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A Proposed Decision Support System for River Water Quality Management in India

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ABSTRACT. *The growing concern for river water pollution in India is witnessing several initiatives from nodal agencies in terms of water pollution control. In a similar context, a need for a supportive platform is envisaged that takes care of management perspectives, feasible for Indian conditions. In this paper the most generic DSS has been proposed that caters to the requirement of regulatory authorities. In its prototype scale of application to improving water quality, at user defined water quality criterion, the system is capable of allocating waste loads to point sources, while liberating the user from writing the input files for simulation and management models. The system is designed for PC-Windows environment with minimal system requirements in terms of models viz., QUAL2E water quality model and LINDO optimizing package, interfaced using SQL Server 2000 Data base Management System. While the most expedient approach of treatment at source towards water quality management in India was addressed by the system, the example run of the DSS indicated a need of including other management options for comprehensive quality management.*

RÉSUMÉ. *Les inquiétudes croissantes dans le domaine de la qualité des eaux en Inde ont suscité un certain nombre d'initiatives pour le contrôle de la pollution. Pour assurer l'efficacité de ces initiatives, la présence d'une plateforme commune qui sous-tend les activités des décideurs est importante. Dans cet article, nous proposons un système d'aide à la décision pour les autorités en charge de la qualité des eaux. Notre prototype permet de faire une allocation des volumes des eaux sales précise, à l'aide de modèles de simulation. Le système fonctionne sous Windows avec une base de données SQL Server 2000. Les essais réalisés avec notre prototype montrent que notre application permet de résoudre les problèmes les plus immédiats, mais que d'autres solutions complémentaires seront nécessaires pour un management intégral de la qualité des eaux.*

KEYWORDS: *Water Use, Mixed Integer Linear Programming, Water Quality Criteria, Decision Support System.*

MOTS-CLÉS : *utilisation des eaux, programmation linéaire, critères de qualité des eaux, aide à la décision.*

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1. Introduction

Water quality management in India is promulgated under Water Act, 1974 (Prevention and Control of pollution) passed by the Indian Parliament. The Central Pollution Control Board (CPCB) together with State Pollution Control Board (SPCB), under the provision of this act, lays out standards for the treatment of sewage and effluents for the prevention and control of water pollution in India. *Designated best use* developed by CPCB under the act, dictates the use based classification of river bodies such that the best use is reflected in five water classes from A,B,C,D and E (CPCB 1989, 1996). However, even with strong legislative provisions such as the Water Act, the untreated or partly treated waste discharged into natural drains is quite voluminous having a detrimental effect on the quality of life of the inhabitants, and the quality of water bodies (Subramanian, 2002). The routine monitoring activities of several government agencies including CPCB and SPCB have indicated that organic loading in terms of Biochemical Oxygen Demand (BOD), and bacterial population in terms of Coliform count continue to be the critical sources of pollution in Indian aquatic resources (Singhal, 2003; Bhardwaj, 2005).

The inadequacy of the authorities in abating water pollution is expressed in a fragmented approach towards data collection and utilization of data for pollution control, information gaps on effluent discharge patterns, and lack of available published data. In view of the above shortcomings, a need for a supportive framework is envisaged that integrates the data collection and analysis and planning tools for an overall management of river water quality (Subramanian, 2002).

In this paper, a Decision Support System (DSS) is described as a tool that attempts to bring the needs of water quality management under a single platform. The system was developed for Hindon river system comprising of three main rivers namely River Hindon (Principal River), River Kali (tributary) and River Krishni (also a tributary) flowing through the state of Uttar Pradesh in Northern India. Each of these rivers is serving the minimum needs of human settlement such as fishing, washing clothes, irrigation, and animal bathing; while actively serving as a free flowing drain to number of industries located in its vicinity.

