"TWO DIMENSIONAL FINITE TIME SIMULATION OF WASTE SPILLS IN RIVERS"

A Thesis

Submitted in partial fulfillment of the requirements for the award of the degree of

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IN

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Under the supervision of

DR. RAJIV GANGULY
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CERTIFICATE

This is to certify that the work which is being presented in the report titled **"TWO DIMENSIONAL FINITE TIME SIMULATION OF WASTE SPILLS IN RIVERS"** for partial fulfillment of the requirements for the award of the degree of Master of Technology in Civil Engineering with specialization in "**ENVIRONMENTAL ENGINEERING"** and submitted to the Department of Civil Engineering, Jaypee University of Information Technology, Waknaghat is an authentic record of work carried out By **Gaurav Chauhan (Enrolment No. 152751**)during a period from July 2016 to May 2017 under the supervision of **Dr. Rajiv Ganguly** Associate Professor, Department of Civil Engineering, Jaypee University of Information Technology, Waknaghat.

The above statement made is correct to the best of our knowledge.

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ABSTRACT

As waste spill in water can cause degradation of the water quality and also creates risk for the consumer of water. Therefore transport and fate of the spill needs to be studied by using model simulation, so that output of that model can help in assessing the risk and contingency measures can be applied. In this study a 2-d model is created which is part of whole TWODIFIN model and consist code to simulate instantaneous spill condition. Code was calibrated, although due to lack of full data required model is not fully accurate, but still gives satisfactory results. Code give much better results in case of Krishna river which is high flow rate, deep, and average speed river than in the case of Pawana river which is shallow, low flow rate, and low speed river. Further calibration with real time data and calculating value dispersion coefficient by practical experiment can further improve this model.

Keywords: spill, simulation, TWODIFIN, calibration, dispersion.

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LIST OF ABBREVIATIONS

Abbreviations	Full form
CPCB	Central pollution control board
GCWW	Great Cincinnati water works
HEC-RAS	Hydrologic engineer center's river analysis system
ICwater	Incidental-command tool for drinking-water protection
MABOCOST	Mixing analysis based on the concept of stream tubes
MCHM	4-methyl cyclohexane methanol
MODI	Model for dispersion
ONEDIFIN	One dimensional finite time
TWODIFIN	Two dimensional finite time

CHAPTER 1: INTRODUCTION

1.1 GENERAL

As it is known, streams of water like rivers can be polluted in many ways. One of them is accidental spilling of pollutant. It can occur by accidental spills from ships in river streams or from any industrial facility nearby river stream. It leaves river water polluted and unusable for many different purposes, for which, it may have been or will be used. So for knowing the fate and transport of this spill, so as to know the effects of spill on the river stream and on the population relying on that water for usage, water simulation of the real life condition is done. Many one-dimensional and two-dimensional models are used such as HEC-RAS [3] (Hydrologic engineer center's river analysis system) model which can be used for contaminant dispersion in stream once transverse dispersing of pollution is complete and a two dimensional model like MODI [3] (Model for dispersion) model which can show detailed spatial structure of the contaminant distribution and pollution source outlet's exact location can be specified which can affect the pollutant cloud's character. These models predict the water quality. The water quality predictions affect uncertainty in inputs related to the analyzed transport process. [4][6] In this study finite time simulation of waste spill in water stream using "TWODIFIN" computer model. This two-dimensional spill model "TWODIFIN" is an acronym for two-dimensional finite-time model. Here the "two-dimensional" part refers to the two spatial dimensions that it considers. These dimensions are the longitudinal or downstream dimension and the lateral or cross-stream Dimension. This model can be easily managed through the use of a transformation in the lateral Dimension known as the stream tube method. The concept of the Stream tube model developed was by yotsukura and cobb (1972). The model uses the Cumulative partial discharge, q, at a given cross-section instead of the lateral Discharge, y, as an independent variable. In this approach, the cross-section is divided into a number of vertical strips termed "stream tubes" such that the Discharge within each stream tube is equal.

