Nature Environment and Pollution Technology
An International Quarterly Scientific Journal | ISSN: 0972-6268 | Vol. 12 | No. 3 | pp. 511-516 | 2013

Original Research Paper

Water Quality Modelling of a Stretch of River Kshipra (India)

R. C. Gupta, Ajay K. Gupta* and R .K. Shrivastava**
Department of Civil Engineering, Govt. Polytechnic College, Ujjain, M.P., India
*Department of Civil Engineering, Govt. Engineering College, Ujjain, M.P., India
**Department of Civil Engineering, S.G.S. Institute of Technology and Science, Indore, M.P., India

Nat. Env. & Poll. Tech.
Website: www.neptjournal.com
Received: 26-4-2013
Accepted: 6-6-2013

Key Words:
Water quality modeling
Kshipra River
QUAL-2Kw Calibration
Simulation

ABSTRACT

River Kshipra is receiving a large volume of untreated sewage daily in its stretch of Ujjain city and the status of water is pathetic during low flow season. A stream water quality model QUAL-2Kw was used in the present study to simulate the contributions from different sources and sinks of dissolved oxygen and to understand the interactions among them. The model was calibrated and validated and the simulated results are in general agreement with measured water quality in River Kshipra. It was established through this study that the QUAL-2Kw model can be used for future river water quality management options for River Kshipra with reasonable accuracy.

INTRODUCTION

The water quality situation in developing countries is highly variable, reflecting social economic and physical factors as well as state of development. While all of countries are not facing a crisis of water shortage, all of them have serious problems associated with degraded water quality (Saremi et al. 2010). The ever increasing population and industrialization have ruined the rivers to suit for the discharge of effluents and waste loads for dissimilation. Most of the Indian rivers and their tributaries viz., Ganges, Yamuna, Godavari, Krishna, Cauvery, Damodar and Bramhaputra are reported to be grossly polluted due to discharge of untreated sewage and industrial effluents directly into the rivers. The concentration of DO is an indicator of general health of rivers, which is a function of various parameters that describe the natural and physical processes taking place in the river.

As to protect and save human life and the life of others, water quality management would be considered as one of the most important activities of mankind. The management of water quality describes and predicts the observed and future effects of a water quality change in the river system which needs modelling the quality of water (Sasikumar et al. 1998, Subbarao et al. 2004).

The River Kshipra flows through the holy city Ujjain. Now-a-days its water is primarily used for bathing purposes on all days and especially on festive occasions. Its water is being contaminated by its tributary River Khan carrying domestic and industrial wastewater from Indore and eight drains carrying domestic wastewater of Ujjain city. Realizing the implications of water pollution on aquatic and human health, the judiciary also directed the state authorities to take initiatives to improve the river water quality. Effective management of this polluted segment of the river is of prime importance. In this context, computer aided models have gained wide acceptance as tools to predict and improve the quality of water. A one dimensional steady state water quality model QUAL-2Kw, a modified version of QUAL-2K was used in the present study. The main objective of the study is to test the suitability of the QUAL-2Kw model for River Kshipra in view of the bathing water quality as prescribed by CPCB (pH = 6-8.5, DO ≥ 5 mg/L, BOD ≤ 3 mg/L and MPN/100 mL ≤ 500).

MATERIALS AND METHODS

Study Area

River Kshipra originates from Kokri Bardi hills (747 meters above MSL) about 11 km south east of Indore, a major town of Malwa region. River Kshipra flows through the city of Ujjain in western part of Madhya Pradesh and is considered holy. Pilgrims bathe at its many ghats with great devotion.

The quality of river water is medium from origin up to Triveni ghat. River enters the city at Triveni ghat where River Khan also joins it. Three other important ghats namely Gaughat, Ramghat and Siddhvat ghat are situated on the river before it leaves the city at Kaliyadeh stop dam (Fig. 1). After Kaliyadeh stop dam there are no major inputs of wastewater. River Khan carries domestic as well as industrial wastewater of Indore city, a major town of the region. River khan is the main source of pollution to the River Kshipra. Eleven drains (single/combined) carrying domestic wastewater of Ujjain city also join it at various locations in this stretch. This stretch, which is 19.79 km in length, is most critical from pollution point of view and needs to be addressed properly. During non monsoon months discharge in the river is very small and sometimes becomes zero and this situation gets particularly aggravated during bathing festivals.

