International Journal of Engineering and Technical Research (IJETR)
ISSN: 2321-0869, Volume-2, Issue-6, June 2014

Mathematical Modelling for Water Quality Prediction along the Stretches of Brahmani River in Angul of Orissa, India

Rizwan Reza And Gurdeep Singh

Abstract— **The most of the existing models assume a constant flow rate of river cross section during quality prediction. The application of such models in wide rivers can't return the accurate results, which may not reliable for devising suitable mitigative measures. The river Brahmani is considerably much wide and many tributaries carry the effluents of different industries such as coal mines, thermal power plants and aluminium smelters etc with various pollutants, which have different characteristics in nature to degrade the river ecosystem. The present study has been conducted to simulate water quality along the stretches of Brahmani river in Angul-Talcher region of Orissa during winter season. The velocity variation over the cross section, changes in river dimensional, the impact of river course, and the percentage and the settling velocity of particulate maters duly incorporated in the present model. It has been observed that the model is effective and economic to study the water quality dispersion along the river stretches with 1.5 to 12.5% of error compare to the analyzed data. The present study may be useful for the concern industrialists and environmentalists to devise the suitable pollution control strategies.**

Index Terms— **computation model, conservation parameters, flow rate, quality prediction, river water, velocity distributive function,**

I. INTRODUCTION

The river water is being utilized for various purposes such as drinking, bathing, agriculture and industrial use. Most of the Industries are responsible for polluting the environment, particularly the nearby river systems by continuous discharge of the industrial effluents. Such Industries are always located on or nearby the bank of rivers. Therefore, it is very much warranted that a study on the dispersion characteristics of pollutant species along multi wastewater- outfall river system has to be considered in order to develop an indigenous and effective algorithm for water quality prediction, which would lead for designing suitable predictive system for better river quality management using appropriate mathematical models for simulating the water quality along the river stretches.

Most of the existing software has many limitations. These models have been developed with many assumptions with the aim to simplify the governing equations into the standard form of differential equations, which can easily be solved through analytical methods. These models assume the velocity over the cross section of the river system as constant. The assumption of constant velocity over the cross section would cause significant error in the measure of flow rate and the predicted water quality data would possess a less accuracy [Grantham, 1970; Thayer and Krutchkoff, 1967; Sundararajan et al. 2002a: Mohan and Sundararajan 2010b]. Therefore, a study has been carried out for predicting non-conservative parameters along the multi-industrial-wastewater-outfall river stretch using the basic Streeter and Phelps model [Streeter and Phelps, 1925], which was improved by incorporating the ratio of setteable bio-flocculated particulate matters [Bhargava, 1989] and later it was further improved duly incorporating velocity variation over the cross section of the river system and river dimensional variations adopting various steps, techniques and tools of system analysis [Sundararajan et al. 2002a].

In this research paper, an appropriate method of predicting surface water quality using various steps, techniques and tools of system analysis has been presented along with a case study carried out for predicting water quality along the stretches of Brahmani River in Angul-Talcher Region of Orissa.

II. MATERIALS AND METHODS

A. Study Area

The study area is bounded by latitudes 20° 37' 00" N to 21° 10' 00" N and longitudes 84° 53' 00" E to 85° 28' 00" E and situated at an average height of 139 m above mean sea level. The river catchment is characterized by Precambrian granites, gneisses and schists of Eastern Ghats with local intrusive and volcanic lithologies; lime stone, sand stone and shales of the Gondwanas (Konhauser et al. 1997; Panda et al. 2006; Sundaray et al. 2006; Sundaray 2009). River Brahmani enters the Angul district through Rengali reservoir and passes through Angul-Talcher-Meramundali region (from northwest to southeast) of Orissa. Finally Brahmani river drains into Bay of Bengal after flowing through Jajpur & Kendrapara district of Orissa. The drainage network is controlled by river Brahmani. It is a perennial river and has innumerable large and small tributaries. It meets with its four tributaries such as Tikira, Singhara and Nandira in Angul-Talcher region of Angul district while Kisinda meets the Brahmani river at Meramundali in Denkanal district. Water of Brahmani and its tributaries cater to the industrial/domestic need of this fast growing industrial complex and in return they release thousands of gallons of wastewater to the river and tributaries. The drainage pattern is controlled by the River Brahmani along with its tributaries. River Brahmani plays as a major source of water, as well as sink for discharging effluents from the existing industries.

Manuscript received June 14, 2014.

Rizwan Reza, Assistant Professor, Dept. of Civil Engineering, B. A. College of Engineering and Technology, Jamshedpur, Jharkhand India

Gurdeep Singh, Professor, Dept. of Environmental Science and Engineering, Indian School of Mines, Dhanbad, Jharkhand, India