DSS in water quality management

Recent advances in computer technology, coupled with the myriad needs of water quality management have seen proliferations of number of computer based decision support systems in the literature. Factors such as massive data requirement, need of models, and need of human intervention have accredited the role of DSS in the field of water quality management (Gauriso and Werthner, 1989).The role of DSS, thus lies in its capability to tackle problems that require decision support by way of creating an integrated and interactive environment for the decision makers, while dealing with databases and models through user interface. Hypertejo (Camara *et al*., 1990); LOADSS (Negahban *et al*., 1995); DESERT (Ivanov *et al*., 1996); WATERSHEDSS (Osmond *et al*., 1997); WARMF (Chen *et al*., 1999); GIBSI (Rousseau *et al*., 2000); Elbe-DSS (Berlekamp *et al*., 2007) are few of the available DSS. All these systems represent a spatial data environment, integrated with number of simulation models for management perspectives.

Where fulfillment of user needs in a supportive, single platform of DSS has seen advancements in its structure including expert system approach, the concept of DSS is still at an infancy stage in India, having only limited field applications. GIS integrated DSSs have been developed in selected sectors of rural development such as water management (Raman *et al.*, 1992; Gosain and Rao, 2008), land/ land use planning (Sharma *et al*., 2006; Adinarayana, 2008; Basu, 2008) and energy budgeting (Ramachandra *et al*., 2005; Banerjee, 2008) only.

Factors such as adaptability, applicability and data requirements of complex models have limited the use of available DSS for managing water quality in India. On the other hand, little effort has been expended in developing DSS based on water quality management perspectives within India, because of limited importance given to interface mechanism between suites of models in the DSS literature, thus restricting its development.

The present work was thus envisaged to utilize the concept in developing most generic DSS, guided by the following basic understanding of pollution control in India.

– What was the most expedient approach to water pollution control in India?

– What is, in general, the criterion of fixing water quality standards?

– What is the existing water quality criteria for the river system under study, and

– Who would be the user of the system and how could his requirements be met from the integrated system that was envisaged?

The present paper objectively attempts to describe the developed DSS as (1) an integrated system with special reference to the interface mechanism that binds its components, and (2) catering to the User needs of handling water quality management problem with a relative ease.

2. Methodology

The architecture of the perceived DSS was conceptualized within the framework as pioneered by Sprague and Carlson (1982). The architecture, as shown in Figure 1, displays the arrangement of its components, their interrelationships and relationships with the outside world.

The data management behaves as the central component that is invoked at the User's interests in interfacing with the models for decision support. The two kinds of models included are descriptive model, which is a simulation model and a decision model, which is an optimization model. Both these models complement each other by way of sufficing each others requirements *i.e.*, simulation and evaluation of an optimal solution respectively.