Model Selection and Description

The selection of a model to predict the behaviour of a system is based on the number of parameters it can model and the level of accuracy achieved, based on the available data source (Chapra 1997). The widely used mathematical model for conventional pollutant impact evaluation is QUAL-2E (Brown & Barnwell 1987, Drolc & Konkan 1996). However, several limitations of QUAL2E/QUAL2EU have been reported (Park & Uchrin 1990, Park & Lee 1996). One of the major inadequacies is the lack of provision of conversion of algal death to carbonaceous BOD (Ambrose et al. 1987, 1988, Park & Uchrin 1996, 1997). QUAL2EU ignores the role of macrophytes in water quality calculations and differs from other available models which do so by expressing macrophytes as dry weight biomass; which is then related to other water quality constituents through stoichiometric relationships (Park et al. 2003). Also QUAL2EU does not actively integrate the impacts of sediments into the model structure as a biological conversion. As a consequence, the material cycles are not closed (Anh et al. 2006). The others include inability of reduction of CBOD due to de-nitrification and no DO interaction with fixed plants.

Park & Lee (2002) developed QUAL2K, 2002 after modification of QUAL2E, which included the addition of new water quality interactions, such as conversion of algal death to BOD, de-nitrification and a DO change caused by fixed plants. Pelletier et al. (2006) developed a model QUAL2Kw, by modifying QUAL2K, 2003 originally developed by Chapra & Pelletier (2003), which was intended to represent a modernized version of QUAL2E/QUAL2EU.

The Kshipra river reach being simulated is long with respect to the mixing length over the cross section and the transport is dominated by longitudinal changes. Thus, the assumption of 1D process is valid. Moreover, this is the data limited study with modest management objectives and hence QUAL2Kw was chosen as a framework of water quality modelling.

QUAL2Kw is a one dimensional, stream water quality model and thus its application is limited to steady state flow conditions. It has many new elements (Pelletier & Chapra 2005). It includes DO interaction with fixed plants, conversion of algal death to CBOD and reduction of CBOD due to de-nitrification. Additionally, it has auto calibration system. It is useful in data limited conditions and is freely available. Applications of QUAL2Kw are found in various literatures such as Carroll et al. (2006), Kannel et al. (2007), Pelletier & Bilhimer (2004). QUAL2Kw can simulate a number of constituents including temperature, pH, carbonaceous BOD, SOD, DO, organic nitrogen , ammonia nitrogen, nitrite and nitrate nitrogen, organic phosphorus, inorganic phosphorus, total nitrogen, total phosphorus, phytoplankton and bottom algae.

For auto-calibration, the model uses genetic algorithm (GA) to maximize the goodness of fit of the model results compared with measured data by adjusting a large number of parameters. The fitness is determined as the reciprocal of the weighted average of the normalized root mean square error (RMSE) of the difference between the model predictions and the observed data for water quality constituents.

Model Calibration and Validation

Reach segmentation: The selected 19.79 km reach of the Kshipra River was divided into 20 reaches with first 19 reaches of 1 km length and the last reach of 0.79 km length. The headwater boundary starts from 100 meter u/s of Triveni ghat. Fig. 3 shows the stream segmentation along with location of tributary, drains and monitoring stations.

Data procurement: The input data regarding river hydraulics and water quality were either measured or procured from other agencies. Assuming the river cross section as trapezoidal and uniform throughout the reach, the wetted width and depth was measured with the help of survey instruments and measuring rod. The slope of the river bed and slope of the river banks in the stretch of Ujjain city were adopted from the records of Water Resources Engineering Department of Govt. of Madhya Pradesh. In the model, Manning's equation was adopted for calculation of river velocity. The discharge of drains was measured with the help of a V-notch.