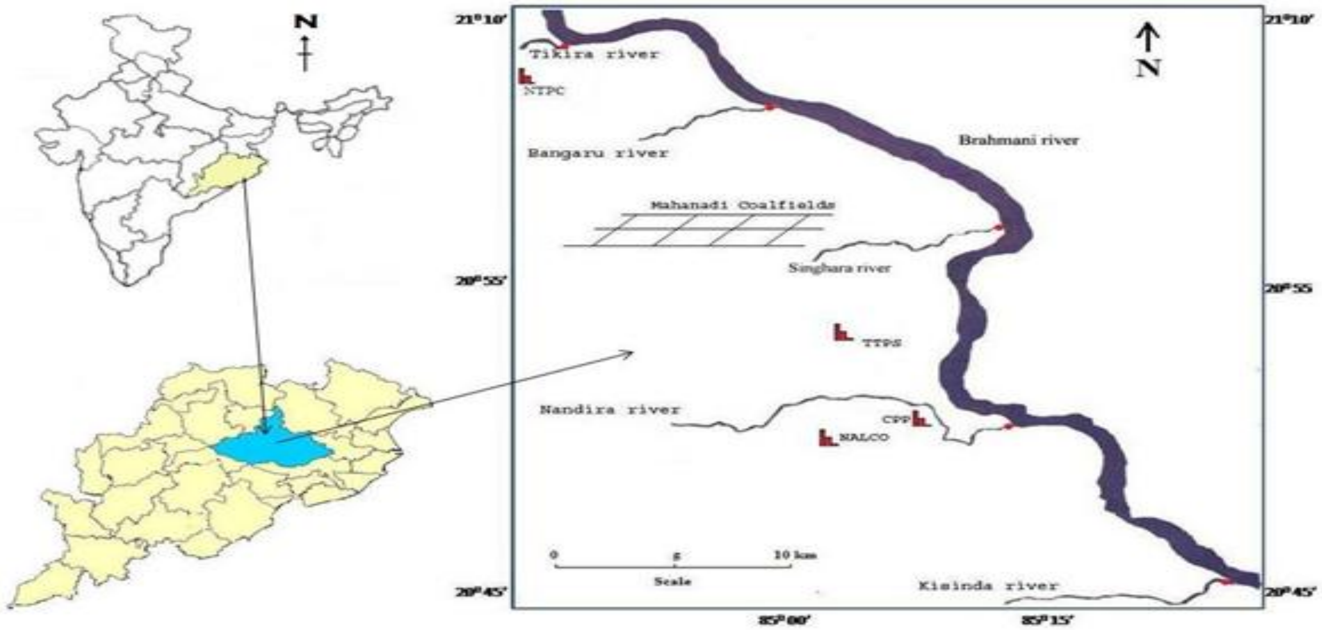

Fig.1. Geographical representation of study area

B. Sampling and analysis

In order to have a fairly comprehensive picture of the intensity of pollution of the river systems, winter season has been considered. For the river dimension can be measured more accurately in winter season than other seasons. In the monsoon season, the pseudo data are inputted as river dimensions due to excess water flow while the flow becomes very lean due to the high evaporation rate and almost rainless days in the summer season. The water samples were collected from all five tributaries, just before meeting into Brahmani river. The Samples were taken from 10 to 15cm below the water surface using previously cleaned polyethylene container as per standard procedures (APHA, 2005). Each analysis was carried out in triplicate and the mean value was taken for consideration. The physical parameters of river such as width, depth and stream velocity the tributaries as well as the main river were considered for the estimation of accurate and rational flow rate. The entire river course between the reference point at Anantapur and the end point at Kisinda Jhor has been divided into six stretches by means of the mixing points of five tributaries i.e., the Tikira, the Singhara, the Bangaru, the Nandira and the Kisinda, and further the model has been applied to predict the water quality along these river stretches.

C. Prediction modeling

The climate condition of the study area does not vary dramatically during winter. Therefore the effect of solar radiation is assumed to be negligible in this area. The quality of water is significantly controlled by the river water flow as well as varying nature of river dimensions such as river width, depth and river course, which considerably alter the stream velocity. As a result, the dispersion scenario of water pollutants in the river stretches considerably vary along the river stretches. Further, the Bramani river has many tributaries, which carry the pollutants and toxic elements from different sources such as coal mines, TPPs, iron & steel, aluminium industries and townships etc, The selected model incorporates the velocity variation over the cross section of the river, dimensions of the river stretches such as width, depth and stream velocities. It also takes into account the physiochemical characteristics of tributaries that blend with the main river.

The model has been developed based on fundamental truth that the concentration of the non-conservative water quality parameter at time ‘t’ is directly proportional to the rate of change in the initial concentration. The measure of BOD contributed by bio-flocculated particulate matters has been accounted in this study. The model has been derived taking the settling velocity of the settleable bio-flocculated particulate matter. The flow rate is one of the most important input parameters in river quality prediction. No model is appropriate to assess the accurate flow rate of the river system. The equations/software are used in assess the flow rate with very less percent of error from data obtained in the field survey. Therefore, an appropriate model has been chosen for computing accurate and rational flow rates in order to avoid error in prediction.

1) Velocity distributive function

The velocity distributive function in the cross section of the water flow region in laminar flow condition has been derived as

$$V(x, y, z) = V_m\left[\left(1-\frac{y}{D}\right)-\left(\frac{x}{a_o}\right)^2\right] \qquad (1)$$

In case of the river whose cross section is non-symmetric subject to depth axis, the velocity of the stream flow may be assumed by the following function:

$$V(x, y,z) = \begin{cases} V_m \left[\left[1 - \frac{y}{D}\right] - \left[\frac{x}{a_o}\right]^2 \right] & \text{if } 0 \le x \le a_o \\ V_m \left[\left[1 - \frac{y}{D}\right] - \left[\frac{x}{b_o}\right]^2 \right] & \text{if } b_o \le x < 0 \end{cases} \qquad (2)$$

1) Computation of flow rate

If $\hat{u}$ (x,y) is the average stream velocity of the finite element whose center is (x,y), then the flow rate of river or stream can be computed as follows:

$$Q = 2 \sum_{\substack{y = \delta y/2 \\ \text{step} = \delta y}}^{D} \left(\sum_{\substack{x = 0 \\ \text{step} = \delta x}}^{a_y} \left[\hat{u}\,(x, y)(\delta x \,.\, \delta y) \right] \right)$$

(3)

In case of non-symmetric cross sectional river system with the extremities of top layer width (a_o, 0) and (b_o, 0), the flowrate can be computed as follows:

The flow rates of the river in the positive and negative direction of width axis have respectively been computed using the following Equations (4) and (5).

