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A STUDY ON THE IMPACT OF COALWASHERY EFFLUENTS ALONG DAMODAR RIVER STRETCH IN DHANBAD DISTRICT, JHARKHAND, INDIA

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ABSTRACT

An appropriate pollutant species transport model has been applied for the prediction of water quality parameters along the Damodar river stretch. This paper addresses the incorporation of various influencing parameters in water quality dispersion phenomena such as velocity variation over the cross section, variation in river dimension and settleable bio-flocculated particulate parameters. A computer aided model has been developed and applied to compute accurate and rational flow rate as the flow rate is one of the most important parameter for accurate water quality prediction. As most of the existing models assume the river as one dimensional while predicting water qualities, 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 Damodar is considerably wide and many tributaries carry the effluents of different industries such as coal mines, coal washeries, coke plants and townships with various types of 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 Damodar river in Dhanbad district during winter season. The velocity variation over the cross section, changes in river dimension, 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 3 to 7% of error compare to the analyzed data. Non-conservative water quality parameters such as Total Suspended Solids (TSS), Total Dissolved Solids (TDS), Biological Oxygen Demand (BOD), Dissolved Oxygen (DO) and Chemical Oxygen Demand (COD) have been predicted in order to study the dispersion phenomena of the river stretch blended with washery effluents. The present study may be useful for decision makers, industrialists and environmentalists to devise suitable Environmental Management Plan and to design appropriate meditative measures

Keywords – Stream velocity distributive function, accurate river flow computation model, river quality dispersion modelling.

INTRODUCTION

The river water is used for various purpose such as drinking without treatment, bathing, non-contact recreational uses, public water supplies, industrial, agricultural, aqua-culture and wild life propagation, navigation and waste receiving etc. The quality requirements of water for various beneficial uses would be different. A good river quality management program should ensure the quality of water at each and every point throughout the river stretch. Water quality is maintained at a level appropriate for the intended use requiring the highest quality of water. To know the suitability of the river water for intended beneficial uses, it is most desired that an accurate and rational assessment of river quality should be made after the confluence point of wastewater effluent outfalls into the river. Therefore it is very much warranted to develop appropriate prediction model. Though the development of mathematical model was in progress in different areas of sciences, the research based on simulation was very much limited due to lack of fast computational facilities [1]. A revolution came three decades ago in modeling and simulation when the super computers were invented [2]. Particularly, there was a sudden change in the tread of number of models developed in water and air environments [3-7]. Though much attention has been paid to simulate the suitable flow sheets for preparing the coals for the indented use on the basis of the characterization of the coal received from the nearby mines in order to increase the production of coal to meet the fast growing demand of the energy of the world, unfortunately less focus has been made for simulating the environmental impact of coal preparation plants on the environment [1]. In the present study, appropriate mathematical models have been developed on the basis of the governing equation derived out of the initial and boundary conditions of the problems. Further, using the models, simulation of water has been done in and around the coal washery complexes situated at the bank of Damodar river stretch. 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 [8, 9]. 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 [10]. Therefore, a study has been carried out for predicting non-conservative parameters along the multi-industrial-wastewater-outfall river stretch using a basic Streeter and Phelps model [11-13], which has been further improved by incorporating the ratio of settleable bio-flocculated particulate matters 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 [14]. In this research paper, an appropriate method of predicting surface water quality using various steps, techniques and tools of system analysis have been presented along with a case study carried out for predicting water quality along the multi-outfall-river stretches of Damodar river, starting from Mahuda coalwashery to the confluence point of Govai nadi and Damodar River in Dhanbad District of Jharkhand State.

MATERIAL AND METHODS

Study area

A window containing seven coal washery complexes, situated nearby the Damodar River stretch of about 38km in Dhanbad district of Jharkhand State in India was chosen for the present study. The geographical boundary of the study area is 23°35'00" to 23°45'00" N latitude and 86°15'00" to 86°30'00" E longitude. The study window has been divided into three sub-windows covering the river course have been considered for the present study and the total area of the study windows is about 50km^2. The location of the study area has been shown in **Fig.1**. The river stretch starts from the outfall point of Mahuda Coal Washery to the confluence point of Gobai River with Damodar, which carries the effluents of coal washeries from Mahuda, Munidih, Jamadoba, Patherdih, Sudamudih, Chasnallah and Bhojudih to the Damodar river stretch. The river stretch, which has been considered for the present study is just, located at the bottom of the Jharia Coalfield in southern side. The Jharia Coalfield is about 100 years old and subjected to intensive mining activities because of easy availability of coal at shallow depths in thick seams. The Coalfield is such exploited due to selective and unsystematic mining during pre-independence period. It is having a total area of 450km^2 and produces about 27,000 tonnes of prime coking coal. The Coalfield is divided into 14 areas and each area is having different opencast and underground mines. These mines are being operated by Bharat Coking Coal Limited (BCCL) under Coal India Limited (CIL). There are 14 coal washeries, being operated by CIL, located along the River Damodar with capacity of 26.53million tonnes per annum. Total clean coal produced by these washeries is 7.9 million tonnes per annum. Coal beneficiation process consumes clear water in range of 0.2 to 0.25 m^3/tone of raw coal input and the total water demand for beneficiation process is approximately 0.5 million m^3 [15]. The washeries discharge the effluent in to the river system 300-500 m^3 in a day. About 6–10 tones of good quality coal are lost in the form of fine particle [16]. Seven coal washeries and other allied industries like coke oven plant, power plants are situated along the stretch between Mahuda Coal Washery and the confluence point of Gobai river and Damodar. The tributaries carry the effluents of nearby coal washeries, surrounding mines and allied industries and finally blend with Damodar River. The selected river stretch for the present study has been reported as a highly polluted zone [17-24].

