WATER QUALITY MODELING OF KRISHNA RIVER REACH USING QUAL2KW MODEL

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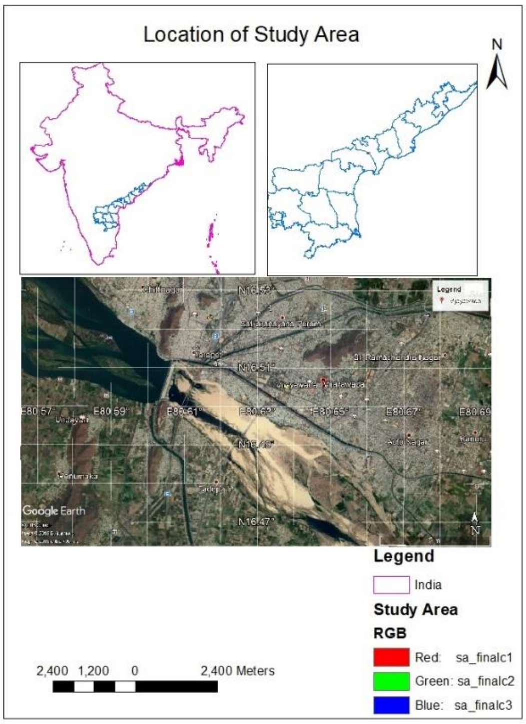
***ABSTRACT*-**Krishna River is the fourth-biggest river in terms of water inflows and river basin area in India. It has been polluted with agricultural, industrial and domestic pollutants. Since the Krishna river stream is polluted as a result of urbanization and industrialization, its biochemical oxygen demand (BOD) concentration is increasing gradually and other quality parameters also violating the standards. It is necessary to use a versatile water quality model to assess the BOD concentration and other quality parameters and make policies for pollution control. In the current study, the QUAL2Kw model has been applied to evaluate the spatial distribution of water quality parameters Dissolved oxygen and NO_3-N in a reach of Krishna river. QUAL2Kw is calibrated and validated using the actual field measurements. This study demonstrated the usefulness of the QUAL2Kw model as a tool to validate critical water quality parameters.

Keywords: Water quality, Modeling, QUAL2Kw, Simulation, Dissolved Oxygen, NO_3-N

1: INTRODUCTION

Increasing water scarcity together with decreasing quality is forcing developing countries into remediation options of river water quality. The assessment and evaluation of human impacts on the quality of surface waters have become the main objectives in river basin management. The problem of predicting chemical loads in a river system has remained a key issue in determining the impact of human activity on aquatic ecosystem environments. A good river health meets the threshold levels of key parameters like dissolved oxygen (DO), carbonaceous biochemical oxygen demand (CBOD), total nitrogen (TN), total phosphorus (TP), temperature and pH.

The Krishna river is the principal resource base of municipal water in Vijayawada. It has various religious places like Sri Durga Malleswara Swami Devastanam at its bank. About 20 years ago, the river was in drinkable condition, highly appreciated for its purity, both physical and ritual. But today, the ritual bathing at holy puskar time is almost a thing of the past as pollution chokes this once beautiful river. To achieve the water quality standards, the assimilative capacity of the river should remain sufficient all along the river. This goal can be achieved by controlling the wastewater pollution loads. The complex relationships between waste loads from different sources and the resulting water qualities of the receiving waters are best described with mathematical models [(1)]. The widely used mathematical model for conventional pollutant impact evaluation is QUAL2Kw which was developed by Pelletier and Chapra (2005) by modifying QUAL2K, 2003 originally developed by Chapra and Pelletier (2003), which is intended to represent a modernized version of QUAL2E.



In this study QUAL2Kw has chosen as a modeling framework for the study of the stream of Krishna river since it simulates the transport and fate of conventional pollutants. The main objectives of this study are (i) to estimate the flow parameters, i.e., velocity and discharge of the sub stream of the Krishna river ii) to assess the physico chemical parameters of Krishna river reach by experimental results iii) to evaluate the spatial variation of water quality parameters like dissolved oxygen and NO_3-N using QUAL2Kw software by validating the software for Krishna river stream using measured data.