So, the distributions of cross-sectional Concentration c(x, q) is predicted through stream tube model and it will be Functions of q. These distributions can be transformed into c(x, y) as a function of distance from the bank, y, by knowing the relation between q and y at each transect. [2]The stream tube concept is shown below in the figure (1.1).

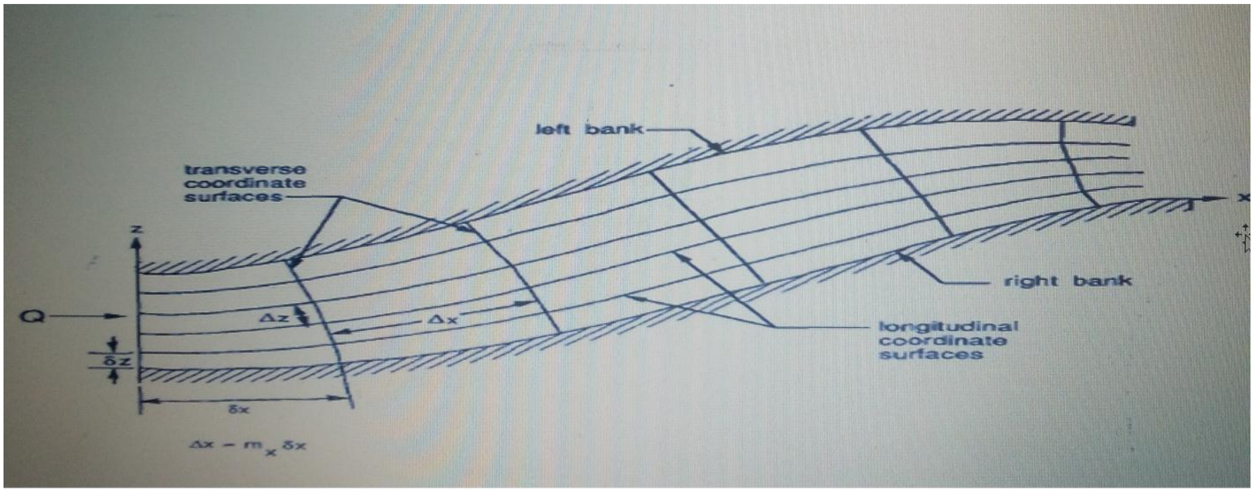

Figure 1.1: Stream tube concept (source: google)

mx and mz = the metric coefficients to account for the length variation between coordinate surfaces,

The derivations of the basic equations of the stream tube model have been Presented by yotsuhura and cobb (1972) and are subject to the following assumptions.[2]

1. The density of solute(or effluent) is the same as that of the receiving Water. This assumption is reasonably satisfactory for most municipal Effluent discharges to rivers.

2. The concentration distributions in far field are not affected by near field mixing processes. Generally, the jet-induced diffusion approaches the natural diffusion for a Short distance below the source in a shallow river.

3. The depth distribution of effluent in the river channel is uniform. Generally the longitudinal distance required to attain depth uniformity is short in shallow rivers. This distance generally is about 50 to 100 times the Channel and the assumption is therefore justified.

4. Decay of the effluent (pollutant) follows first order kinetics.

In TWODIFIN, the river is divided longitudinally into number of reaches, and laterally into the stream tubes. It is such that each reach of the river is considered to be a section of almost constant hydrodynamic characteristics. TWODIFIN uses constant dispersion coefficients within each reach. The position of the stream tube boundaries are determined only at transects where the velocity, depth measurements have been surveyed. TWODIFIN has only a single source at the beginning of the first reach. The reaches are not treated independently. Instead, the concentration for each reach is calculated by considering the flow of pollutant from the source all the way to the end of the reach. To take into account the variation of hydrodynamic parameters from reach-to-reach, moving averages are maintained that approximate the effective values of river width, depth, and velocity of flow. [2]

1.2 Input Data Requirements

- The input requirements for the models are those set of reference values which are used to describe the characteristics of each stretch of the river under study and the set of design values which describe the spill event. In this case

Input variables are:

- River water depths.
- Flow velocity.
- Spill decay.
- Coefficients of longitudinal and/or lateral dispersion are at selected river cross-sections.
- Flow discharge.
- Total mass of the material or waste discharged instantly background river concentrations.
- Temperature value.
- Decay rate constant.
- Kinematic viscosity.