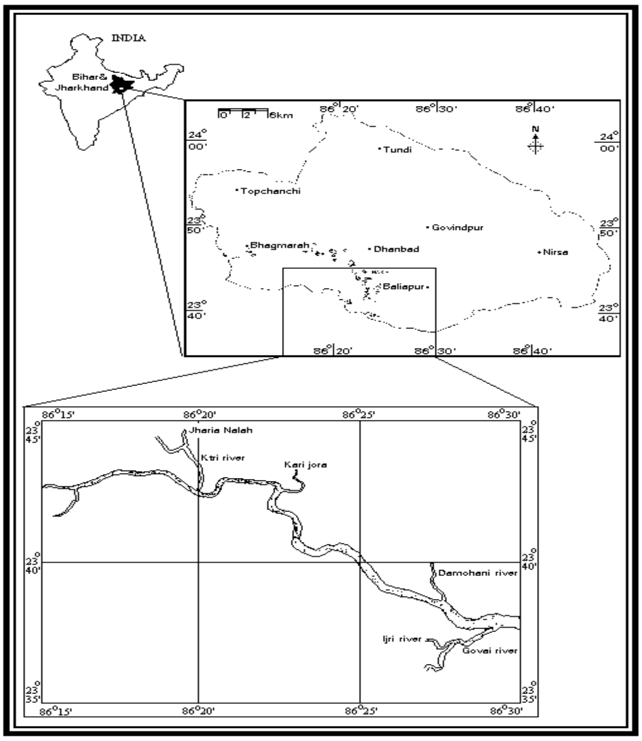

Fig.1 Location map of the study area

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 clean polyethylene container as per standard procedures [25]. 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 Mahuda and the end point at confluence Point of Govai River and Damodar River has been divided into nine stretches.

Water Quality Dispersion 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 significantly vary along the river stretches. Further, the Damodar River has many tributaries, which carry the pollutants and toxic elements from different sources such as coal mines, coalwasheries and townships. The selected model incorporates the velocity variation over the cross section of the river, dimensions of the river stretches such as width, depth and river course in term of stream velocity as impacts flow augmentation [14]. 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 suitable numerical method 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. An appropriate computer aided model based on the velocity distribution model has been chosen for computing accurate and rational flow rates in order to avoid error in prediction.

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

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

In case of the river whose cross section is non-symmetric subject to depth axis, which defined to be the length of line joining vertically a point on the top most layer whose steam velocity is maximum and a point at the bottom of the river, where the river depth is maximum, the velocity of the stream flow may be assumed by the following function:

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

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:

$$Q = 2 \sum_{\substack{y = \delta y/2 \\ step = \delta y}}^{D} \left(\sum_{\substack{x = 0 \\ step = \delta x}}^{a_y} \left[\hat{u}(x,y)(\delta x \,.\, \delta y) \right] \right) \qquad (3)$$

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).

$$Q^+ = \sum_{\substack{y = \delta y/2 \\ step = \delta y}}^{D} \left(\sum_{\substack{x = 0 \\ step = \delta x}}^{a_y} \left[\hat{u}(x,y)(\delta x \,.\, \delta y) \right] \right) \quad \text{if } 0 \le a_y \le a_o \qquad (4)$$

$$Q^- = \sum_{\substack{y = \delta y/2 \\ step = \delta y}}^{D} \left(\sum_{\substack{x = 0 \\ step = -\delta x}}^{b_y} \left[\hat{u}(x,y)(\delta x \,.\, \delta y) \right] \right) \quad \text{if } b_o \le b_y < 0 \qquad (5)$$

where values a_y corresponding to its depth y is estimated using $a_o\ (1\text{-}y/D)^{1/2}$. Similarly, values b_y corresponding to its depth y is estimated using $b_o\ (1\text{-}y/D)^{1/2}$. 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 layer thickness δx is tending to zero, Q tends to accurate. Using least square method, the equation of right fit for the plots different layer thickness and its corresponding computed flow rates was derived and the accurate flow rate was computed while layer thickness equal to zero using limit in order to avoid prediction error in the water quality.

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 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, 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:

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

where u is average stream velocity, t_1 and t_2 are the mean times of passage for the dye cloud to move past stations 1 and 2, and σ^2_{t1} and σ^2_{t2} are the variance of the time versus concentration curves.

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, C_s with respect to the fraction of settleable BOD component, p.

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

where v_s is the settling velocity of the component, C_o 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, in 1989, Bhargava has also derived the other component of BOD prediction, resulted by the non-settleable BOD component as follows:

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

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.

Bhargava [26] has derived a prediction model to simulate 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 c_o and v_o 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 three-dimensional water quality prediction model may be obtained duly incorporating the effect of settling velocity of settleable bio-flocculated particulate matters as follows [14]:

$$C(x,y,z) = p\left(\frac{c_o v(x,y,z)}{v_o}\right)\left[1 - \frac{v'_s e^{-k' v(x,y,z)}}{\frac{D}{a_o^2}(a_o^2 - x^2)}\left(\frac{z}{v(x,y,z)}\right)\right] + (1-p)\left(\frac{c_o v(x,y,z)}{v_o}\right) e^{-\frac{kz}{v(x,y,z)}} \quad (9)$$

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.

Development of Flowchart and Algorithm

Appropriate models for river flow estimation and river quality prediction were selected for developing algorithm. The river system was divided into ten stretches and various river dimensions such as average depth, width and critical mixing distance, maximum stream velocity were analyzed. River network showing the outfall points and length of the stretches for water quality prediction modeling has been presented in **Fig.2.**