2. STUDY AREA

The study area is a part of Krishna river basin, one of the perennial rivers in India. The stream is about 10 km stretch of Krishna river, which lies at downstream of Prakasam barrage, located at Vijayawada in Andhra Pradesh (fig.1).The area is bounded between Bay of Bengal and West Godavari district from East, Guntur and Nalgonda districts from West, Khammam district from North and Bay of Bengal from South. Krishna district bounded by longitude 80^0 00' E and 81^0 33' E and latitude 15^0 43' N and 17^0 10' N. The river reach has been discretized into four sub categories, each of length about 2 km.

3. MATERIALS AND METHODS

3.1 Water quantity estimation

For any hydraulic modelling, estimation of discharge at a specified location is mandatory. To estimate discharge, velocity and area are the two main parameters to be determined. Velocity can be estimated in field practically by several methods. Float Area method is adopted in the current study to estimate velocity. The basic idea here is to measure the time that it takes a floating object to travel a specified distance downstream. These calculations were in m and Seconds for convenience in converting to CMS (Cubic M Per/Second flow rate). To get an overall channel area measurement, width of the channel was measured and then 10 or more depth readings were taken across the width. Depth readings must be taken about every 1 foot across (depending on the width and uniformity of the channel) for accurate measurement. Hence the area of the stream cross section was obtained from the depth and width of the section, there by flow rate can be obtained.

3.2. Water quality estimation

Water quality parameters monitored were: temperature, pH, dissolved oxygen (DO), fluoride, nitrate-nitrogen (NO_3– N), Alkalinity, Hardness. The river stream is discretized into 4 reaches each about 2 Water quality parameters like temperature, pH, dissolved oxygen (DO), fluoride, nitrate-nitrogen (NO_3– N), alkalinity and hardness were measured as per the standard procedure IS 3025. The river stream is discretized into 4 reaches each about 2 km named as Head warer-4A, 4A-4c, 4C- PC, PC-KI .Water samples were collected at every reach upstream and downstream and all the above mentioned quality parameters were determined at every downstream and upstream. Here quality parameters at other than headwater location were determined for validation purpose.

3.3 Model calibration and validation

The QUAL2Kw is a model for the simulation of water quality in rivers and streams, distributed by the USEPA. The QUAL2Kw model is based on ordinary differential equations for one-dimensional systems and an assumption of constant flow. The QUAL2Kw can simulate number of constituents including temperature, pH, carbonaceous biochemical demand, sediment oxygen demand, dissolved oxygen, organic nitrogen, ammonia nitrogen, nitrite and nitrate nitrogen, organic phosphorus, inorganic phosphorus, total nitrogen, total phosphorus, phytoplankton and bottom algae.

The user can choose between a permanent or a dynamic flow condition. In dynamic condition the model allows the simulation of each water quality parameter along the watercourse. On this basis, it is possible to perform mass-balance calculations for each constituent of the model, except for variables related to river-bottom algae. The reach is considered to be complete mix reactor, and the succession by the following elements allows the model to represent the evolution of the water quality along the river (Pelletier et al., 2006). Figure 2 illustrates the mass-balance scheme used as the computational element in the model. The general mass-balance equation for a constituent concentration c_i in the water column (excluding hyporheic) of a reach i (the transport and loading terms are omitted from the mass-balance equation for bottom algae modeling) as (Equation 1):

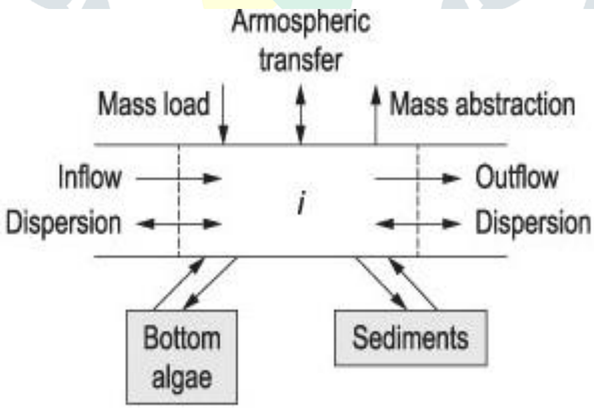


Figure 2. Mass balance in a reach segment I(adapted from Pelletier and Chapra, 2005)

$$V\frac{\partial C}{\partial t} = \frac{\partial\left(AE\frac{\partial c}{\partial x}\right)}{\partial x}dx - \frac{\partial(AU)}{\partial x}dx + V\frac{dC}{dt} + s \quad \text{-----(I)}$$