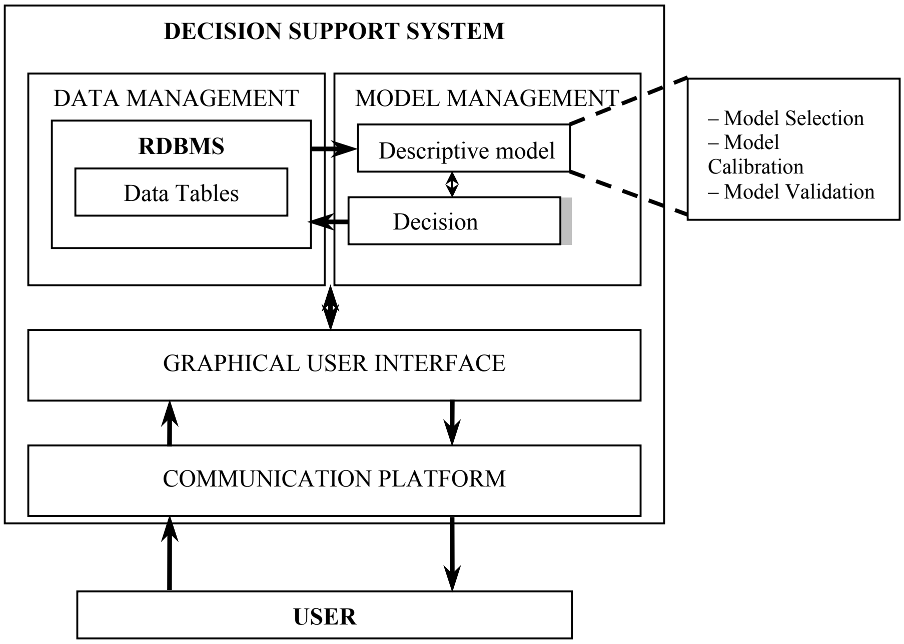


Figure 1. *Adopted methodology for DSS*

The selection of a descriptive model, however, remained one of the challenges. A proper enumeration of available alternatives, as well, there likely scope of inclusion in the modeling component was considered at this stage. QUAL2E, as a steady state receiving water quality model was selected as against a dynamic model or watershed scale model because of limited data resources available, as is normally the case with Indian rivers. This model was, however, calibrated and validated before its inclusion in the modeling component of DSS.

The role of a mixed integer linear programming optimizing model was considered fit in generating a decision space, thus optimally supporting a User's decision in predicting the desired water quality improvement. The popularity of LINDO as an optimizing software package was utilized in writing and executing an optimization model, however as with QUAL2E model, it also required a mechanism that would liberate the user from the difficulty of writing the input files of the model.

In doing so, a relational database development was therefore conceived that would centrally facilitate the interaction of the user with the models through a constructive Graphical User Interface (GUI). This was also designed in a fashion that the database inherited dynamism so as to allow the resetting of data sets, each time a new request was made by the User.

3. Application area

The study area taken for a prototype application of DSS is a grossly polluted stretch of two rivers, draining economically self sufficient districts of Uttar Pradesh in Northern India. The dendritic river system bounded between 29^0 and $30^015'$ north latitude and $77^015'$ and 78^0 east longitudes (Figure 1) comprises of Hindon as a main river and Kali river (West) as its tributary, flowing in south western direction till it finally submerges into mighty Yamuna.

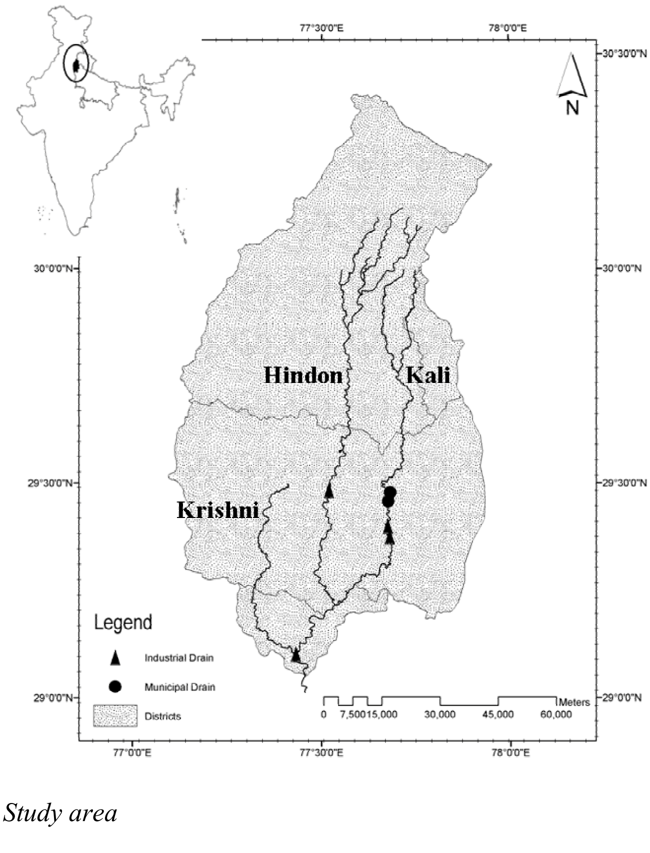


Figure 2. *Study area*

Known as sugar bowl of India, the state of Uttar Pradesh is populated with number of sugar industries, paper industries and other agro based industries; all dependent on abundantly grown sugar cane as raw material in the region. Few of these industries are located in close vicinity of the two rivers under study. Therefore these industries are utilizing the rivers as drains for discharge of high concentration of biodegradable pollutants. It was observed that the water quality situation worsened during lean seasons, when low flows predominate and effluents continue to discharge at the same rate, and also because of the fact that the operative time of the industries coincided with the lean flows *i.e.* October to June in the river system.

