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Estimating Assimilative Capacity of Kanhan River Using MIKE-11

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ABSTRACT: Rivers and streams are the important components of the biosphere as they serve dual purpose as a major resource for utilization and waste assimilation. River supports multitude of uses such as drinking, bathing, irrigation, recreation etc., and therefore, it is expected that river water quality be maintained as per the criteria developed by Central Pollution Control Boards (CPCB) for various uses of water. However, it is seen that due to discharge of industrial and municipal wasteloads, waste assimilation capacity of a river is exploited to such an extent that the water becomes unfit for various uses.

The Assimilative Capacity (AC) of a perennial river at a given location for a given pollutant is defined as the maximum amount of the pollutant load that can be discharged into the river at that location and still maintain the quality of water to the desired criteria with respect to BOD, DO and other parameters. Waste assimilative capacity for a river is usually computed for minimum or low flow conditions. The methodology is based on flow data analysis; identification of wastewater discharges; identification of critical water quality parameters and behaviour of river stretch for modelling; model setting and choice of model coefficients; model calibration; and number of iterative simulations for estimation of assimilative capacity of the river.

The paper presents assimilative capacity estimation study for Kanhan River in Nagpur district. Kanhan River enters in Nagpur District near village Temurdoh, and after flowing for 120 km joins river Wainganga near village Chichghat. The river network is defined by tributaries Kolar, Pench and Nag. The Irrigation Department Govt. of Maharashtra has installed four gauging stations at Temburdoh, Kamthi, Mathani and Chichghat in this 120 km stretch. The major wastewater carrying stream to river Kanhan is Nag river meeting at 96 km from Temburdoh. Monthly flow data at various locations in the river indicated that river flow in summer and winter ranges from 5–50 m^3/s. Accordingly, 5, 23 and 50 m^3/s were considered as critical seasonal flows for estimation of assimilative capacity of river Kanhan.

MIKE 11, a software tool for simulation of hydrology, hydraulics, water quality in estuaries, rivers, irrigation systems and other inland waters was set up for simulating 1-D open channel flow and water quality in the river. With tributaries Pench and Kolar, the river receives four wastewater drains, of which wasteload from Nag river was considered for AC estimation. The river morphology was defined at 17 stations by river survey. Model results for DO-BOD simulation indicated that the assimilative capacity of Kanhan River near confluence with Nag river for minimum river flow (Q) 5.85 m^3/s is 1033 kg/day of BOD; and for winter flow of 50 m^3/s is 6220 kg/day of BOD, in order to satisfy class C water quality criteria in the river according to CPCB Classification.

INTRODUCTION

Rivers and streams are the important components of the biosphere as they serve dual purpose as a major resource for utilization and waste assimilation. River supports multitude of uses such as drinking, bathing, irrigation, recreation etc., and therefore, it is expected that inland water quality be maintained as per the criteria developed by Central Pollution Control Boards (CPCB, 1978–79) for various uses of water. However, in addition to natural processes of soil erosion and sedimentation; anthropogenic activities such as human settlements along the banks, industrialization, irrigation, recreational use are placing increasing waste load on available water resources. Reduction in quantity due to over exploitation, and discharging the wastewater has resulted in water quality deterioration in many rivers in India. It has been reported that nearly 80% of the river pollution is due to raw sewage. The findings are frequently reported in local magazines and news papers (Pepper, 2007). Water pollution control therefore, warants assessment of assimilative capacity of receiving

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water body to discharge treated wastewater by protecting its designated use. The treatment provided should reduce the specific pollutant load considering assimilative capacity of waterbody at a particular location and at a particular time. Since, rivers also form the major sources of potable water supply, assimilative capacity estimation for water quality management is an important tool for scientists, engineers and planners.

The Assimilative Capacity (AC) of a river at a given location for a given pollutant is defined as the maximum amount of the pollutant load that can be discharged into the river at that location and still maintain the desired water quality criteria. The waste AC of a given medium depends on characteristics of the medium, type of pollutant, site-specific conditions and acceptable standard for the pollutant in the medium. Since, the river flow varies from one season to other, assimilative capacity of a river is a function of time, location and the type of pollutant. In this context, simulation modelling for various scenarios of river flow, taking into consideration waste water characteristics and environmental conditions forms an important tool for estimation of the AC of river. The algorithm for estimation of assimilative capacity considering water quality parameters BOD i.e. the maximum amount of organic load that could be discharged to the river, and still maintain water quality as per the desired class of CPCB criteria .

The paper presents a case study for estimation of assimilative capacity of Kanhan river in Nagpur District using a one-dimensional water quality model MIKE-11. The water quality indicator parameters DO-BOD were used with seasonal variability in river flow.

MIKE11: 1-D WATER QUALITY MODEL

MIKE-11 is a software tool for simulation of hydrology, hydraulics, water quality in estuaries, rivers, irrigation systems and other inland waters. It is based on an integrated modular structure with a variety of basic modules and add-on modules, each simulating certain phenomena in river systems. Each module can be operated separately and data transfer between modules is automatic. Coupling of physical processes (e.g. river morphology, sediment re-suspension, and water quality) are facilitated.

Saint Venant Equations

MIKE-11 HD applied with the dynamic wave description solves the vertically integrated equations of conservation of continuity and momentum (the 'Saint Venant' equations), based on the following assumptions:

The water is incompressible and homogeneous, i.e. negligible variation in density, the bottom-slope is small, thus the cosine of the angle it makes with the horizontal may be taken as 1, the wave lengths are large compared to the water depth. This ensures that the flow everywhere can be regarded as having a direction parallel to the bottom, the flow is subcritical.