Where, V= Volume; C= Concentration; A=Cross section Area

E=Longitudinal Dispersion; X= Distance;

U=Averaged Velocity,

S=Sources (+)/sink (-)

By performing a heat balance on each element in the study area, temperature is modeled in QUAL2K. Transfer of heat in the model includes the inflow and outflow of heat from water flowing into and out of the particular element. The model also takes into account the water flowing into and out of each element from point and non-point inputs and withdrawals. Dispersion of heat, heat transfer to and from the atmosphere, and heat transfer to and from sediments are also included in the heat balance for each element as shown in figure 3..

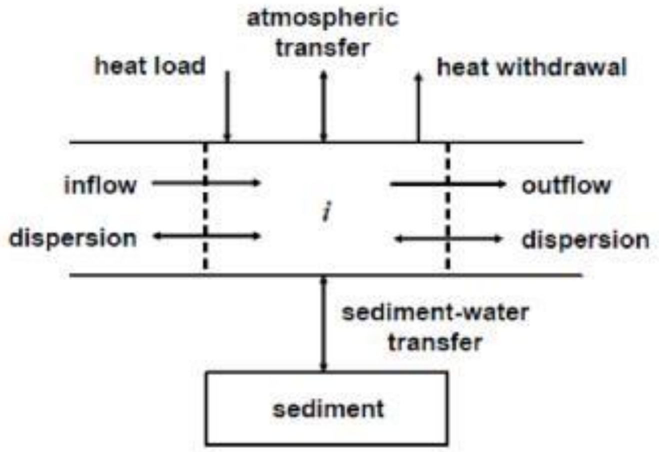


Figure 3. Heat balance for an element

The measured river geometries and river velocities were used to determine the hydraulic characteristics at each sampling locations. The model allows the input of the river reach hydraulic characteristics (coefficients and exponents of velocity and depth) as empirical equations to estimate average water velocity (V) and depth (D) of the river:

$$U = aQ^b$$

$$H = \alpha Q^{\beta}$$

Where *a*, *b*, α and β are empirical coefficients that are determined from velocity-discharge and stage-discharge rating curves, respectively.

Note that the sum of *b* and β must be less than or equal to 1. If their sum equals 1, the channel is rectangular. Once the boundaries of each reach are defined, QUAL2K will determine the average water depth and velocity using Manning's equation also

$$Q = \frac{1}{n} R^{\frac{2}{3}} S^{\frac{1}{2}} \times A \ldots\ldots \text{(II)}$$

Where, *Q* is the discharge in m3 s-1, *S* is the bottom slope; *A* is the cross-sectional area in m2, *n* is Manning's roughness coefficient, and *P* is the wetted perimeter in meters. QUAL2K can also determine water depth and velocity based on weir heights and rating curves. The velocity and flow measurement of the study reach was obtained by float method.

For auto-calibration, the model uses a genetic algorithm to maximize the adjustment of the simulated results based on data measured in the field. 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 (Kannel et al., 2007).

4. RESULTS AND DISCUSSIONS

4.1 Water quantity estimation

The Krishna river reach of study area was discretized as mentioned in the previous sections and velocity, depth of flow and discharge was determined using floating object technique. The results are shown in table 1.

Table 1. Hydraulic parameters of the Krishna River reach

STATION	Velocity(m/s)	Flow(CMS)	Depth(m)	a	b	α	β
HW	0.2533	0.9828	0.235	0.22	0.9	0.23	0.1
4A	0.2176	0.796	0.23	0.2176	0.122	0.232	0.72
4C	0.2091	0.6064	0.182	0.244	0.1945	0.211	0.7085
PC	0.2397	0.536	0.138	0.271	0.267	0.19	0.697
KI	0.2975	1.2	0.2426	0.271	0.267	0.19	0.697

4.2 Water quality estimation

The experimental results of physico chemical analysis of collected water samples from different locations are shown in table 2. These data are used for validation of the software.