Thus the total flow rate of the stream over the non-symmetric cross sectional river system can be obtained as $Q=Q^{+}+Q^{-}$.

When the finite element thickness δx and δy are tending to zero, Q tends to accurate.

$$Q^{+} = \sum_{\substack{y = \delta y/2 \\ \text{step} = \delta y}}^{D} \left(\sum_{\substack{x = 0 \\ step = \delta x}}^{a_y} \left[\hat{u}(x, y)\,(\delta x \,.\, \delta y) \right] \right) \text{ if } 0 \le a \le a_o$$

(4)

$$Q^{-} = \sum_{\substack{y = \delta y / 2 \\ \text{step} = \delta y}}^{D} \left(\sum_{\substack{x = 0 \\ step = -\delta x}}^{b_y} \left[\hat{u}(x, y)\,(\delta x \,.\, \delta y) \right] \right) \text{ if } b_o \le b_y \le 0$$

(5)

Estimation of dispersion coefficient

The extent to which a stream can be approximated by a one or two-dimensional model also influences how well dispersion coefficients can be estimated. Furthermore, the degree of averaging in space and time in solving the affective-dispersive equation can influence the magnitude of the dispersion coefficient shown by calibration. In some cases, numerical dispersion can be comparable, to actual dispersion. When this occurs, the dispersion is specified as zero (i.e., Dx=0), or better still as the difference between the actual and the numerical dispersion. Dispersion coefficients can be estimated for every river and such estimation may quantify the ability of the river to assimilate waste. Later dispersion studies were conducted to show that dispersion was not an important part of the steady-state waste assimilate capacity. More recently, interest seems to have returned to the dispersive capability of a stream as concern have heightened regarding the mixing of hazardous waste spills and as efforts have intensified in the modelling of dynamic water quality conditions. The dispersion coefficient (k) for the river can be estimated using the following mathematical formula.

$$k = \frac{u^2}{2} \left(\frac{\sigma^2_{t_2} - \sigma^2_{t_1}}{t_2 - t_1} \right) \qquad (6)$$

where u is average stream velocity, t1 and t2 are the mean times of passage for the dye cloud to move past stations 1 and 2, and σ2t1 and σ2t2 are the variance of the time versus concentration curves.

Influence of settleable BOD component

The fraction of settleable BOD component contributes while it is transported along the river stretch up to some distance depending upon the settling velocity of the settleable components in dynamic condition. If the settling velocity is significantly less, then the distance along the downstream stretch will be increasing. Bhargava has attempted to incorporate the contribution of settleable BOD component in order to predict the concentration of part of BOD concentration, Cs with respect to the fraction of settleable BOD component, p.

$$C_s = pC_o \left[1 - \frac{v_s}{D} t \right] \quad \text{when } v_s t \le D \qquad (7)$$

where vs is the settling velocity of the component, Co is the initial concentration, D is the average, depth of the river and t is the time travelled by the components along the river stretch in the downstream. Further, Bhargava [1989] has also derived the other component of BOD prediction, resulted by the non-settleable BOD component as follows:

$$C_{ns} = (1 - p)C_o\, e^{-kt} \qquad (8)$$

The above Equations (7) and (8) are added up to get the combined effect of settleable as well as non-settleable BOD components in BOD prediction along the river stretch.In the above attempt, the influence of stream velocity on the settling velocity of the setteable particulate matter in dynamic river system has not been accounted. The model has been further improved by modifying as a 3D model, taking the variation of velocity and depth over the cross section of river system as follows.

Three-dimensional water quality prediction model

Bhargava (1989) have been derived to predict the water quality along the river stretch assuming the river stretch as one-dimensional and the depth and width of the river are constant. This model can be easily modified as a three-dimensional if the cross section of the river is divided into finite number of volumetric element in order. By using the velocity distributive function, the velocity of each volumetric element can be predicted. Since the length of each stretch is known, the varying time length taken by each volumetric element to travel the constant length of the stretch can be computed. Here it can be noted that the number of elements over the cross section will be constant for each stretch of the river. It is assumed that the dimensions of the volumetric element corresponding to either width or depth axis increases when there is an increase in the respective dimensions of width or depth. In this case, it is necessary to assess the flow rate of water passing the cross section of each volumetric element. Since such tasks involve number of calculations and incorporation of depth and width variation of stretches, the river stretch can be sufficiently divided into finite number of segments. However, the computer program has to be designed to incorporate all the data related to the river dimensions as well as the in-taking and discharging rate of water and effluent and the physico-chemical characteristics of the effluent of the point source mixing with the main river system. If there is no such source, except the river dimensions all other parameters can be taken as zero.

