Water quality management of river Kshipra (India)

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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. In this paper, various water quality management approaches i.e. Defensive approaches and Proactive Approaches are being described. Defensive approaches relates to the generation of additional flow in the river either naturally or artificially. Various Proactive approaches may also be adopted for cleaning of the river. The main objective of the study is to suggest approaches to bring the water quality upto bathing standard. A stream water quality model QUAL-2Kw was also used in the present study to calculate the dilution flow requirement in various scenarios. The various water quality management strategies were examined considering: (1) pollution loads modification and; (2) flow augmentation. The combination of these alternatives is necessary to curtail BOD and Pathogens and to retrieve the DO level. The QUAL-2Kw model can be used for future river water quality management options for River Kshipra with reasonable accuracy.

Key words: Water quality modeling, Kshipra River, qual-2kw, calibration, simulation

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 a river, 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 other things, water quality management would be considered as one of the most important activities of mankind. The management of water quality describe and predict the observed and future effects of a water quality change in the river system which needs modeling the quality of the river (Shashikumar K. and Mujumdar P, 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 analysis.

The main objective of the study is to suggest approaches to achieve the desired level of water quality i. e. bathing water quality as prescribed by CPCB (pH = 6-8.5, DO ≥ 5 mg/L, BOD ≤ 3 mg/L and MPN / 100 mL ≤ 500) and also to determine the maximum allowable pollutant discharge into the River Kshipra by the use of Qual-2Kw model

2. Materials and methods

2.1 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. Kshipra River catchment measuring 6123 sq. km is located on Malwa Plateau in western Madhya Pradesh at latitude between 22° – 24° and longitude between 75° – 76°, at an average altitude of 553 metres above MSL. The region is known for its fertile soil, gentle slopes and moderate rainfall. The region has flat topography with very gentle slopes varying from 1 in 1000 to 1 in 3000. Total Length of the river is about 195 km.

The quality of river water is medium from origin upto 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 (Figure 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 joins 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. Kshipra has plenty of water during the monsoon months. During non monsoon months discharge in the river is very small and sometimes becomes zero and this situation gets particularly aggravated during bathing festivals.

Figure 1: Location of tributary, drains and important ghats
3. Water quality management approaches

3.1 Defensive approaches

1. Water shed Management (for increasing natural flow in the river).
2. Modeling of the river (for calculating additional dilution flow requirement which is to be injected artificially).
3. Aeration – It is required if the BOD is too high or if the DO is too low.

3.2 Watershed management

Watershed management is done to:
1. To reduce soil loss.
2. To reduce runoff velocity.
3. To store water in small amount.
4. To recharge the ground water storages.
5. The structures specifically suitable for Kshipra catchment are:
   6. Contour trenches.
   7. Boulder bunds
   8. Gabian structures
   9. Check dams

3.3 Modeling

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, G.J. and Chapra, S.C., 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 and Bilhimer (2004). QUAL2Kw can simulate a number of constituents including temperature, pH, carbonaceous BOD, SOD, DO, organic nitrogen, ammonia nitrogen, nitrite and nitrate nitrogens, 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 (PDER, 1981, Pelletier, G.J. and Chapra, S.C., 2005). 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.

4. Model calibration and validation

4.1 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 Figure 2 shows the stream segmentation along with location of tributary, drains and monitoring stations.

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

4.2 Data procurement

The input data regarding river hydraulics and water quality were either measured / 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 was 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 Fecal 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/AWWA/WEF 1998). 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 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.

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

<table>
<thead>
<tr>
<th>Location (km)</th>
<th>Headwater</th>
<th>Point Sources</th>
<th>Observed Data</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Flow DO BOD FC pH Flow DO BOD FC pH</td>
<td>D O B O D FC pH</td>
<td></td>
</tr>
<tr>
<td>0.00</td>
<td>4.2 6.0 7.0 2500 7.5</td>
<td>1.8 4.3 36 2000 8.2</td>
<td>5.2 12.0 120 8.3</td>
</tr>
<tr>
<td>0.10</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**4.43 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, S., 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 modeling. 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.

**4.4 Calibration**

As per CPCB, the bathing water quality (class B) is described by four water quality parameters namely pH, DO, BOD, and Fecal 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 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).

4.5 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 Oct. – Dec. 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.

4.6 Model results

The model in this study has been applied to frame strategies that would help to keep the water quality of the River Kshipra within acceptable limits. The simulations was done in a stepwise manner to explore how the water quality would change with change in loads as well as environmental modifications, i.e., flow augmentation to the river. The QUAL-2Kw results are in the form of graphs combined with the observed data sets. Also the model itself creates a source summary of input data which get updated in every running. The flow and velocity pattern are varying significantly because of the low flow and the sudden discharge of effluents form drains across the reach. The simulation was done considering four different scenarios: (1) Both Khan River and drains merging with parent channel, (2) Only Khan River merging with parent channel, (3) Only drains merging with parent channel and (4) Both Khan River and drains are completely isolated from the parent channel. Table 2 shows the dilution flow requirement in each case.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dilution Flow Requirement (cumec)</td>
<td>30</td>
<td>14</td>
<td>15</td>
<td>1.5</td>
</tr>
</tbody>
</table>

Recently a project named Sewar Khedi dam project has been sanctioned by Govt. of Madhya Pradesh which will be executed on Kshipra River on the upstream of Triveni Ghat. One of the aims of this multipurpose project is to supply additional water for the purification of the River Kshipra. The additional water requirement will be met through this reservoir. As regards BOD load modifications, Khan River water may be completely diverted through an artificial channel which will join on the u/s side of Kaliyadeh stop dam. Similarly, wastewater of drains may be collected and sent to a treatment plant, the effluent of which may join later on the d/s side of Kshipra River.