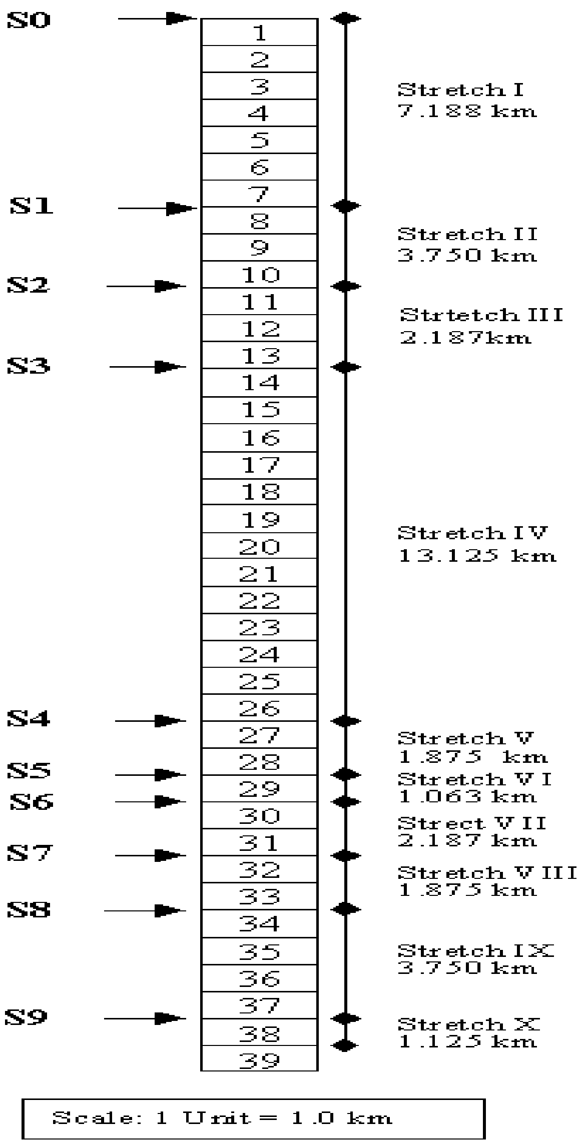

Fig.2 River network showing the outfall Points and length of the stretches for water quality prediction modelling

An algorithm, which consists five modules has been developed for predicting water quality along the river system.The first module, Part-A is 'User Authentication Module' to use this software an authorized user is allowed. This module verifies that the user who wants to access the software must enter authenticated username and password. The second module, Part-B is 'Velocity Estimation Module' is the module, which helps the user to estimate maximum velocity corresponding to the co-ordinate where maximum depth occurs over the cross section of the river system.

The third module, Part-C is "Flow Rate Computation Module This module helps the user to compute total accurate and rational flow rate of the river water over the cross section,. The fourth module, Part-D is 'Water Quality Prediction' takes the flow rate value from the previous module (Part C) and helps the user for predicting the conservative as well as non-conservative water quality parameters along the river stretches which the user desires for prediction. The fifth module 'Presentation Module' takes the predicted data from the previous module (Part D) and helps the user for plotting the water quality parameters against the river stretches. The algorithm is given in the next page.

Algorithm

Part A: User Authentication Module: To use this software an authorized user is allowed. This module verifies that the user who wants to access the software must enter authenticated username and password.

1. Input: UserName
2. Input: Password
3. If UserName = <User Data Base.Username> then

   (a) If Password = <User Data Base.Password> then

      (a.1) Grant access of RQM Infosys main module
      (a.2) else prompt to enter valid password
         GOTO step 2

   (b) else initialize counter to 0 (cnt = 0)
      (b.1) prompt to enter valid user name
         GOTO step 1
      (b.2) increase cnt by 1 (cnt =cnt+1)
         (b.2.1) if cnt > 3 then exit

Part B: Velocity Estimation Module: This module helps the user to estimate maximum velocity corresponding to the co-ordinate where maximum depth occurs over the cross section of the river system.

1. Input: distance to the point where the velocity measured from the bank of the river (a_y)
2. Input: distance to the bank of the river from the point where maximum velocity occurs (a_o)
3. Input: Stream velocity measured (v_x)
4. Estimate maximum velocity at top layer of river where maximum depth occurs

$$V_o = v_x /[1-(a_0 - a_y)/a_0]^2$$

Part C: Flow Rate Computation Module: This module helps the user to compute total accurate and rational flow rate of the river water over the cross section.

1. Prompt then read the data to be processed. (D= Depth of River; a_o = Positive side of the river width in

respect of x axis; b_o = Negative side of the river width in respect of x axis; V_m = Maximum Velocity at top layer of river)

2. Divide the cross sectional area in the positive direction of x-axis into finite number of small distinct square elements with dimensions δx, δy.
   The number of partitions in the width of surface layer is $(n = (a_o - b_o) / \delta x)$

   The number of layers with thickness δy in the cross section is $(m = D / \delta y)$

3. Initialize counter to 0 (y=0; x=0; F=0)
4. While (y <= m) do
   a. Calculate $a_y = |\pm a_0(1-y/D)^{½}|$
   b. While ($x <= a_y$) do
   (b.1) Calculate the Average velocity of cross sectional area for layer between the depth
   D =(m-1) δy and D = mδy.
   (b.1.1) At left-top corner point:
   $v(x, y)= [v_m(0,0)(1-y/D)-(x/a_y)^2]$
   (b.1.2) At right-top corner point:
   $v(x+\delta x, y)= [v_m(0,0)(1-y/D)-((x+\delta x)/a_y)^2]$
   (b.1.3) At left-bottom corner point:
   $v(x, y-\delta y)= [v_m(0,0)(1-(y-\delta y)/D)-(x/a_y)^2]$
   (b.1.4) At right-bottom corner point:
   $v(x+\delta x, y-\delta y)= [v_m(0,0)(1-(y-\delta y)/D)-((x+\delta x)/a_y)^2]$
   (b.1.5) Calculate Average Velocity
   $v=[v(x,y)+v(x+\delta x,y)+v(x,y-\delta y)+v(x+\delta x,y-\delta y)]/4$
   (b.2) Calculate Average Flow rate: f= v* δx*δy and add it to the previous flow rate
   (F = F + f) and save the calculated data.
   (b.3) increment x by δx GOTO step 4b
5. Increment y by δy GOTO step 4.
6. Computation of Coss Sectional Area:
   (6.1) $comp1=D(a_o - b_o)$
   (6.2) $comp2= D(a_o + b_o) *(a_o^2 - b_o^2) / 2a_o b_o$
   (6.3) $comp3= D*(a_o^3 - b_o^3) / 3a_o b_o$
   (6.4) CSA= comp1 -comp2 + comp3
7. If $a_0 = b_o$ then
   (7.1) Total Flow rate of cross section of river Q= 2*F GOTO step 8
   (7.2) Else, Q1=F and repeat the step 4 set $a_y = b_y = |\pm b_0(1-y/D)^{½}|$, Q=Q1+F

Part D. Water Quality Prediction: This module takes the flow rate value from the previous module (Part C) and helps the user for predicting the conservative as well as non-conservative water quality parameters along the river stretches which the user desires.