The river system fouls due to strong aromatic effluents, observed with rich soapy and frothy appearances that are almost blackish in color, at the outfall sites during this time. In addition to these industrial drains, two municipal drains also contribute to the water quality degradation in selected stretch of river waters.

Based on its routine analysis of water quality parameters at various stations, CPCB has designated Class E as the existing class of the Hindon River System up to its confluence with River Yamuna. It is worth noting that the existing class of the river system has pathetically fallen from Class D to Class E in the recent years (CPCB, 2003).

4. Integrated role of DSS components

Based upon the scope and the requirements to be met from the overall system, an interface mechanism was developed in Microsoft Visual Basic 6 (VB) environment. The selection was made after careful exploration of the alternate data connectivity mechanisms, basic input/ output file structure of the models and the user needs envisaged, as described below.

4.1. *Data management*

For a Microsoft based windows application Microsoft SQL Server 2000, a client server Relational Database Management System (RDBMS) was selected to design, query, update and retrieve the data stored in the tables of the database.

In view of central position that database would hold in the present application, the tables in the database were bifurcated in terms of purpose to be solved by different tables. *Static tables* contained data tables unaffected by the model invocations but allowed the user to update the water quality data, as monitored on several days of the month, for general water quality information. *Dynamic tables* contained tables for which the structure was designed but did not contain any data initially, rather was uploaded only when so desired by the User. These tables thus served as temporary storage for transferring of information to and from the models.

Several options were explored while attempting to interface the database with the VB environment. Microsoft's Universal Data Access (UDA) strategy provides several dynamic library links to configure an interface conveniently. In the present application, the Open Data Base Connectivity (ODBC) was configured with the information of the database as *data source*, and a name to the *driver* or the mechanism that linked the ODBC as *data provider*.

4.2. *Model component*

4.2.1. *Descriptive model*

QUAL2E, as a descriptive model, was selected since this model has been successfully applied to various river systems across the globe, including Indian tropical rivers. The model has a long history of applications as both simulation as well as a planning tool model (Brown and Barnwell, 1987). It was, particularly, found suitable for the study area because of the simplified assumptions underlying the model structure such as steady state simulations and one dimensionality of mass transport equation used in simulation.

The two rivers under study, Hindon and Kali, are small and slow moving rivers flowing under more or less steady state conditions. Smaller widths of the two rivers also eluded the necessity of modeling in more than one dimension, but the length of river. Increased costs associated with increased data requirements of other complex simulation models was, therefore, thought to be unnecessary.

The set procedures of water quality modeling *viz*., calibration, sensitivity check, validation and predicting the robustness of the model for two rivers were performed before its inclusion in the modeling component. Water quality samples were collected from different monitoring sites, as shown in Figure 1, during different seasons of the year 2004-2006. A total of eight stations for Hindon river (105 Km) including one point source and a total of ten stations on Kali river (86 Km) including four point sources were selected for sample collection. The second tributary of Hindon, river Krishni was, however not simulated, and therefore taken as a point source to Hindon river. These stations were selected on the basis of accessibility, major inflows to the rivers, and adequate representation of water quality condition at these stations. The samples were analyzed for water quality parameters such as Dissolved Oxygen (DO), BOD, Ammonia Nitrogen, Organic Nitrogen and Nitrate Nitrogen using Standard Methods of analysis (APHA, 1998). Various model parameters were then deduced from the field collected data to fine tune the model (calibration), so that the model results were in accordance with the observed data. The reader is referred to Brown and Barnwell (1987) for discussion on QUAL2E data requirements and creation of input files.