4.7 Pro-active approaches

4.7.1 Improving the sewerage system

Presently about 60% of the city area is covered by underground sewerage network. Waste water from unsewered localities finds its way ultimately into the river through eleven
nallahas. There is no proper wastewater collection system in the area situated on the banks of the river. Wastewater generated from there directly enters into the river especially at important Ghats. Improvement in sewerage system would help in restoring the water quality to some extent.

4.7.2 Wastewater treatment and disposal

The present wastewater generation in the city is about 110MLD. The wastewater collected through sewers is sent to anaerobic oxidation pond (STP) of 56 MLD treatment capacity located at sadawal. Hence about 54 MLD of wastewater goes into the river without any treatment. It is urgently required to create additional treatment capacity. Effluent from STP is discharged again into the river through a natural drainage known as Bhandariya khal. Though the effluent BOD (8-20 mg/L) meets the prescribed standard for discharge into the river, but again it is a sort of burden on river because of absence of minimum required flow. The treatment efficiency of STP could be improved further by proper operation and maintenance which is presently lacking for want of funds.

4.8 Preventing contamination coming through Khan River

River Khan is major tributary of River Kshipra which meets it little upstream of Ujjain at Triveni. Hundreds of industries are located in Indore, which discharge wastewater directly or indirectly into Khan during rainy season. River water appears to be full of foam during rainy season and there are several incidences of fish killing in Kshipra. During non rainy season also the water of Khan appears dark in colour and there is a presence of heavy metals like Cr, Zn, Pb, As, etc. in it. Thus river Khan is the biggest source of contamination. There is an urgent need to prevent contamination from Khan. One of the alternatives would be to construct a barrage on Khan. Sediments will be retained u/s of it which may be flushed during rainy season.

4.9 Proper use of fertilizers

Due to indiscriminate use of chemical fertilizers, nutrients like N, P & K reaches to water body leading to algal bloom. A layer of algae is often seen on the surface of Kshipra post rainy season which in turn reduces DO. Farmers in the catchment area of Kshipra, Khan and Gambhir should be educated to avoid indiscriminate use of chemical fertilizers, pesticides etc. Measures like wetlands and riparian zones should be developed as long term projects to reduce entry of nutrients.

4.10 Solid waste management

The quantity of solid waste generated in Ujjain city is about 200MT/day. Solid waste dumping ground is located at Gondia and MR-5. Due to improper system of waste collection, heaps of solid wastes are seen at various places. Polythene bags often clog the sewer lines. Leachate from solid waste leads to river and contaminate it. An efficient method of solid waste collection and disposal should be developed for Ujjain city.

4.11 Construction of improved crematoria

Presently cremation is done on the river bed itself at Chakratirth Ghat and people directly through ashes into the river. There is a need to construct improved wood based crematoria
and to educate people to use electric crematoria. Electric crematoria often remain closed due to power failure and O & M problems.

4.12 Development of holy pond

Due to religious convictions and beliefs people use to dump holy material and offerings of puja into the river. Remains of holy materials and flowers are often seen floating on the surface creating an ugly scene. The problem can be solved by constructing a holy pond at a suitable place which should be filled by Kshipra water. This fill and draw type pond may be emptied as and when required and again filled with river water after removing the sediments. The plants of lotus could also be grown in this pond to absorb heavy metals (Kumar Y, 2007).

4.13 Afforestation in the catchment area

Afforestation in the whole catchment area in general and along the banks specially should be developed on priority basis. This will reduce erosion of soil and will prevent entry of silt, nutrients and pesticides into the river. The most favorable tree for plantation along the river banks is Banyan tree (Bargad or vut) having a long life and high soil binding capacity.

4.14 Legislation and fines

Standards should be framed according to the specific industry and assimilative capacity of the river. Polluter Pay Principal should be strictly implemented. Industries/municipality violating effluent standards should be suitably penalized. Fine may also be imposed on general public if they are found polluting the water bodies.

5. Conclusions

The River Kshipra has reached to such a pathetic condition because of (i) severely reduced flow and (ii) pouring of wastewater in excess of its assimilative capacity. River water can be made suitable for bathing if flow is increased and wastewater is prohibited to meet river. River flow can be increased through watershed treatment but it is a long term process. Dilution water calculated through QUAL-2Kw model may be injected artificially as a short term measure provided sufficient storage is nearby available. Other measures especially diversion of drains / diversion of Khan River and development of holy pond will prove to be beneficial for the restoration of the health of the river. The strategy of BOD load curtailment along with flow augmentation seems to be viable as required dilution water will be made available from proposed Sewarkhedi dam project.

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. These scenarios could help planners to evaluate the effectiveness of the actions intended to prevent pollution before they are actually implemented.

6. References