Table 2. Physico chemical parameters of the Krishna River reach

Station	DO(mg/l)	Chlorides(mg/l)	Hardness(mg/l)	pH	NO3-N(µg/l)	Fluoride (mg/l)	Alkalinity(mg/l as Caco3)
HW	6.3	66.64	130	8.45	5700	0.16	131.2
4A	6.6	70.9	125.34	8.56	3800	0.33	144
4C	7.1	66.64	120	8.15	2500	0	142.6
PC	6.2	75.15	129.34	8.55	2200	0.38	147.94
KI	5.6	66.64	132.6	8.39	2000	0.33	222.6

4.3 Calibration and validation

The model is calibrated by using measured data at specified locations of the stream. The two important sample parameters were identified and validated using simple regression analysis. It is used to understand the correlation between observed and simulated data. DO and NO3-N were considered as the most important parameters for aquatic life because human activity generated contamination from agricultural, municipal and industrial activities introduces significant amount of nutrients and organic materials into the rivers and streams, accelerating eutrophication process and decreasing dissolved oxygen below a threshold value which is apparent during low flow periods. The impacts of low dissolved oxygen (DO) concentrations and high nitrates concentration are an un balanced ecosystem with fish mortality, odors and aesthetic nuisances.

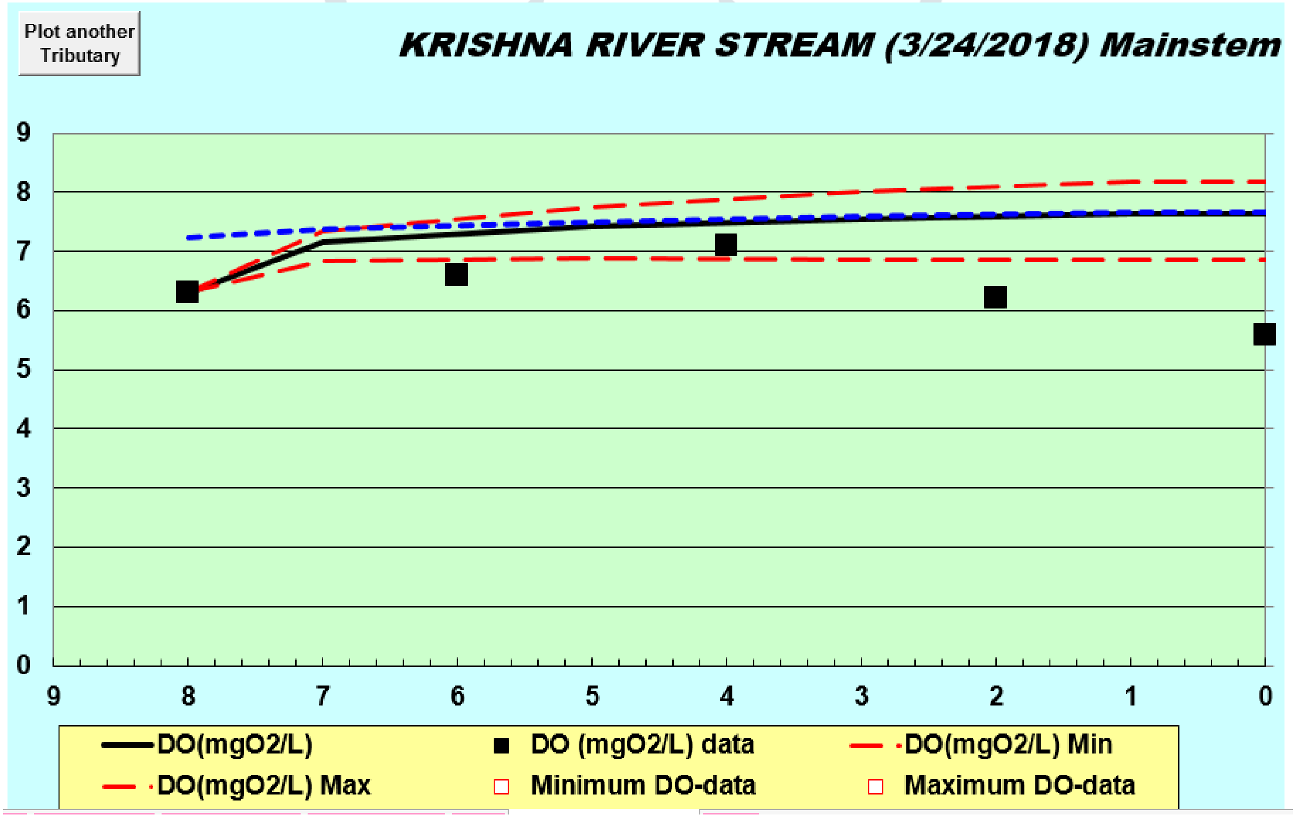


Fig 3.Spatial variation of Dissolved Oxygen

In the present study charts were obtained by simulating QUAL2Kw model using measured data as shown in figure 3 and 4.It depicts the model output and data versus distance (km) along the river. Figure 3 shows the spatial variation of dissolved oxygen whereas figure 4 represents the spatial variation for ammonia nitrogen. The black line is the simulated mean parameter (as displayed on the WQ Worksheet), whereas the dashed red lines are the minimum (WQ Min Worksheet) and maximum (WQ Max Worksheet) values, respectively. The black squares are the measured mean data points that were entered on the WQ Data Worksheet. The white squares are the minimum (WQ Min Worksheet) and maximum (WQ Max Worksheet) data points, respectively. From the simulated results, it is evident that the model calibration results are in well agreement with the measured data.