The headwater DO, BOD, faecal coliform and pH were measured in the laboratory. The DO at the headwater station was measured by titration of preserved water samples (with the addition of divalent manganese and alkali iodide-azide reagent) collected from the field using standard methods (APHA 1985). BOD, F.C. and pH were also measured at the same location using standard methods. The values of these parameters at four important bathing ghats were also procured from M.P. Pollution Control Board. The same water

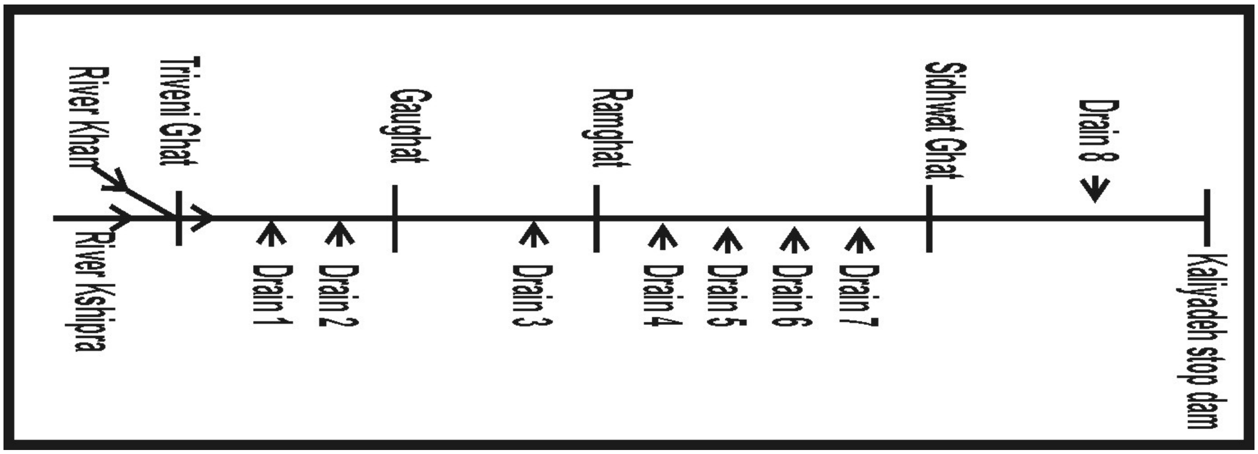

Fig. 1: Location of tributary, drains and important ghats in Khipra river in Ujjain.

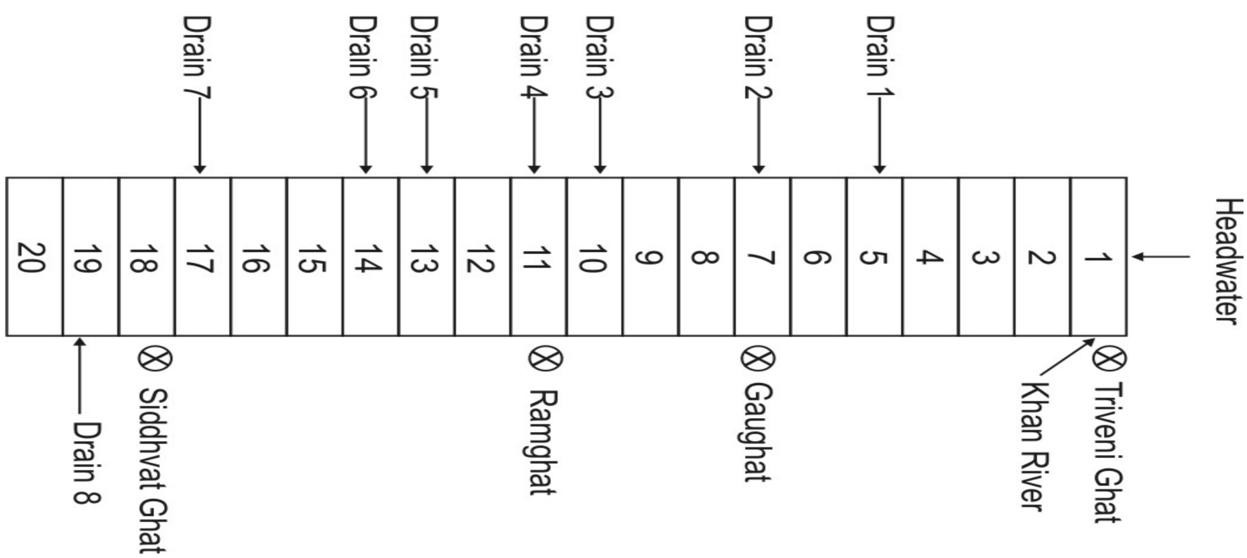

Fig 2: Reach segmentation along with tributary, point sources and monitoring stations.

quality parameters were also measured for the drains. The flow data for River Kshipra and Khan were procured from Central Water Commission, Jaipur. The water quality data for River Khan were procured from M.P. Pollution Control Board, Indore. Table 1 shows the headwater, point sources and observation data for calibration.