1. Input: Length of a unit distance (in meter); u
2. Input: Maximum Velocity at Ref. Point; Part-A . Step5 . v_o
3. Input: Upstream river flow at Ref. Point; Part C.Step 7 . Q:
4. Input: Cross Sectional Area at Ref. Point; Part C.Step (6.4).CSA
5. Input: No. of outfalls; n
6. Input: Upto what distance you would like to predict the water quality from the last outfall point; x dist
7. Initialze counter to 0 (i=0;d=0)
8. While (i <= n) do
   (8.1) Input: Code of the outfall station; S$(i)
   (8.2) Enter River Dimensions for (i+1)th Stretch:
   (8.2.1) Input: right x-coordinate; a(i)
   (8.2.1) Input: left x-coordinate; b(i)
   (8.2.1) Input: maximum average depth; D(i)
   (8.3) Input: Distance to the previous outfall; x(i)
   (8.4) Assign z(i) = x(i): d = d + z(i)
   (8.5) Input: Critical mixing distance; m(i)
   (8.6) Input: Percentage of settle able bio-flocculated particulate matters; bfp(i)
   (8.7) Input: Setteling velocity of settle able bio-flocculated particulate matters; sv(i)
   (8.8) Input: Setteling coeficient of settle able bio-flocculated particulate matters; sc(i)
   (8.9) Input: Dispersion coeficient of water quality parameter; k(i)
   (8.10) Input: Quantity of water pumped out from river; w(i)
   Input : Effluent discharging rate; q(i)
   (8.11) Input: Concentration of the parameter in the river water just before outfall point (i+1); cr(i)
   (8.12) Input: Concentration of the parameter in the outfall just before the mixing point; ce(i)
   (8.13) If i = 0 then calculate; p(i) = Q – w(i)
   Else r(i)=p(i)+q(i)
   (8.14) else p(i) = r(i-1) - w(i)
   (8.15) Assign r(i) = p(i) + q(i); Q(i) = r(i)
   (8.16) Calculate the concentration of the parameter just after the critical mixing point;
   c(i) = [p(i)*cr(i)+q(i)*ce(i)]/ [p(i) +q(i)]
   (8.17) Computation of Coss Sectional Area:
   (8.17.1) comp1=D(a(i) – b(i))
   (8.17.2) $comp2= D(a(i) + b(i)) *(a(i)^2 - b(i)^2) / 2a(i) b(i)$
   (8.17.3) $comp3= D*(a(i)^3 - b(i)^3) / 3a(i) b(i)$
   (8.17.4) CSA(i)= comp1 - comp2 + comp3
   (8.18) Computation of River Velocity at (i+1)th Stretch
   (8.17.1) $rv(i) = (CSA/CSA(i)) *(Q(i)/Q)* v_o$
   (8.19) Assign: Q = Q(i)
   (8.20) Increment i= i + 1
9. Input "Which stretch you would like to predict?"; stretch

10. Input stream type: x, y
11. Initialize counter to 0(i=0; j=0; z=0)
12. While z <= z(stretch)) do
    (12.1) Compute Section-A
    (12.2) Assign: z = CINT(z(stretch - 1) + i)
    (12.3) Calculate: if x>=0, then v(x,y,z)=rv(i)*[(1-y/D(i)) – (x/a(i))^2] Goto Step (12.5)
    (12.4) Else: v(x, y, z) = rv(i)*[(1-y/D(i)) – (x/b(i))^2]
    (12.5) Comp1= sv(i)*(1/exp(sc(i))*v(x, y, z)) / D(i)
    (12.6) Comp2 = z / v(x,y,z)
    (12.7) Compute: c(z) = [bfp(i)*c(i)*v(x,y,z) / rv(i)]*(1-comp1*comp2)
    (12.8) Store z*u, c(z)
    (12.9) Increment i = i + 1: z = z+1
13. Input "Whether you would like to continue prediction (Y/N)?"; Ans$
    (13.1) Verify: If Ans$ = "y" or "Y" then Goto Step 9 Else Step (13.2)
    (13.2) Verify: If Ans$ = "n' or "N", then Goto Step (13.4)
    (13.3) Else "Syntax error!, please enter again"; Goto Step 13
    (13.4) Display "Successfully Prediction has been completed!

Part E. Presentation Module: This module takes the predicted data from the previous module (Part D) and helps the user for plotting the water quality parameters against the river stretches.

(1) Input: z*u, c(z) from stored data
(2) Draw x coordinate with context of z*u
(3) Draw y coordinate with context of c(z)
(4) While not EOF z*u do
    (4.1) x= stored data field Z*u
    (4.2) y = stored data field c(z)
    (4.2) draw line with pixel coordinates of x and y

Input Parameters

The average concentration of water quality at the reference point and the effluent quality of the coal washeries along with the water quality of tributaries that carry the effluents of coal washery and thermal power station were studied. The average values of physico-chemical parameters of the samples drawn from the river, streams and industrial effluents have been presented in **Table-1**.

These values are used as input parameters to the model. Further, the point to point water quality prediction along the river stretches from Mahuda to the confluence point of Gobai nadi with Damodar river using the present model with the average initial stream velocity 0.3013 m/s and 0.43571 m/s at the reference point for both pre-monsoon and post monsoon season respectively for non-conservative parameters Total Suspended Solids (TSS), Total Dissolved Solids (TDS), Dissolved Oxygen (DO), Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD).

Table-1 Concentration of water quality in Damodar River, Coal Washeries and Other Industrial and Tributaries

Source Code	Sources	Discharged Through:	Concentration Of Non-Conservative Parameters (Mg/L)									
			TSS		TDS		DO		BOD		COD	
			A	B	A	B	A	B	A	B	A	B
R	Damodar River (Upstream source)	Damodar	114	230	263	245	5.58	5.78	10.92	4.25	182.5	78
S0	Mahuda Washery	Directly	1273	1148	303	378	3.37	4.42	7.23	12.98	3598	2605
S1	Loyabad Coke Plant Loyabad PH Loyabad Township	**Katri River**	238	333	260	303	5.975	6.65	19.95	16.9	308	313
S2	Moonidih Washery	Directly	1208	1478	337	373	3.90	3.48	4.45	14.43	3675	7286
S3	Jamadoba Washery Jamadoba Ph-1&3 Jamadoba Township	Jitpur Jore	374	418	285	313	5.75	5.63	6.22	6.25	126	136
S4	Patherdih Washery Patherdih Township	Patherdih Jore	643	630	392	429	4.63	5.15	6.63	5.88	1933	1981
S5	**Sudamudih Washery**	Directly	1789	1534	563	414	3.38	4.43	7.23	12.98	3967	7507
S6	Chasnallah Washery	Directly	1458	1594	362	400	3.90	3.48	4.45	14.43	3675	7310
S7	FCI Sindri (outfall No.1) P&D Sindri and Sindri Township	Directly	889	1226	423	497	6.40	5.90	3.85	9.88	1876	851
S8	FCI Sindri (outfall No.2)	Damohani River	589	643	355	187	4.60	5.90	5.55	7.23	76	476
S9	Bhojudih Washery Santaldih TPS Bhojudih Township	Govai River	558	657	423	326	6.58	10.52	4.85	7.38	555	72