The 3D-water quality prediction model for predicting the non-conservative parameters, whose initial concentration and maximum stream velocity just after the critical mixing distance are co and vo respectively at the location x=0, y=0, z=0 has been derived adding the Equations (7) and (8) in order to have the combined effect of settleable and non-setteable particulate matters. Thus, the 3D water quality prediction model may be obtained duely incorporating the effect of settling velocity of settleable bio-floculated particulate matters as follows:

$$C(x,y,z) = p\left(\frac{c_o v(x,y,z)}{v_o}\right)\left[1-\frac{v_s^{'}e^{-k^{'}v(x,y,z)}}{\frac{D}{a_o^2}(a_o^2-x^2)}\left(\frac{z}{v(x,y,z)}\right)\right]+(1-p)\left(\frac{c_o v(x,y,z)}{v_o}\right)\mathrm{e}^{-\frac{\mathrm{kz}}{\mathrm{v(x,\,y,z)}}}$$

where C(x,y,z) is the concentration of the non-conservative parameter in the water transported through the volumetric element whose centre is the point P(x,y,z) and the velocity is v(x,y,z). p is the fraction of the bio-flocculated particulate matters, v’s is its settling velocity in static condition of the river, D is the maximum depth of the river over the width but average over the length of the stretch, k is the dispersion coefficient of the pollutant species and k’ is the dispersability coefficient of the settleable bio-flocculated particulate matters. First, the computer program input the data related to the reference point of the river. Successively, the subroutine starts for n times where n is the number of outfalls considered for the prediction studies and the program inputs the dimensions of the river and the physico-chemical parameters related to respective outfalls for the respective number of subroutines in order to predict the concentration of the water quality along the successive stretches. The flowchart of the computer program for water quality prediction along the river stretch joining the points, where the stream velocity is more than the velocities over the cross section of the river system has been presented in Figure 2.

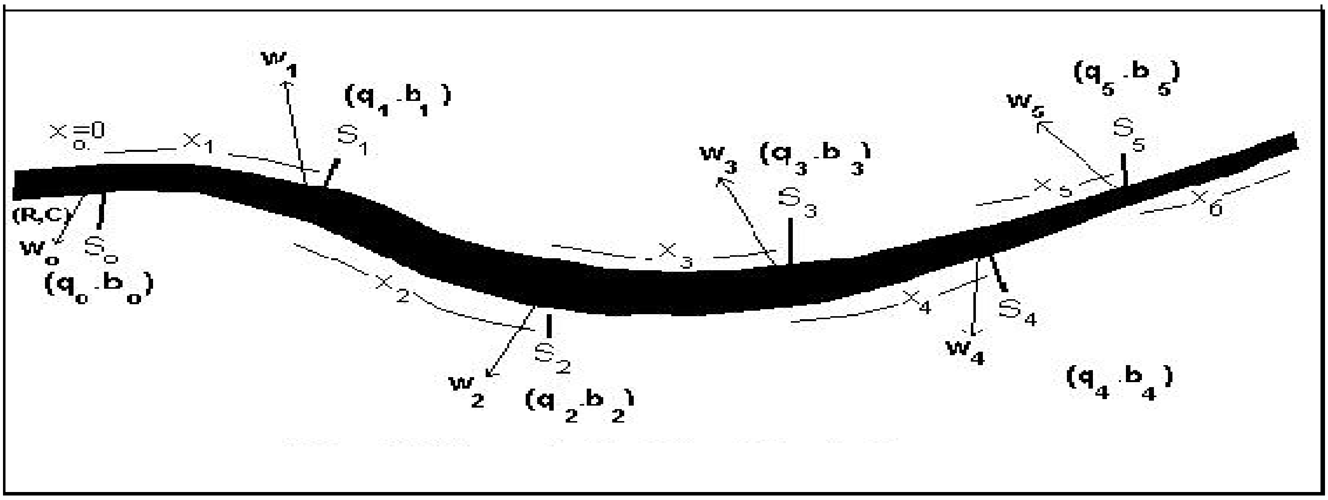

Fig. 2 Schematic diagram for river stretch along with their tributaries

R = River flow rate of at reference point
C = Water quality of river at reference point
X = Distance from last outfall (X1=2 km, X2=5km, X3=19.5km, X4=36.5km, X5= 49km)
S =Name of Outfalls/Streams (S0= Reference point, S1=Tikira Stream, S2= Singhara Stream, S3=Bangaru Stream, S4=Nandira Stream, S5= Kisinda Stream
W = Water quantity drawn from outfalls
q = Flow rate of each outfall and
b = Water quality of outfall.

Table.1 Details of input data along with tributaries of Brahmani river

Code	Parameters / Rivers	Longitude	Latitude	Distance from last out fall (km)	Total Width (W)	Maximum Depth (Dm)	Maximum Velocity (Vm)	ao	bo	Flow Rate (m3/sec)
S0	Reference Point (near Ananta pur)	85007’19”	21006’09”	0.0	55.0 m	1.06 m	0.14 m/s	-30	25	2.57
S1	Tikira river	85005’07”	21005’40”	2.0	35.0 m	1.02 m	0.25 m/s	-15	20	1.15
S2	Singhara river	85006’50”	21004’00”	3.0	14.0 m	0.73 m	0.13 m/s	-4	10	0.352
S3	Bangaru river	85014’00”	21000’40”	14.5	10.0 m	0.61 m	0.17 m/s	-0.5	9.5	0.274
S4	Nandira river	85015’35”	20053’00”	17.0	20.0 m	0.76 m	0.4 m/s	-10	10	1.613
S5	Kisinda river	85020’30”	20048’30”	12.5	8.5 m	0.67 m	0.14 m/s	-5	3.5	0.174