A sensitivity analysis was performed to identify the uncertain parameters in the calibrated model. During this analysis, a perturbation of the input model parameters was done individually by constant percentage of $\pm 50\%$. The response of perturbations on DO along the two rivers was found to be satisfactory for parameters like nitrogen rate constants, BOD rate coefficient including decay coefficient, settling rate coefficient and reaeration coefficient. Detailed description of the parameters and the performance of the sensitivity analysis are given in Babbar (2008).

Table 1. *Statistical evaluation of model for various water quality parameters*

River	Measure of error evaluation	Water quality parameter			
		DO	BOD	Ammonia-N	Organic Nitrogen
HINDON	RE (%)	44.31	20.1	23.29	27.88
	RMSE	0.82	15.83	0.61	1.58
	r^2	0.91	0.96	0.66	0.67
	W-Index	0.92	0.96	0.87	0.87
KALI	RE (%)	37.86	21.36	19.53	27.38
	RMSE	1.06	11.22	0.97	0.16
	r^2	0.92	0.52	0.98	0.54
	W-Index	0.95	0.81	0.97	0.81

Finally, robustness of the calibrated model was tested by running the model for an independent data set, collected during extreme water quality conditions. These conditions corresponded to minimum low flows as computed for the last 10 years and high water temperatures. Several statistical tests of paired observations: observed and predicted were performed to gain adequate confidence in terms of models performance as a verified simulation model for decision support. The statistical evaluation for different parameters is given in Table 1. It was observed that a high value of relative error (RE) was obtained for DO, however, this high value is generally expected to go up to 65% for small streams (Thomann, 1982). In terms of correlation coefficient (r^2), the model displayed a good correlation for simulations. Finally, a good model agreement between the observed and simulation results was indicative from the estimate of W-index, with two parameters showing a value close to 1.

Given the severity of the two rivers in terms of high BOD loadings, as observed from field data, it was decided to take BOD as the only controlling parameter for managing DO content of the rivers.

4.2.2. *Decision model*

Considering BOD as the controlling input variable and DO as the resulting output water quality variable, the decision problem was formulated based on the prevalent water pollution control activities in India.

The model was formulated so as to determine the minimum treatment levels for BOD at source, so as to obtain desired levels of DO at various locations downstream of point source stations. Of various pollution control options, treatment at source remains the most important and expedient approach adopted in India (CPCB, 1996) and therefore used in formulation here.

For any raw concentration of BOD (W_i) discharged at point source *i,* there is a value P_i as a fraction of waste removed by a treatment option; and in the event of the availability of number of treatment options *k*, an equation can be written as described by Loucks *et al.* (1981).

$$BOD_i = W_i(1 - P_{ik} Z_{ik}) \qquad [1]$$

In terms of inequality, the Equation [1] can be re-written as:

$$W_i(1 - P_{ik} Z_{ik}) \le BOD_{i\max} \qquad [2]$$

Where,

– Z_{ik} is an integer representing whether a particular treatment option is feasible while satisfying other constraints or not.

– $BOD_{i\max}$ represent the maximum allowable concentration of BOD [mg/l], that any point source, *i* can discharge in river waters. CPCB (1996) has prescribed *Mi*nimal *Na*tional *S*tandards (MINAS) for river systems within India. These standards dictate the maximum allowable concentration of BOD, for different type of point source that can be allowed to enter a river. Defined as effluent standards, these values are documented for various industries and were directly adopted here.

Similarly, if minimum DO ($c_{\min}$) content is a desired criteria that is required to be met at all times, then Equations [3a] and [3b] describes the control on waste inputs such that water quality criteria is never violated.

$$\sum_i C_{jHi} P_i \ge \Delta c_{jH} \qquad [3a]$$

and

$$\sum_i C_{jKi} P_i \ge \Delta c_{jK} \qquad [3b]$$

with $\Delta c_{jH} = c_{\min} - c_{av}$, and $\Delta c_{jK} = c_{\min} - c_{av}$

Where,

– C_{jHi} and C_{jKi} are the transfer matrix coefficient for Hindon and Kali rivers. This coefficient represents the DO response due to various waste point sources, downstream of any simulated river. The coefficients are extracted from the QUAL2E model run, after user inputs the observed BOD loadings of waste point source.