Input variables: Hydraulic constants simulate the transport of constituents, i. e., pollutants, in the water system. The River Kshipra is a natural stream channel with weeds, pools and windings. For such a stream, Manning's coefficient is taken as 0.07 (Chapra 1997). The reaeration model selected was the internal model. The solution of integration was done with Euler's method, and Newton-Raphson method was adopted for pH modelling. The sediment oxygen demand and bottom algae were assumed as 25%. All other variables and rate constants were adopted as default values of the model.

Calibration: As per CPCB, the bathing water quality (class B) is described by four water quality parameters namely pH, DO, BOD, and faecal coliforms. Accordingly, the simulation was done for these four parameters. Except for the monsoon months (July-September), when the catchment area receives 80% of the annual rainfall, the low flow conditions of the non monsoon period prevail for most of the year and are critical from the viewpoint of water pollution. Thus, in this study, average river flow in the dry season is considered to apply across scenarios. For this study, QUAL-2Kw was

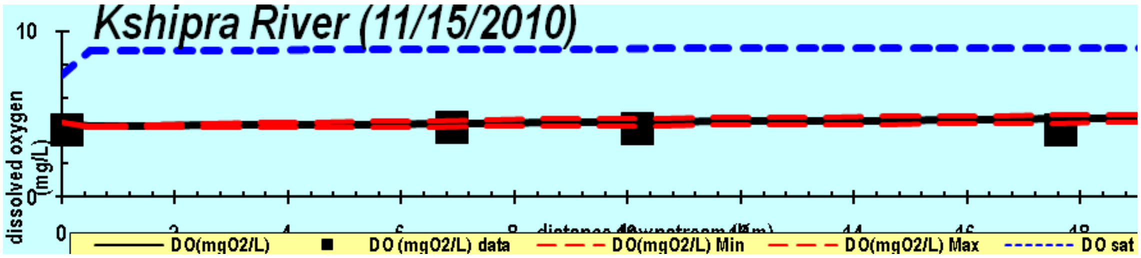

Fig. 3: Calibration for dissolved oxygen.

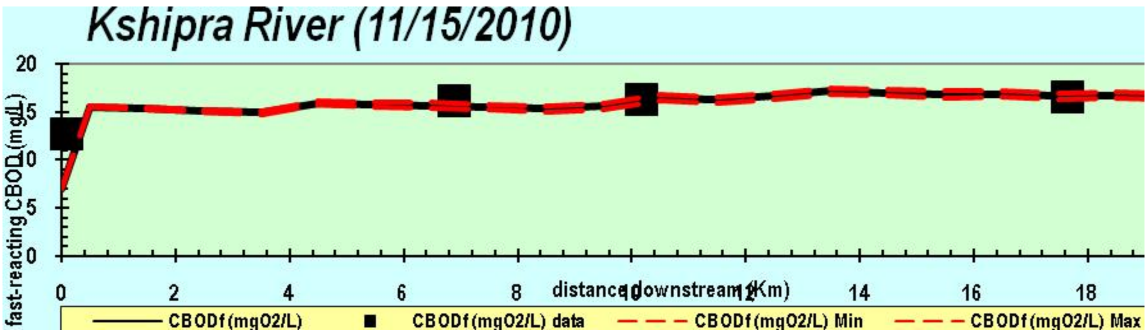

Fig. 4: Calibration for biochemical oxygen demand.