RESULTS AND DISCUSSIONS

It has been found that the concentrations of TSS and TDS in pre-monsoon are lower than the post monsoon season. This may be due to increased turbidity of water caused by soil erosion and surface wash out, which occurs in the rainy season. The concentration of BOD and COD decreasing in the downstream gradually and the quality of water is found to be improved in the downstream. Further it can be noticed that the concentration of DO is increasing in the downstream and it conforms that the quality of water is gradually improved. It has been observed that the river stretch has a capacity to improve the quality of water subject to some parameters whereas the concentration of TDS is increasing in the downstream from Mahuda to confluence point Gobai nadi with Damodar. After this confluence point the TDS is significantly decreasing as river is wide comparatively with other tributaries with less pollutants that meet the river in between Mahuda and the confluence point of Govai with Damodar whereas the Katri, Damohani, Kari nalah and Patherdih joria are smaller than the Govai nadi and carries more dissolved solids of the industrial effluents from the upstream river. The abundance of Gobai nadi dilutes the concentration of TDS significantly when it meets the main River Damodar. Further it can be noticed that the travelling distance of the Govai nadi water which carry the effluent of Bhojudih coalwashery and Santaldih Thermal Power Station is comparatively very less than the traveling distance of the effluents from the upstream of Damodar along its stretch. This may be the reason for high suspended solids and low dissolved solids after the point of the confluence point of Govai nadi with the main River Damodar. The non-conservative water quality parameters have been presented and the graphical representations of the predicted water quality have been presented in **Fig.3 to 12.**