– c_{av} is the available DO concentration at any time

– $c_{\min}$ is the minimum DO that should be met at all times for maintaining river water use. This variable is the water quality criteria that are prescribed for different rivers of India by CPCB.

For given set of above constraints, the objective function is defined as:

$$\text{Minimize } \sum_{k} P_{ik} Z_{ik} \qquad [4]$$

The equations used above are standard equations that were modified to incorporate the policy constraint as in Equation [2] and water quality goal constraints as in Equation [3a}] and [3b] for Indian conditions. This general purpose mixed integer linear model can be solved using any optimizing package. In this study, commercially available LINDO optimizing package was used. The selection was mainly guided by its popularity and availability of this package in the Department of Hydrology at Indian Institute of Technology Roorkee (India), where this DSS was developed.

Variables defined for execution of above model are either predefined, such as effluent standards for a particular discharge point (*i*) or, are user defined such as $c_{\min}$. The coefficients such as c_{av}, C_{jHi} and C_{jKi} can be obtained from the QUAL2E run for given data input from the User for two rivers, Hindon and Kali.

4.3. *The Graphical User Interface (GUI)*

The interfacing of the models and database with each other and in turn with the GUI was customized with various controls on the front end of application.

It was found that the type of models *i.e.*, QUAL2E and LINDO build input and output files as text files or sequential files supported by Visual Basic, and therefore could accept the text files, if created by some exterior source. A mechanism was, therefore, developed such that models could be supplied with an input file that was edited or modified externally at the request of the User, given to the model for execution and generated an output that could be interpreted. Visual Basic's commands such as opening a text file in read/output mode for file input/output access and its ability to store information in database and access it with ODBC was conjunctively used to develop interface with the models.

5. Example illustration

The DSS, that was developed, is capable of handling the distinct phases of decision making *i.e.* intelligent, design, choice and implementation phase as illustrated below:

5.1. *Intelligence phase*

At this stage the User, who is a regulatory authority such as CPCB official, identifies the problem of managing point source discharge source limited to effluent standards. Figure 3 displays a window, on the User's request, to identify the point sources to be managed. The window also reveals the user with an option to run the application in a default mode or User defined CBOD values for different point sources. A description about the point source, its location and its characteristics is also highlighted for User's help.

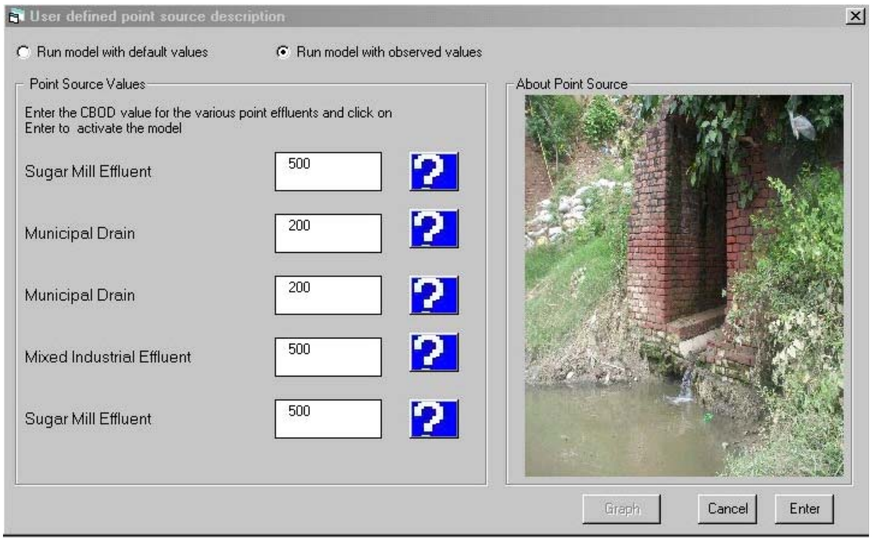
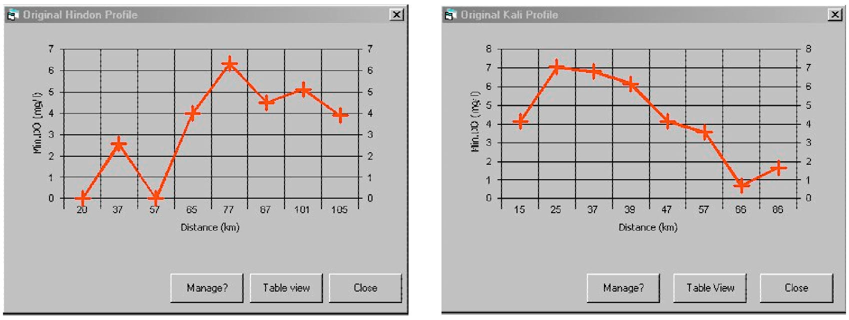