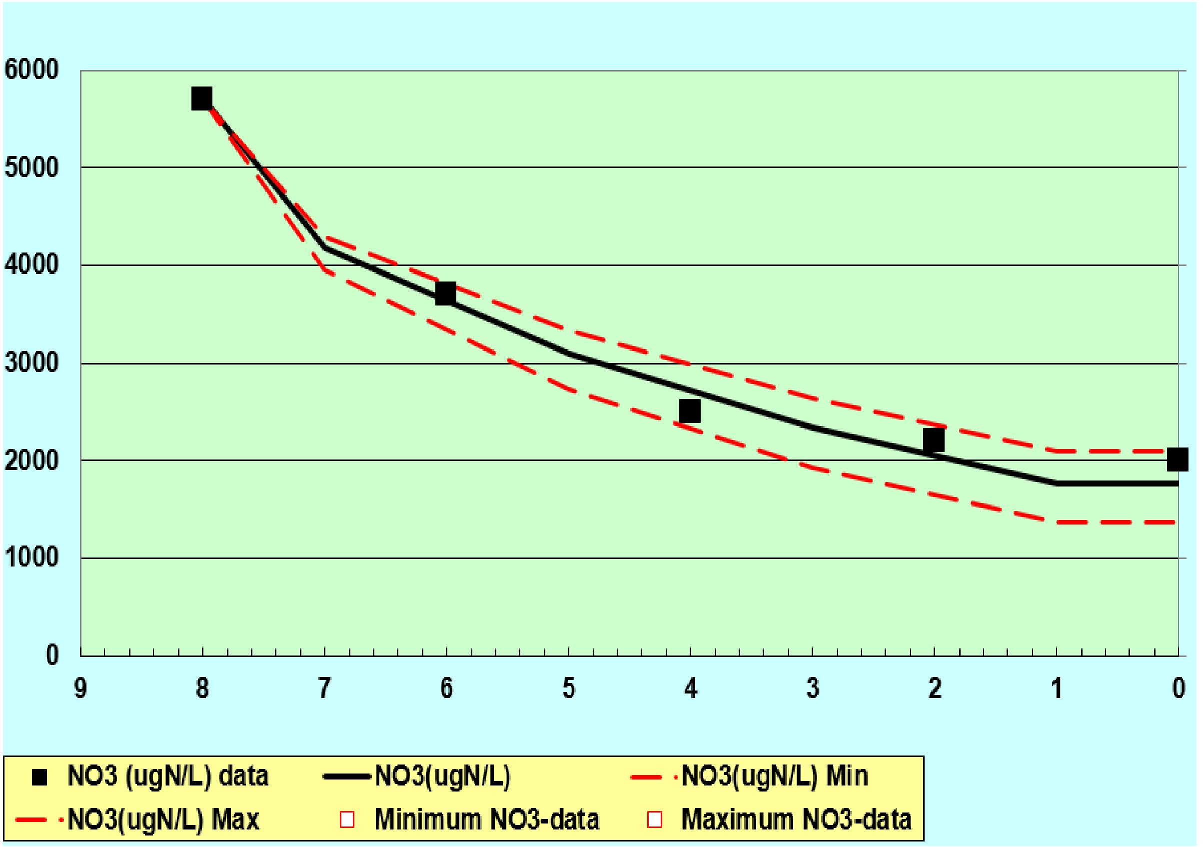


Fig 4. Spatial variation of NO3-N.

The simple regression analysis is performed on the two crucial parameters to validate the simulated and observed results. The Dissolved Oxygen values obtained from simulation and actual Dissolved Oxygen values from the samples collected at site were plotted in the graph as shown below (fig. 5). The root Mean Square Error (RMSE) is 0.6965. Similarly, the other important parameter for Nitrate Nitrogen also plotted the graph between observed and simulated results, the RMSE for this parameter is 0.9912 (fig. 6). For both DO and NO_3-N good correlation is observed.

5. CONCLUSIONS

A stream water quality model, QUAL2Kw, was calibrated and validated for a reach of 10 km stretch downstream of Krishna River. Both qualitative and quantitative analysis of water was performed by field