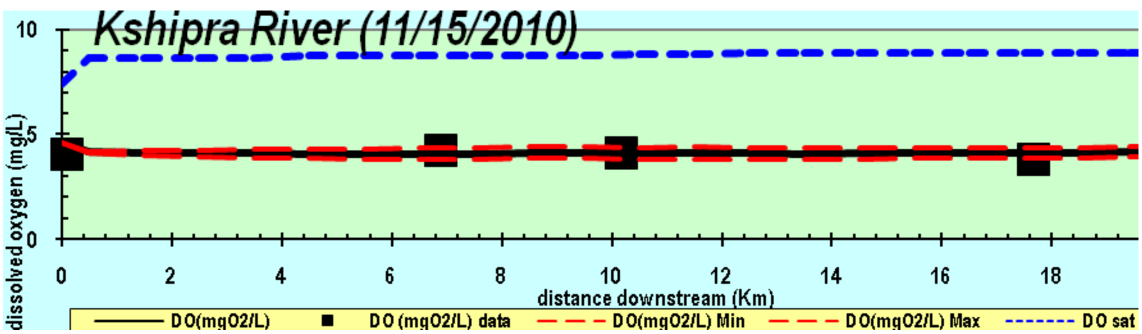

Fig 5: Validation for dissolved oxygen.

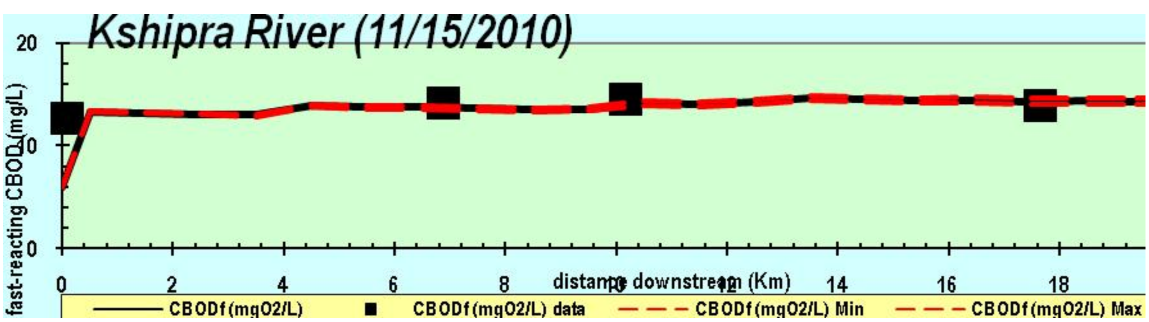

Fig 6: Validation for biochemical oxygen demand.

Table 1: Headwater, point sources and monitored data for calibration.

Location (km)	Headwater					Point Sources					Observed Data			
	Flow	DO	BOD	FC	pH	Flow	DO	BOD	FC	pH	DO	BOD	FC	pH
0.00	4.2	6.0	7.0	2500	7.5									
0.10						1.8	3.2	36	2000	8.2	5.2	12.00	1200	8.3
4.43						0.23	2.9	45	10000	7.5				
6.15						0.012	2.8	62	11000	7.2				
6.90											4.8	14.20	1750	8.4
9.32						0.058	3.5	72	9000	7.9				
10.19											4.8	14.00	2000	8.5
10.90						0.12	3.0	70	10500	7.1				
12.14						0.06	2.8	75	11500	6.9				
13.37						0.10	3.1	63	12000	7.5				
16.98						0.02	3.0	55	10500	7.0				
17.66											3.9	15.00	2000	8.5
18.15						0.02	3.2	75	12000	7.2				

Units: DO and BOD (mg/L); FC (Number/100 mL)

calibrated for the months of April-June 2010 representing a low flow period. The model was operated as a one dimensional steady state and completely mixed system.

The model was run until the system parameters were appropriately adjusted and the reasonable agreement between model results and field measurements were achieved. Model was run for a population size of 100 with 50 generations in the evolution. This is because a population size of 100 performs better than smaller numbers and as nearly as a population size of 500 (Pelletier et al. 2006).

Model validation: In order to test the ability of the calibrated model to predict water quality conditions under different ambient weather and flow conditions, model verification studies were performed using average fall conditions. The model was validated for the data procured during October-December 2010. The system coefficients were kept identical to those values determined during model calibration. Then the model was used to simulate water quality conditions during the critical period. The model was run for the validation of the data and the results are obtained in the form of comparison plots between observed data and predicted data.

RESULTS AND DISCUSSION

The calibration and validation was done for the data procured in the year 2010. The deoxygenation constant was found to be 0.4123/day and reaeration constant was found to in the range of 1.00/day to 1.39/day. Fig. 3 and 4 shows the calibration graphs for the two important parameters DO and BOD, while Figs. 5 and 6 show the validation graphs for the same parameters. The validation graphs show that discrepancy between observed and predicted data is maximum up to 10%. Hence, there is a reasonable agreement between the observed and predicted data and the model is said to be validated.