The equations of continuity and momentum, as used by MIKE-11 are,

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = q \qquad \ldots (1)$$

$$\frac{\partial Q}{\partial t} + \partial\left(\alpha \frac{Q^2}{A}\right) + gA\frac{\partial H}{\partial x} + \frac{gQ|Q|}{C^2AR} = 0 \qquad \ldots (2)$$

Where, Q = discharge, A = flow area, q = lateral flow, h = stage above datum, C = Chezy resistance coefficient, R = hydraulic or resistance radius, α = momentum distribution coefficient.

Basic Modules in MIKE-11

Hydrodynamics (HD)

The HD module contains an implicit, finite difference computation of unsteady flows in the rivers and estuaries. The complete non-linear equations of open channel flow (Saint-Venant) can be solved numerically between all grid points at specified time intervals for given boundary conditions.

Advection-Dispersion and Cohesive Sediments (AD)

The AD module is based on the one dimensional equation of conservation of mass of a dissolved or suspended material (e.g., salt or cohesive sediments). The behavior of conservative materials which decay linearly can be simulated. The module requires output from the hydrodynamic module, in space and time, of discharge and water level, cross-sectional area and hydraulic radius.

Water Quality (WQ)

WQ is coupled to the Advection-Dispersion (AD) module and simulates the reaction processes of multi–compound systems including the degradation of organic matter, the photosynthesis and respiration pf plants, nitrification and exchange of oxygen with the atmosphere. The mass balance for the parameters involved is calculated for all grid points at all time steps using a rational extrapolation method in an integrated two- step procedure with the AD module. A number of modules have been developed describing

BOD-DO relationships, nitrification, the influence of bed vegetation on water quality, sedimentation and re-suspension and oxygen consumption from reduced chemicals. Two add-on modules are available for the WQ-module: Water Quality Heavy Metals module (WQHM) and the Eutrophication module (EU).

Solution Scheme

The solutions of the equations of the continuity and momentum are based on an implicit finite difference scheme. The scheme is structured in order to be independent of the wave description specified (i.e. kinematic, diffusive or dynamic). A computational grid of alternating grid Q (discharge) and h (water level) points is used. Q-points are placed midway between neighboring h-points and at structures, while h-points are located at cross-sections, or at equidistant intervals in between if the distance between the cross-sections is greater then maximum dx. The discharge is defined by convention as positive in the positive x-direction (increasing chainage).

For the stability of numerical scheme, the selection of Δt and Δx should be small enough to resolve non-linear variations in the time and space, respectively. For example, the space step Δx (dx-max) should be selected in such a way that rapidly changing river geometry is described accurately. The time step Δt should be fine enough to provide an accurate representation of the wave. The Courant condition can be used as a guide for selecting the time step. Typically a value of Cr as determined from Eqn. (3) is of the order of 10 to 15,

$$C_r = \frac{\Delta t(V + \sqrt{gy})}{\Delta x} \qquad \dots (3)$$

Where, V is velocity:

Model Calibration

The river system network was digitized as shape file in GIS and imported in MIKE-11 software. The river locations or chainage points where cross-section data was available were defined through cross-section editor. For observed river flow of 5.85 m^3/s and wastewater loadings in October 2004, model was calibrated for DO-BOD system, with BOD decay rate of 0.5 /day (Brown and Barnwell, 1987), and considering reaeration rate by O'Conner-Dobbins formula (Mc Cutchean, 1989; Chapra, 1997).

Assimilative Capacity Estimation

River flow data at four stations was obtained from Hydrological Data User Group (HDUG). Monthly flow variations in the Kanhan river were analysed for past 10 years (1995–2004). It was observed that river flow in summer and winter season ranges from 5–50 m^3/s. Accordingly, 5, 23 and 50 m^3/s flows were considered as seasonal flows for estimation of assimilative capacity.

For estimation of assimilative capacity of river Kanhan, calibrated model was used for DO-BOD simulation in iterative manner. The river flow in the range 5–50 m^3/s was varied as 5, 23 and 50 m^3/s and the waste from Nag river or nallah meeting river Kanhan at 96 km from Temurdoh was varied for each river flow condition e.g. for the river flow of 5 m^3/s, wasteload was varied as 1808, 1550 and 1033 kg/day. The combinations of river flows and waste load conditions are given in Table 1. In all the three cases background river DO and BOD were maintained as 7 mg/l and 2 mg/l, respectively. The model simulations which satisfied the class C water quality criteria for the given waste load was considered as the assimilative capacity of the river for that flow.

Table 1: Estimated Assimilative Capacity

River Flow (m^3/s)	*Wastewater Flow (m^3/s)*	*BOD (mg/l)*	*Waste Load (kg/day)*	*Simulated BOD < 3 mg/l*	*Simulated DO ≥ 6.5 mg/l*
5.85	0.997	21	1808	N	N
	0.997	18	1550	N	N
	0.997	12	1033	Y	Y
23	0.997	40	3445	N	N
	0.997	30	2584	N	N
	0.997	25	2153	Y	Y
50	1.2	80	8294	N	N
	1.2	70	7257	N	N
	1.2	60	6220	Y	Y

CONCLUSIONS

- The model study demonstrates that water quality modeling is a powerful tool for simulation of existing scenario indicating the level of pollution.
- The seasonality in river flows which is explained by variations in flow patterns due to unequal rainfall distribution over the year can be taken into consideration for seasonal variability in waste assimilation capacity of the river .
- The AC was 1033 kg/day waste load for river minimum flow of 5.83 m^3/s.
- The AC estimation based on model results can be used as guideline for planning wastewater treatment.

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