study and experimental analysis conducted in March 2018. The results from the practical study were used for simulating the model, thereby model could be calibrated. The simulated parameters were compared with the observed data for validation. The two vital parameters, i.e., Dissolved Oxygen and Nitrate Nitrogen were validated using regression analysis. The Root Mean Square Error (R^2) values between the simulated and observed data for DO and NO_3-N are 0.69 and 0.99 respectively. From the result, good correlation is observed for both parameters; therefore, QUAL2Kw model could be used for modeling the stream water quality.

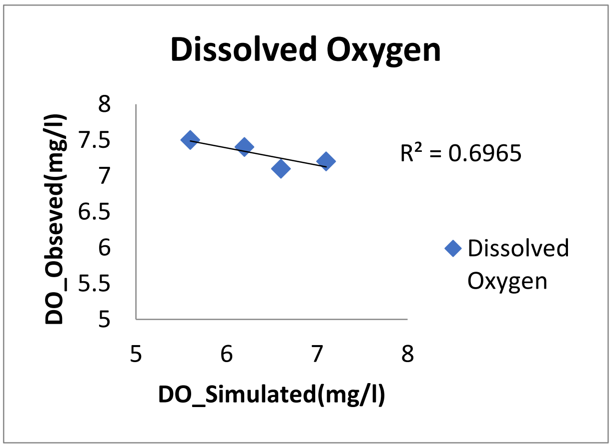


Fig. 5 Comparison of Observed and Simulated DO

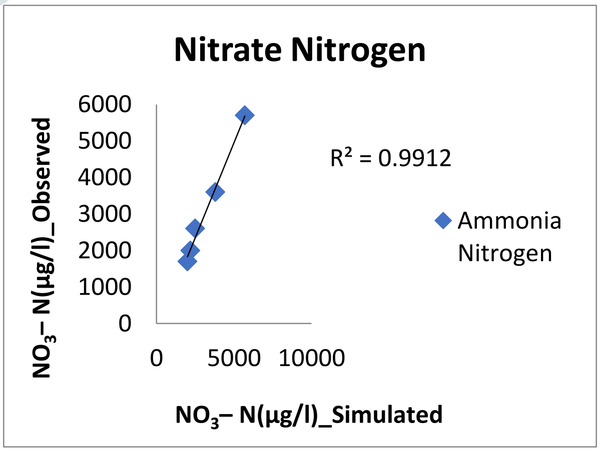


Fig.6 Comparison of Observed, Simulated NO_3-N

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