Table 2. Water Quality of various Tributaries of Brahmani river in Winter Season

Sl. No	Parameters	Ref. Point (S0)	Tikira (S1)	Singhara (S2)	Bangaru (S3)	Nandira (S4)	Kisinda (S5)
	TDS (mg/l)	174	206	411	594	288	341
	SS (mg/l)	41	74	156	216	56	97
	Fluoride (mg/l)	0.1	0.1	0.9	1.2	1.3	1.8
	Chloride (mg/l)	7.1	14.2	67.2	46.2	10.7	28.4
	Sulphate (mg/l)	40	28	52.8	62.9	25.0	42.5
	DO (mg/l)	7.0	7.8	4.9	4.3	6.7	4.2
	BOD (mg/l)	1.8	1.9	2.7	4.9	1.3	1.7
	COD (mg/l)	27.0	44.6	107.3	126.5	66.8	86.3

III. RESULTS AND DISCUSSION

As the concentration of non-conservative parameters change due to dispersion phenomena, the concentration of such parameters varies with respect to the ‘time’ or ‘distance’. Using the mathematical formula, which has been discussed elsewhere in the thesis, the dispersion coefficients have been estimated and used for the prediction of non-conservative parameters as follows: k = -2.0 x 10-5 for BOD, COD, TSS, SO4, Fluoride and Chloride, k = -2.0 x 10-7 and k = 1.4 x 10-7 DO and TDS. The calibrated model was used to predict the water quality with an independent set of data as a part of validation exercise. Results of model predictions were fairly good, and performance of the model was further confirmed through statistical evaluation of the results.

A. Biological Oxygen Demand

A reference point two km away from the confluence point of Tikira tributaries with Brahmani river was considered at Anantapur. Initially the concentration of BOD was 1.8 mg/l and it was decreasing in the downstream into1.1 mg/l and then mixed with the Tikira tributary. The concentration after the critical mixing distance increases to 1.3mg/l, which has been predicted to be 1.43 mg/l with acceptable error of 10% using the present model. Again the concentration of BOD decreases gradually into 0.78 mg/l after travelling of 3 km distance and then mixed with Singhara tributary whose BOD concentration was 2.7 mg/l. The concentration of BOD in Brahmani hikes into 1.45 mg/l after the critical mixing distance, whereas the predicted data shows to be 1.41mg/l with error 2.8% which is acceptable. Now the BOD concentration decreases significantly into 0.16 mg/l after travelling of 14.5 km. The concentration of BOD in Brahmani river goes up into 0.53 mg/l after the mixing distance when Bangaru tributary blended with the main river. In the case the predicted concentration is 0.55 mg/l with error of 3.6%. The concentration of BOD in Brahmani river after following of 17.5 km significantly decreases and blends up with Nandira tributary whose BOD concentration is 2.4 mg/l. After well-mixing, the concentration of BOD in Brahmani becomes 0.75 mg/l, which has been predicted as 0.7 mg/l with error of 6.6%. The concentration gradually decreases and mingles with Brahmani and results into the concentration of 0.23 mg/l, which has been predicted as 0.22 with error of 3.4%. The concentration of BOD was predicted for five kilometers after the confluence point of Kisinda and Brahmani and it has been observed from the result that the quality of water has been significantly improved. In all the above cases, the error percentage varies from 2.8 to 10, which may be acceptable for practical purpose of river quality management.

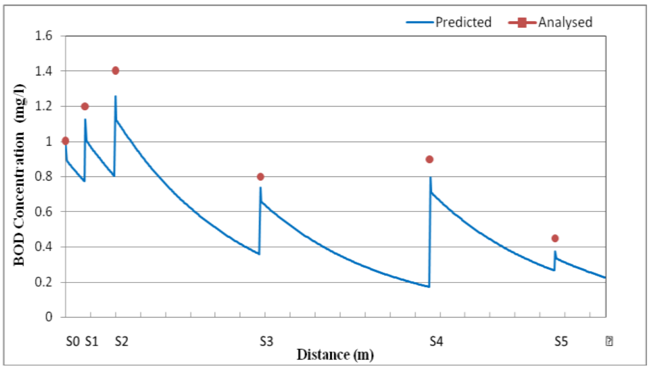

Fig. 3 Prediction of BOD concentration within river stretch

B. Dissolved Oxygen

Initially the concentration of DO at the reference point of river was 6.9 mg/l. In actual analysis of DO, the concentrations of DO in the downstream of Brahmani river are: 7.3 mg/l just after the confluence of Tikira and Brahmani, 7.2 mg/l just after the confluence of Singhara, 7.1 mg/l just after the confluence of Bangaru, 6.9 mg/l just after the confluence of Nandira and 7.1 mg/l just after the confluence of Kisinda, whereas the predicted concentration of DO are 7.3 mg/l, 7.1 mg/l, 7 mg/l, 7 mg/l and 6.9 mg/l at the respective confluence points of the tributary with the main river. In all the cases, the error varies from 0 to 2.8%, which may be acceptable.