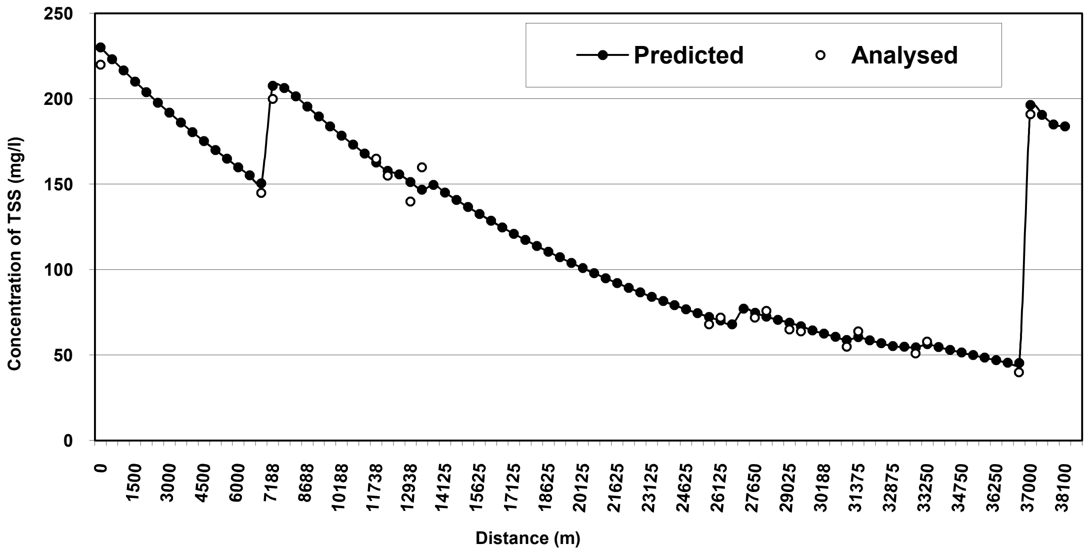

Fig.3- Prediction of Total Suspended Solids(TSS) during Pre-monsoon season

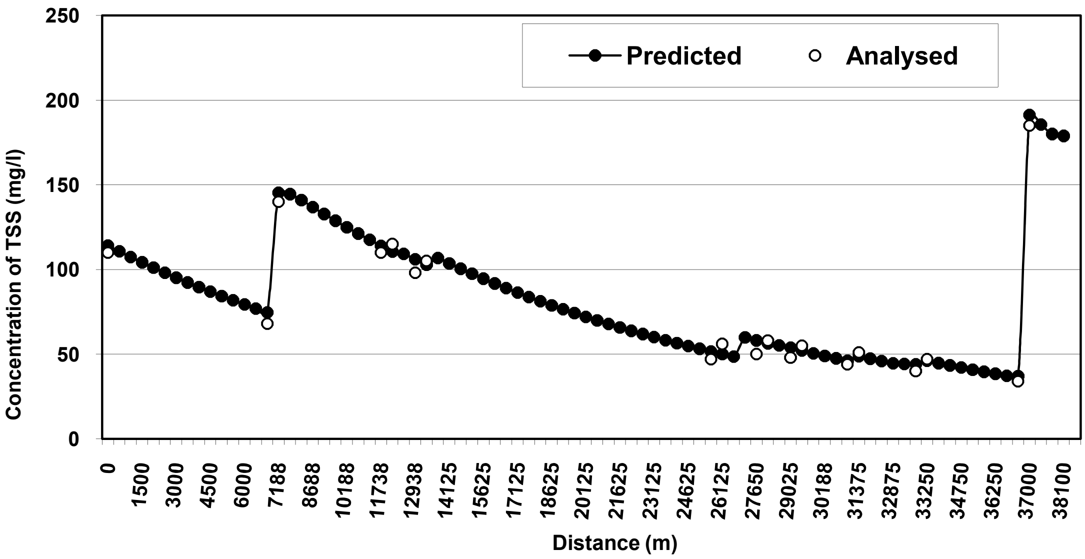

Fig.4 Prediction of Total Suspended Solids (TSS) During Post-monsoon season

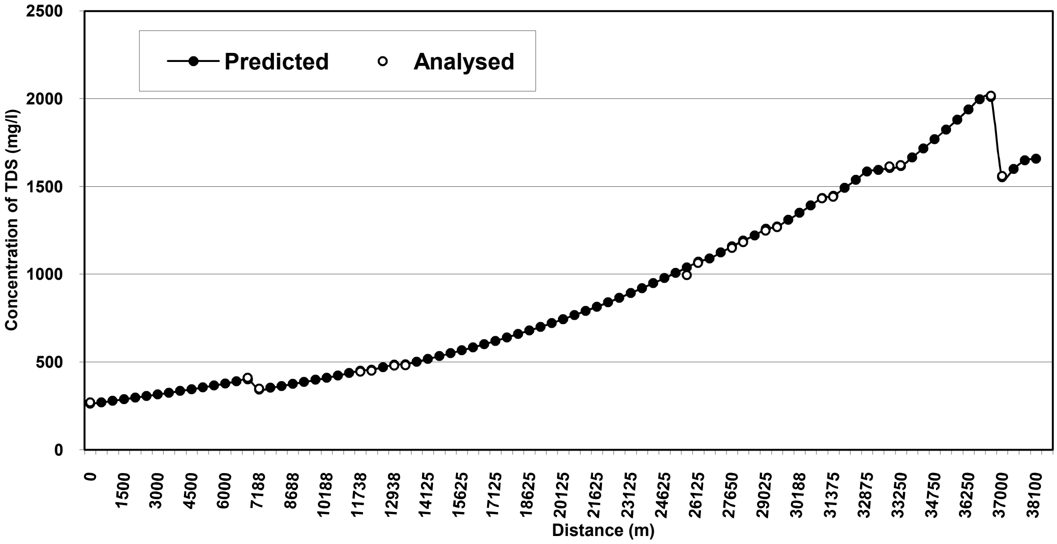

Fig.5- Prediction of Total Dissolved Solid (TDS) during post -monsoon season

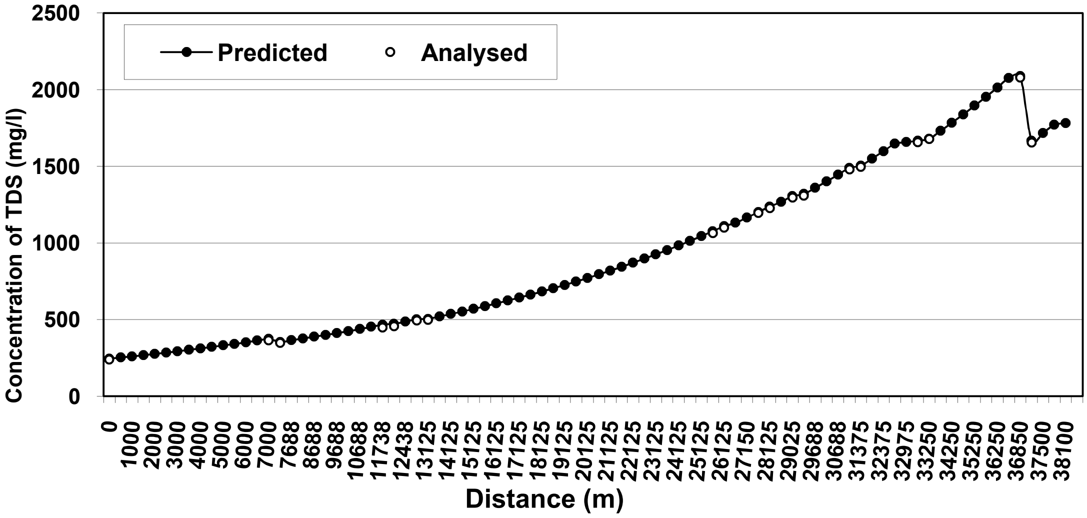

Fig.6 Prediction of Total Dissolved Solids(TDS) during post-monsoon season

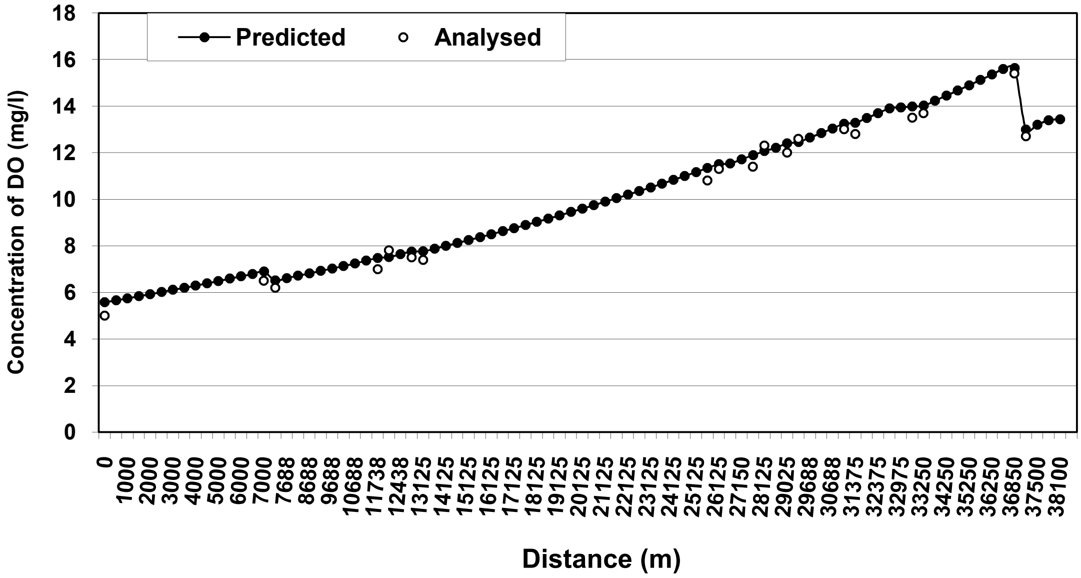

Fig.-7 Prediction of Dissolved Oxygen (DO) during pre-monsoon season

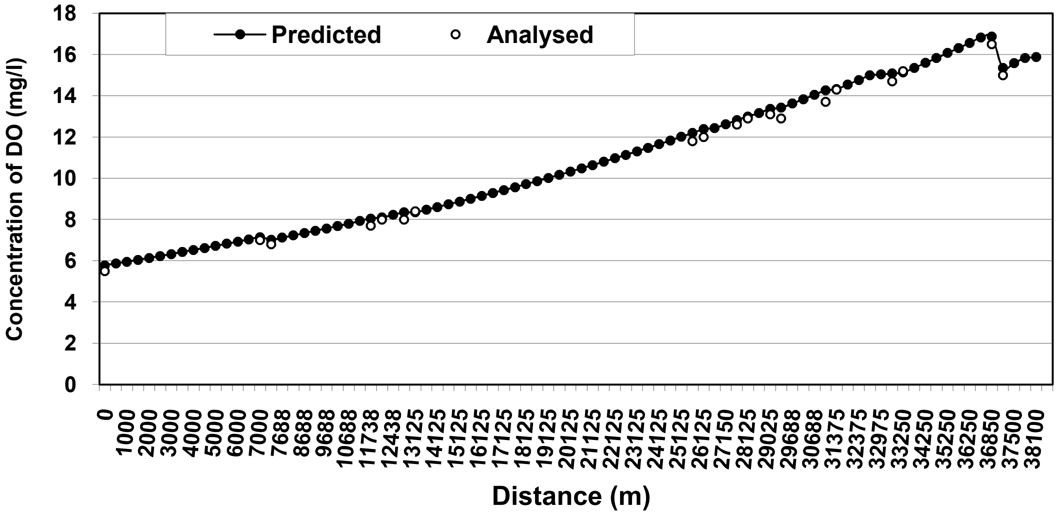

Fig-8 Prediction of Dissolved Oxygen (DO) During post-monsoon season

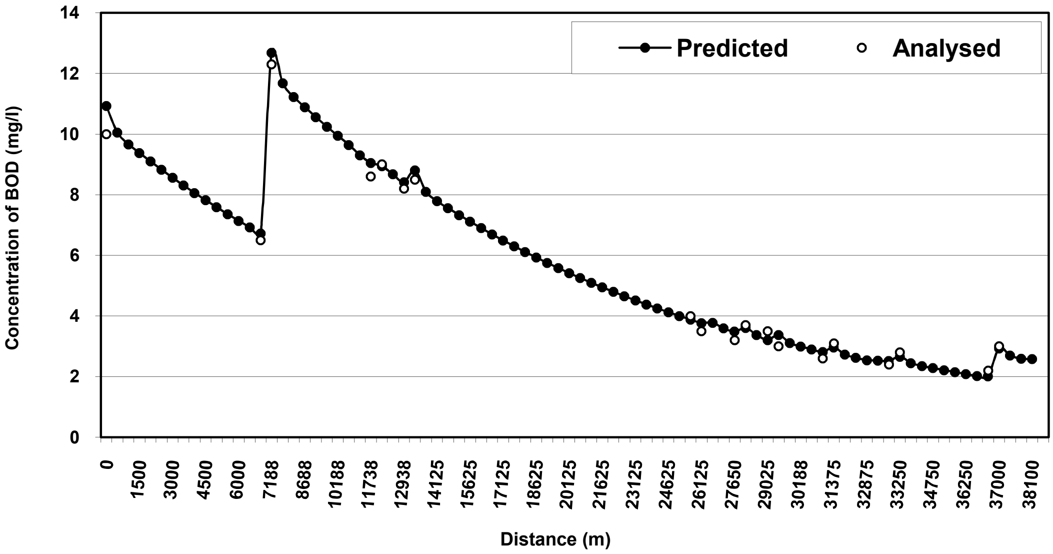

Fig.9 Prediction of Biological Oxygen DEmmmand (BOD) during pre-monsoon season

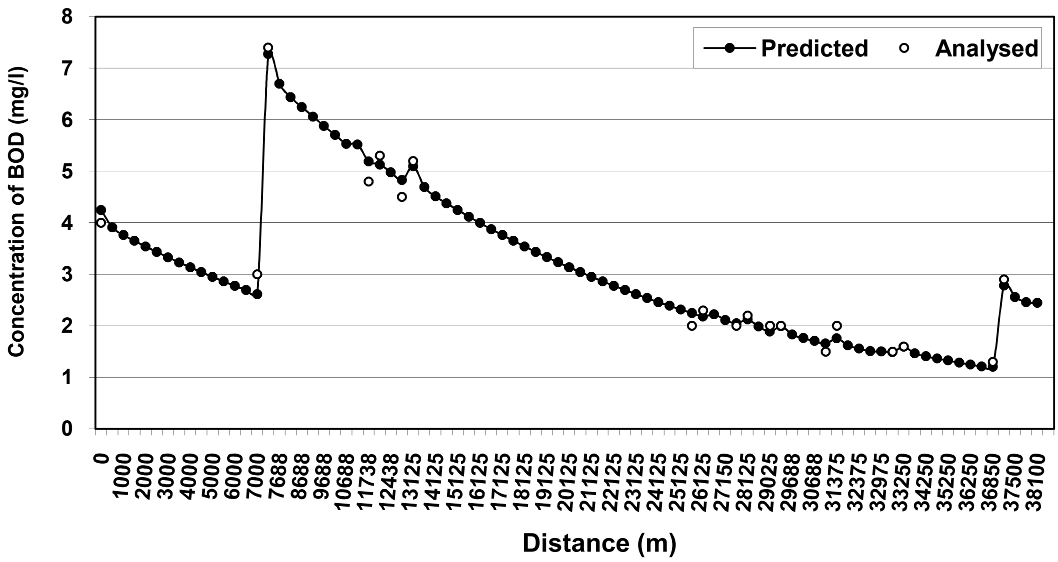

Fig.10 Prediction of Biological Oxygen Demond (BOD) during post-monsoon season

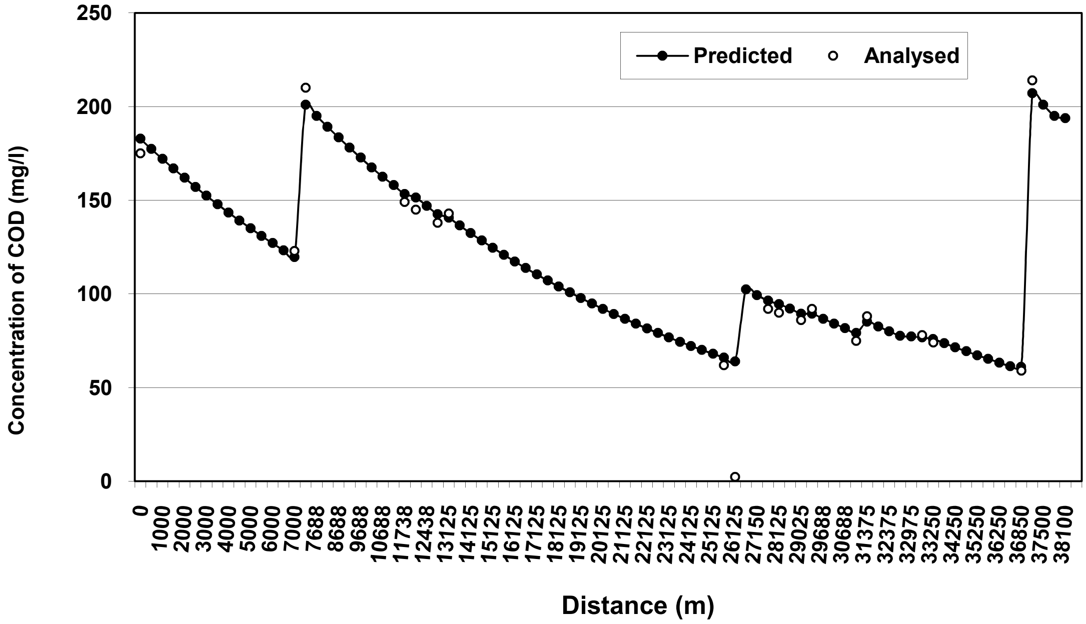

Fig. 11 Prediction of Chemical Oxygen Demand (COD) during pre-monsoon season

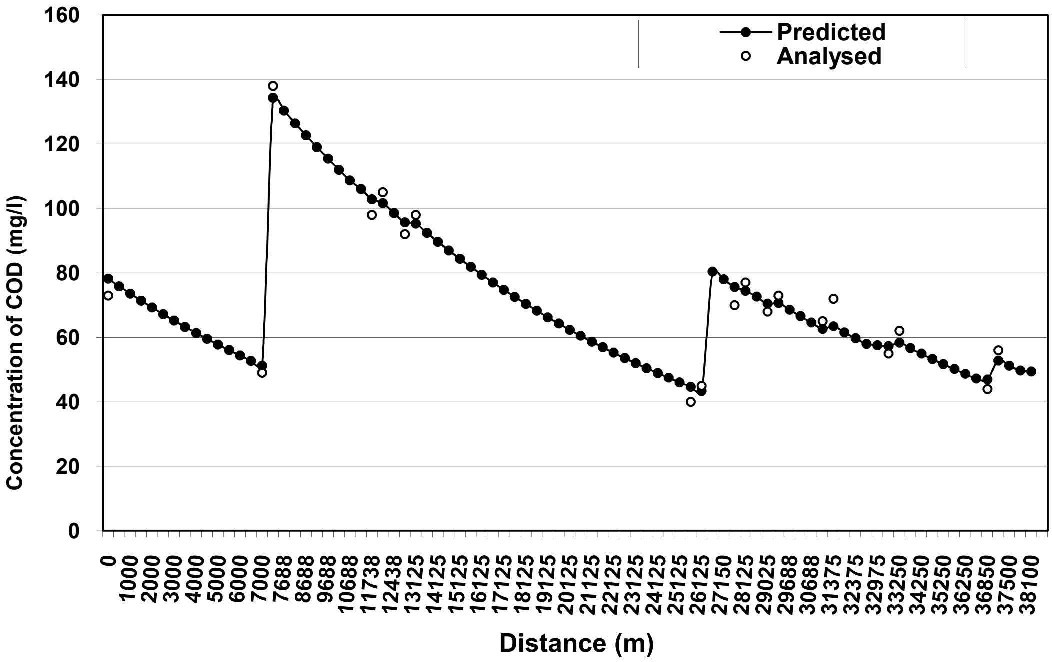

Fig-12 Prediction of Chemical Oxygen Demand (COD) during post-monsoon season

