R., and Haith, D.A. (1981). Water Resource Systems Planning and Analysis. Prentice Hall, Inc., Englewood Cliffs, New Jersey.

Mahajan, S.P. (2002). Pollution Control in Process Industries. Tata McGraw-Hill, New Delhi.

Marchi, D.C., Ivanov, P., Jolma A., Masliev, I., Smith, M.G. and Somlyody, L. (1999). Innovative Tools for water quality management and policy analysis: DESERT and STREAMPLAN. *Water Science and Technology.* Vol. 40(10), pp. 103-110.

Mujumdar, P.P., and Sasikumar, K. (2002). A fuzzy risk approach for seasonal water quality management of a river system. *Water Resources Research,* Vol. 38(1), pp. 1-9.

Mujumdar, P.P., and Vemula, S.V.R. (2004). Fuzzy Waste load allocation model: Simulation-Optimization Approach. *Journal of Computing in Civil Engineering,* Vol. 18(2), pp. 120-131.

Sasikumar, K., and Mujumdar, P.P. (2002). Fuzzy optimization model for water quality management of a river system. *Journal of Water Resources Planning and Management*, Vol. 124(2), pp. 79-88.

Subramanian, S. India: Assessment (2002). Water Supply and Sanitation. A WHO-UNICEF Sponsored study. Government of India, http:// www. planningcommission. co. nic. in (last accessed 16 November, 2010), India.

Thomann, R.V. (1974). Systems Analysis and Water Quality Management, McGraw-Hill Company, USA 1974.