Figure 3. *User input in problem identification*

5.2. *Design or analysis phase*

Here the User provides information for creation of QUAL2E input files and is directed to run the file and generate an output. The output file is then transferred to the database in the *dynamic tables*. The user is then prompted to view the water quality profile for Hindon or Kali River. Shown in Figures 4a and 4b is the observed water quality profile shown in two separate forms.



(a) (b)

Figure 4. *Water quality profile for User observed values of CBOD (a) Hindon, and (b) Kali river*

5.3. *Choice phase*

For the observed water quality profile, the User makes his first choice. This will be whether management is required and if yes, then where and what will be the criteria of management.

A fill-in form opens up in a window, shown in Figure 5, where user sets the water quality criteria for different reaches, individually for Hindon and Kali river in different tabs. For each reach, the DO available, as obtained from QUAL2E output run, is displayed for the user to set the desired DO (shown as 4 mg/l here).

The User provides information in terms of water quality criteria *i.e.* desired DO and type of point source to be managed to the database for determining associated MINAS level and balance DO response required to be managed as variables of decision model. This phase can be described as a design phase for development of decision model. After its execution, the User makes a second choice of evaluating the alternative treatment options that meet the optimality criteria defined by Equation [3].

The list of these alternate treatment options is extracted from the most commonly employed wastewater treatment technologies prevalent in India and stored in the database for different type of point sources. The list, though, exhaustive with regard to conditions in India, can always be extended to incorporate more wastewater treatment options in the database.

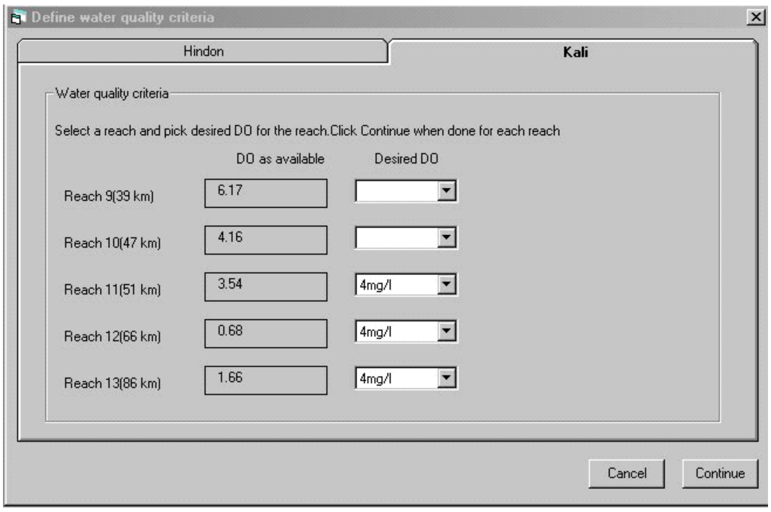


Figure 5. *User defined the water quality criterion*

5.4. *Implementation phase*

This phase has been designed to provide the user with a facility to review the impact of his choice made in the previous step. For the User's choice, QUAL2E model generates an output file corresponding to efficiencies of selected treatment options.