Statistical analysis of the predicted and analyzed water quality data were carried out in order to evaluate the results of the model. There exists a fair correlation between predicted data and analyzed data. In case of total suspended solids (TSS) (mg/l), the standard deviation is 4.799245 and the regression coefficient is 0.952008. In post monsoon, the standard deviation is 7.2451 and regression coefficient is 0.901022. It was found that $\pm$5.25% error in the predicted data with reference to the field experimental data. Similarly $\pm$6.15% error occurs in the prediction of total dissolved solids (TDS), $\pm$5.5% in dissolved oxygen (DO), $\pm$5.3% in biological oxygen demand (BOD), $\pm$5.25% in chemical oxygen demand (COD). From the results of statistical analysis, it has been perceived that the water quality prediction model is reliable to use in and around the coal washery complexes in order to plan or device the suitable mitigative measures.

CONCLUSIONS AND RECOMMENDATIONS

Based on the findings of the study on transport modeling of fluid components in and around the coal washery complexes, it is recommended for further research that the effluent and the waste that would be generated by the coal washeries could be quantified along with their physico-chemical characteristics through the integrated software package, developed using appropriate mathematical tools if a database consisting the data such as feed rate of raw coal, the physiochemical characterization of coal and the yield rate of each processing units of the coal washeries is developed by each washery and the same is maintained every year,. Such a software package may be useful for more effective water quality prediction in order to simulate the environmental parameters, which would be more cost effective as the simulation starts from the feeding of raw coals to the prediction of pollutants avoiding sampling and laboratory analysis. This would be a very useful information system for the coal washeries in order to visualize at the contribution of each processing unit during the operation of the plant. The effect of heat balance, reaeration coefficient, solar radiation and conduction may also be considered for the water quality prediction studies if appropriate mathematical models are incorporated in the present software. The mathematical models developed from the present study are common to find the solution for river water quality issues. If the models used in the present software would be applied in some other areas and subsequently validated, this could be used as generalized computer model so that it can be applied for any river system, environmentally degraded by any type of industries.

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