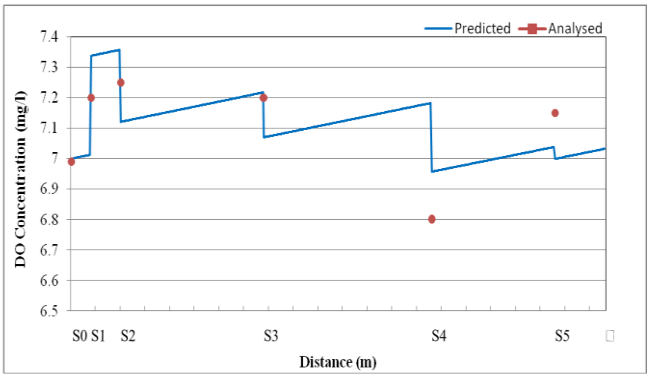

Fig. 4 Prediction of DO concentration within river stretch

Total Dissolved Solids

The actual concentration of TDS, near the reference point, was 194 mg/l and it was decreasing in the downstream and then it mixed with the Tikira tributary. The concentration of river becomes 199 mg/l. After the mixing of Singhara and Bangaru tributaries the predicted TDS concentration of river goes up to 216 and 210 mg/l while the actual data was 209 and 214 mg/l respectively. After travelling of 17.5 km distance the concentration was reduced to 205 mg/l and then mixed with Nandira (233 mg/l), the predicted TDS concentration of river becomes 211 mg/l while the actual concentration of the river water was 202 mg/l with 1.8% error. The concentration has been predicted as 208 mg/l after the mixing of Kisinda whereas the actual concentration was 211 mg/l with error of 4.4%. Predicted model results indicate that, simulated TDS results were relatively in best agreement with the analysed values with relative error of 1.8-4.4%.

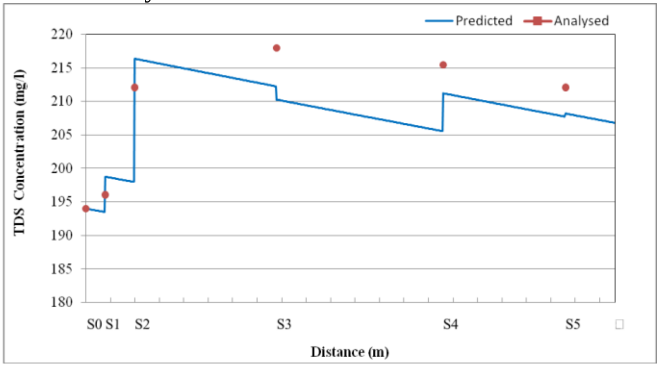

Fig. 5 Prediction of TDS concentration within river stretch

C. Total Suspended Solids

TSS value near the reference point was 41 mg/l and decreased into 31.8 mg/ in downstream. After the mixing of Tikira the maximum predicted concentration of TSS in river water was 49 mg/l whereas the actual was 45.5 mg/l with error of 7%. Similarly the TSS concentration was predicted as 43.7 mg/l after the mixing of Singhara while the actual data was 46.5 mg/l with 6% error. The TSS concentration were decreasing (6.4 mg/l) with the distance of 14.5 Km, then mixed with Bangaru and the concentration was raised up to 11.2 mg/l with maximum error of 9%. Again after the travelling of long distance (17 km), then the river water with the TSS concentration of 1.2 mg/l mixed to the Nandira and concentration of TSS was going to increased up to 16.2 mg/l where as the actual concentration was 14 mg/l with error of 7%. After the mixing of Tikira the TSS concentration was predicted as 6.5 mg/l while actual concentration was 7.1 mg/l with 7.6 % error.

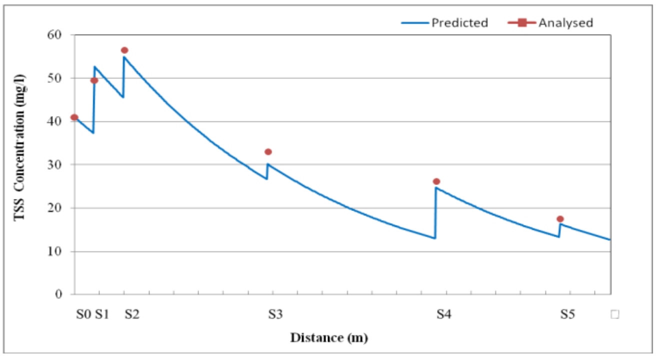

Fig. 6 Prediction of TSS concentration within river stretch

D. *Chemical Oxygen Demand*

In the case of COD, initially the concentration of COD was 57 mg/l and it was decreasing in the downstream into 44.2 mg/l and then mixed with the Tikira tributary. The concentration after the critical mixing distance increases to 51mg/l, which has been predicted to be 55 mg/l with acceptable error of 7.8%. Again the concentration of COD decreases gradually into 37.3 mg/l after travelling of 3 km distance and then mixed with Singhara tributary whose COD concentration was 127 mg/l. The concentration of COD in Brahmani hikes into 43 mg/l after the critical mixing distance, whereas the predicted data shows to be 44.5 mg/l with error 3.4% which is acceptable. Now the COD concentration decreases significantly into 6.3 mg/l after travelling of 14.5 km. The concentration of COD in Brahmani river goes up to 9 mg/l after the mixing distance when Bangaru tributary blended with the main river, while the predicted concentration was 8.4 mg/l with error of 6.6%. The concentration of COD in Brahmani river was significantly decreased after following of 17.5 km and blends up with Nandira tributary whose COD concentration is 76.2 mg/l. After well-mixing, the concentration of COD in Brahmani becomes 19.5 mg/l, which has been predicted as 18 mg/l with error of 7.7%. The COD concentration gradually decreases and mingles with Kisinda and results into the concentration of 6.2 mg/l, which has been predicted as 5.6 with error of 9.6%. The concentration of COD was predicted for five kilometres after the confluence point of Kisinda and Brahmani and it has been observed from the result that the quality of water has been significantly improved. In all the above cases, the error percentage varies from 3.4 to 9.6 which may be acceptable for practical purpose of river quality management.