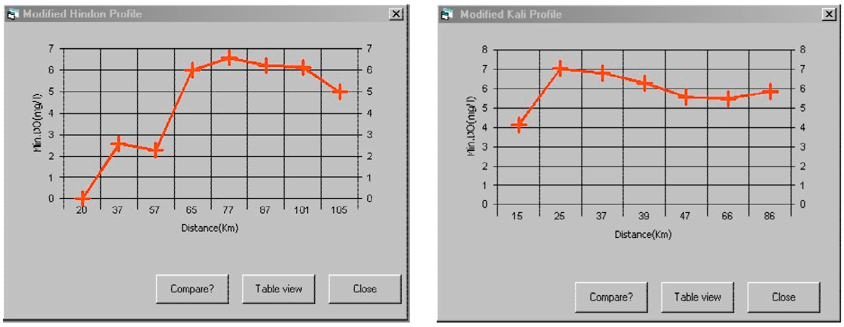
The output file is transferred to the database for the purpose of extractions in a form acceptable to the user and seeks the user requirement to view water quality profile for Hindon or Kali river using option button.

The water quality profile for the Hindon and Kali River for the two situations as obtained is shown in Figure 6a and Figure 6b. The User also has an option to view the situation before and after managing the desired water quality, downstream of point source discharge.

It has been observed that the present DSS application is capable of meeting the requirements of the user for Kali river entirely with the modified graph showing a minimum of 4 mg/l of DO everywhere in the Kali River. However, Hindon river shows only slight improvement in its initial stretches while the condition improves after 37 km from Headwaters, if compared from the original profile (Figure 4b).

It may be noted that the headwaters are under the influence of high organic loads and the incapability of the DSS to manage a river reach without any point source upstream of the reach is highlighted. This necessitates a comprehensive modeling exercise for the rivers under study.

In an overall sense, the water quality situation has improved with the user's managerial decision towards the treatment options, to be adopted for a predefined water quality criterion of 4 mg/l of DO all along the river stretches, a minimum required for upgrading the existing class from Class E to Class D.



(a) (b)

Figure 6. *Managed water quality profile (a) Hindon, and (b) Kali river*

6. Conclusion

The prolific growth of Decision Support System's in the field of water quality management has proved their efficacy in handling the myriad dimensions of such problems. One such system is suggested here for Indian conditions, where need for similar effort is gaining attention.

In its present form, the decision system caters to the water quality improvement in terms of DO with BOD discharge of municipal and industrial drains as the controlling parameter. Water quality can be improved at User's need of maintaining water quality for desired criteria. A regulatory authority was identified as the User of the DSS. QUAL2E and LINDO optimizing model have been interfaced through MS SQL Server database system and a discussion to this interface mechanism was also made.

The system has been exemplified for Hindon and its tributary Kali, flowing through industrially developed state of Uttar Pradesh in India. Sensitivity analysis was performed to ascertain the uncertainty associated with model inputs and model parameters, before the QUAL2E model was incorporated in the modeling component of the system. Statistical techniques were employed to support the robustness of the model prediction in decision making process. In view of large data requirements, the inability to conduct risk associated decision making process restricted the study to simple statistical techniques in its present form.

Since a calibrated model was required for inclusion in modeling component, therefore, in the present form the proposed system runs only for Hindon river system but the mechanism of interface can be adopted for any river system in India.

The limitations that have been felt at the first stage development of this system are still being worked out. This include the necessity to add a spatial component such as integrating with GIS software and secondly, inclusion of alternate management options such as flow augmentation and instream aeration at point of discharge for a situation, when water quality criteria is not met but the discharge outlets are respecting the effluent standards.

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