CONCLUSIONS

The QUAL-2Kw model was calibrated and subsequently validated for low flow conditions to simulate water quality parameters namely DO, BOD, pathogens and pH for the data procured. The model is able to capture the scenario of the river system conceptually almost correctly with some simplifying assumptions. The QUAL-2Kw can be effectively applied for River Kshipra to simulate various management scenarios with reduced waste loadings so that the stated parameters of the river water can be brought up to permissible limit with constant efforts. The scenarios with different waste loadings could help planners to evaluate the effectiveness of the actions intended to prevent pollution before they are actually implemented.

REFERENCES

Ambrose, R.B., Wool, T.A., Connolly, J.P. and shanz, R.W. 1987. WASP5, A Hydrodynamic and Water Quality Model. U. S. Environmental Protection Agency, Athens, GA, EPA/600/3-87/039.

Anh, D.T., Bonnet, M.P., Vachaud, G., Minh, C. V., Prieur, N., Duc, L.V. and Anh, I.L. 2006. Biochemical modeling of the Nhue River (Hanoi Vietnam): Practical identifiability analysis and parameter estimation. Ecol. Model., 193: 182-204.

APHA 1985. Standard Methods for the Examination of Water and Wastewater. American Public Health Association, Washington DC.

Brown, L.C. and Barnwell, T.O. Jr. 1987. The Enhanced Stream Water Quality Models QUAL2E and QUAL2E-UNCAS: Documentation and User Manual. USEPA, Environmental Research Laboratory, Athens, GA, EPA/600/3-87/007.

Carroll, J.O., O'Neal, S. and Golding, S. 2006. Wenatchee River Basin Dissolved Oxygen , pH and Phosphorous Total Maximum Daily Load Study. Washington State Department of Ecology, Washington, Publication No. 06-03-018, pp. 154, retrieved 15 July from: http;/ www.ecy.wa.gov/bibilio/0603018.html.

Chapra, S. 1997. Surface Water Quality Modelling. The McGraw-hill Companies, Inc. Intl. Edn., Bangkok.

Drolc, A. and Konkan, J.Z.Z. 1996. Water quality modeling of the River Sava, Slovenia. Water Res., 30(11): 2587-2592.

Kannel, P.R., Lee, S., Lee, Y. and Anh, K.H. 2007. Application of QUAL2Kw for water quality modeling and dissolved oxygen control in the river Bagmati. Environ. Monit. Assess., 125: 201-217.

Park, S., Na, Y. and Uchrin, C.G. 1996. A multiconstituent moving segment model for the water quality predictions in steep and shallow streams. Ecol. Model., 89: 121-131.

Park, S., Na, Y. and Uchrin, C.G. 2003. An oxygen equivalent model for water quality dynamics in a macrophyte dominated river. Ecol. Model., 168: 1-12.

Park, S., Na, Y., Uchrin, C.G. 1990. Water quality modeling of the lower south branch of the Raritan River, New Jersey. Bull. N.J. Acad. Sci., 35(1): 17-23.

Park, S., Na, Y. and Uchrin, C.G. 1996. Waste load allocation for macrophyte growing impoundment: A combined modeling approach. J. Environ. Sci. health, A31(2): 411-428.

Pelletier, G. and Bilhimer, D. 2004. Stillaguamish River Watershed Temperature Total Maximum Daily load Study. Washington State Department of Ecology, pp. 119 (Publication No.04-03-010), retrieved 24 December 2006 from: http://www.ecy.wa.gov/biblio/0403010.html.

Saremi, A., Sedghi, M., Manshouri, M. and Kave, F. 2010. Development of multiobjective optimal model for Haraz River. World Applied Sciences Journal, 11(8): 924-929.

Sasikumar, K. and Mujumdar, P.P. 1998. Fuzzy optimization for water quality management of a river system. J. Water Resources Planning and Management, ASCE, 124(2): 79-88.

Subbarao, V.V., Mujumdar, P.P. and Ghosh, S. 2004. Risk evaluation in water quality management of a river system. J. Water Resources Planning and Management, ASCE, 130(5): 79: 8411-8423.