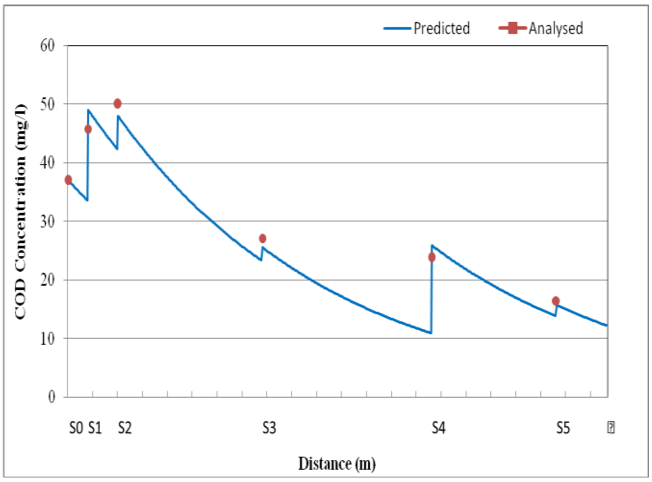

Fig. 7 Prediction of COD concentration within river stretch

E. *Chloride*

Chloride concentration at the reference point of river was 14.2 mg/l. In actual analysis of chloride, the actual concentrations of chloride in the downstream of Brahmani river are: 15.5 mg/l (after the confluence of Tikira and Brahmani), 15.2 mg/l (after the confluence of Singhara and Brahmani), 3.6 mg/l (after the confluence of Bangaru and Brahmani), 2.8 mg/l (after the confluence of Nandira and Brahmani) and 1.35 (after the confluence of Kisinda and Brahmani), whereas the predicted concentration of chloride are 16.3mg/l, 14.3mg/l, 3.3 mg/l, 2.65 mg/l and 1.3 mg/l respectively. In all the cases, the error varies from 6 to 9% which may be acceptable.

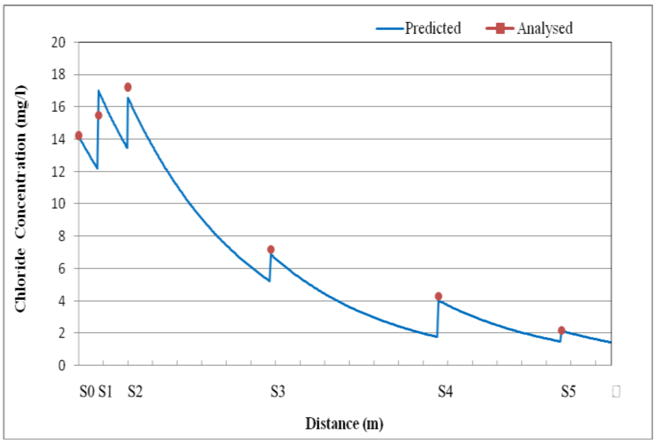

Fig. 8 Prediction of Chloride concentration within river stretch

F. *Sulphate*

The actual concentration of sulphate near the reference point was 28.3 mg/l and it was decreasing in the downstream and then it mixed with the Tikira tributary. The sulphate concentration of river was 30.9 mg/l while the predicted concentration becomes 32.2 mg/l with error of 4%. The concentration of sulphate decrease gradually in to 21.8 mg/l and after the mixing of Singhara and Bangaru tributaries the predicted sulphate concentration of river goes up to 26 and 7 mg/l while the actual concentration was 28 and 8.5 mg/l respectively. After travelling of 17.5 km distance the concentration was reduced to 0.75 mg/l and then mixed with Nandira (45 mg/l). The actual sulphate concentration was 13.5 mg/l where as the predicted concentration of river becomes 12.8 mg/l l with 5.5% error. The concentration has been predicted as 4.4 mg/l after the mixing of Kisinda whereas the actual concentration was 4.8 mg/l with error of 10%.

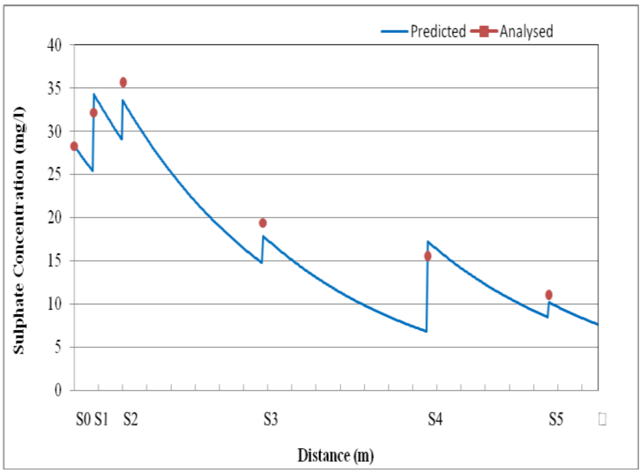

Fig. 9 Prediction of Sulphate concentration within river stretch

G. *Fluoride*

Fluoride's concentration near the reference point was 0.9 mg/l and decreased into 0.7 mg/l in downstream. After the mixing of Tikira the actual concentration of fluoride in river water was 0.74 mg/l whereas the predicted was 0.72 mg/l with error of 4%. Similarly the fluoride concentration was predicted as 0.55mg/l after the mixing of Singhara while the actual data was 0.5mg/l with 9.3% error. The fluoride concentration were decreasing (0.08 mg/l) with the distance of 14.5 km, then mixed with Bangaru and the actual concentration was raised up to 0.24 mg/l while the predicted concentration was 0.22 with error of 9%. Again after the travelling the distance of 17 km, the river water with fluoride concentration of 1.2 mg/l mixed to the Nandira then the concentration was increased up to 0.37mg/l where as the actual concentration was 0.34mg/l with error of 8%. After the mixing of Tikira the fluoride concentration was 0.13mg/l while prediction concentration was 0.14 mg/l with 7.6 % error.

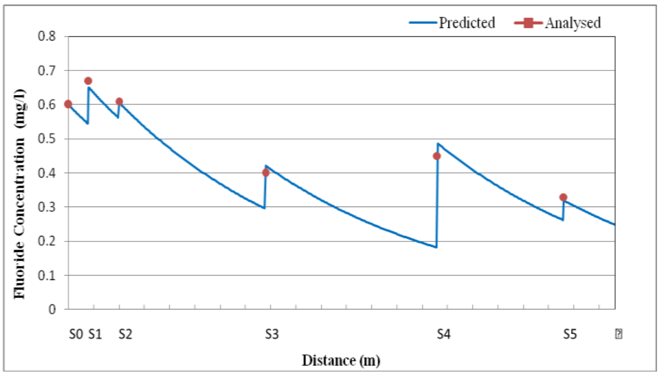

Fig. 10 Prediction of Fluoride concentration within river stretch

IV. CONCLUSION

The model has been applied for predicting river water quality during winter only as turbulence flow takes place during monsoon and lean flow during summer season. The selected model is only applicable while laminar flow takes place. Water quality prediction during lean period in Bramani river is somewhat complex as diversified flows take place in the wide river bottom.

The model is effective in predicting the non-conservative parameters with errors varying from 0 to 10%. In the cases of predicting the non-conservative parameters, the error percentage varies from 0 to 10%, which is acceptable in predicting water quality in mining and its allied industrial complexes [Sundararajan, 2004]. Here the error percentage may again decrease if the non-point sources are considered in the present study as the present study has been carried out only considering the point sources.

ACKNOWLEDGEMENT

The authors would like to express sincere gratitude to the Orissa state pollution control board (OSPCB) and Ministry of Human Resource and Development (MHRD), Government of India for funding the study. One of the authors (Rizwan Reza) is grateful to Indian School of Mines (ISM) for its support and providing research fellowship.

REFERENCES

[1] Ghose, M.K. and Kumar, A. (1993) Impact of Surface Water due to Discharge of Coal Washery Effluent and Dispersion Profile of Pollutants in Damodar River, Asian Environment, pp.32-40.

[2] Thayer, R. and R. G. Krutchkoff, (1967).Stochastic Model for BOD and DO in Streams, J. San. Eng. Div., ASCE, 93(SA3).

[3] Sundararajan, M (2004). Mathematical Modeling of Fluid Components Transport for Prediction of Environmental Parameters in and around Coal Washery Complexes, Dept. of Applied Mathematics, ISM, Dhanbad. (Unpublished thesis).

[4] Sundararajan, M. et al (2002a) Role of IT In River Quality Management and Application of RQM Infosys for Water Quality Prediction Studies, National Seminar on Mine ventilation, Safety and Environment, Organized by CMRI, Dhanbad, Pp.623-634.

[5] Sundararajan, M. et al (2002b) Impact of Coal Preparation Plants On Nearby Fluvial Systems and Assessment Through Mathematical

[6] Modeling And Computer Simulation, International Conference on challanges in Coal & Mineral Benefeciation, Organized at I.S.M, Dhanbad, Pp.303-310.

[7] Grantham, G. R.,(1970) Model for Flow Augmentation Analysis - an Overview, J. San. Eng. Div., ASCE, 96(SA5), Proc. Paper 7578.

[8] Wunderlich, W. O. (1972) Heat and Mass Transfer Between a Water Surface and the Atmosphere Water Resources Research Laboratory Report No. 14, Report No. 0-6803, Tennessee Valley Authority Norris.

[9] Streeter, M.W and Phelps, E.E. (1925) A Study of the pollution and Natural Purification of the Ohio River, U.S.Public Health Service Eulletin, pp.146.

[10] Bhargava, D.S. (1989) Most Rapid BOD Assimilation in Ganga and Yamuna, Jl. Env. Engg, American Society of Civil Engineers, vol.109, no.1, pp.pp.194-196.

[11] Mohan A and Sundararajan M (2010). Algorithm Development for Water Quality Prediction System along Industrial Outfall River Stretch Using Modeling and Computer Simulation. International Journal of Engineering Science and Technology, Vol. 2(11) 6204-08.

Dr. Rizwan Reza is a Assistant Professor and Head of Civil Dept of BACET, Jamshedpur, Jharkhand, India. I did graduation, post graduation and Ph.D in Environmental Sc. & Engg. My areas of Research Interests are: water & waste water Engineering; Solid Waste management and EIA/EMP. He has about 06 years of Research and Consultancy experiences. I published 09 international journals and 02 nation journals along with several national and international conferences.

Prof. Gurdeep Singh is the founder member of the Centre of Mining Environment, ISM, Dhanbad. His areas of Research Interests are: Water & Air Pollution; Environmental Aspects of Solid Waste Disposal Utilization; EIA and Environmental Auditing. He has about 25 years of Teaching, Research, HRD/Consultancy. He has completed 9 R&D projects sponsored by MOEF, World Bank and MHRD. He has published about 224 Research papers, edited 9 books and guided 17 Ph.D students. He is also on the Editorial Boards of few Journals and associatedwith various professional bodies such MGMI, MEAI, IAEM, IGS, SGAT, IAAPC, IES, etc.