1.3 OBJECTIVES

- Making “TWODIFIN” program more accessible as to be coded using MATLAB.
- Collection of data regarding spill scenario.

- Testing different spill scenario (i.e. the case of conservative and non-conservative material as spill in instantaneous and constant discharge spill situation).
- To assess the contingency plan study for the spill situation using the TWODIFIN model in surface water stream.
- To assess the Risk assessment for spill condition using the TWODIFIN model.

1.4 SCOPE OF PROJECT

This project study can be used in many ways for various things, major scope being:

- For devising contingency measures in river and water streams' spill situation.
- Assessing the risk to populace which might be or is using the polluted water.
- Knowing the behavior of the contaminant transport of different types in different situations.

CHAPTER 2: LITERATURE REVIEW

2.1 GENERAL

Bahadur R. et al. (2015) has done a report on the modelling of MCHM(4-methycyclohexane methanol) plume's to forecast time of travel and concentration as the plume traveled downstream toward the Greater Cincinnati Water Works intake by using incident-command tool for drinking-water protection (ICWater). The issues addressed in this study were the flow regime, source term to describe the spill event, use of real-time and to forecast streamflow, and comparing the model results with observations at the Charleston, Huntington (West Virginia), and the GCWW intake. This ICWater model is linked with national river network which was coupled with the real-time streamflow and river forecast data which makes the model to simulate leading edge, Downstream tracing was initiated at the spill site to forecast the location of the leading edge, the peak concentration and the trailing edge of plume for the drinking-water intakes as far downstream as 402 km from the origin of elk river.

Study for this paper was conducted as on 9th January 2014, as an estimated amount of 37,854 L of (MCHM), solvents used in coal processing were leaked from a ruptured container into the Elk River. The spill just occurred 1.61 km upstream of a water-treatment plant, forced officials to ban residents and the businesses in the nine West Virginia counties from using water for anything but flushing toilets or fighting fires. It was estimated that about 300,000 residents of West Virginia were affected by this spill.

Major challenge in modelling for this spill was the characterization of the source term, in particular, spill duration. The most important advantage of ICWater is that it can be quickly applied under emergency situations as it does not require any extensive pre-set-up before the event. The model gives quite reasonable results.

Gore &Storrie Ltd. Cannada (1988) in this study reports on the developing of the 1-d (i.e. ONEDIFIN), 2-d (i.e. TWODIFIN), and hybrid models (i.e. ONETWO) for the concentration study of the spill in Ottawa River, Canada . These models were developed as in August 1981 a nuclear material (i.e. Tritium) was accidentally spilled from Rolphton NPD facility into Ottawa river in Ontario, Canada. These models were developed for the prediction of arrival times, duration of the passage, and the concentration distribution of spilled tritium at river intakes and some other important strategic locations downstream. To simplify the governing equation into the analytical solution an approximate integration procedure i.e. Laplace method, is used. The model inputs are the geometric parameters, hydraulic parameter and tritium decay rate. For this the river is divided into longitudinal segment with fairly constant values of parameter by the help of stream tube method. The degree of skewness was very small. Which helped drawing the conclusion that convective period can be neglected.

After examining relation between lateral mixing zone and convective period it was concluded that detailed assessment could not be made as there was lack of relevant information. It was recommended evaluate this aspect by gathering more field data. This model was found to be applicable in near-field and far field-zones, and method for linking near and far-field models was presented. These methods permit continuing the use of their model in these zones in case of future studies.

Luk G. et al. (1990) In this study developed numerical model, the mixing analysis based on the Concept of Stream Tubes (MABOCOST), for the analysis of 2-d, transient mixing of non-conservative substances in natural streams. MABOCOST is applicable for steady flows in sinuous and non-prismatic channels. Pollutants that are non-conservative in nature and the one having sources or sinks can also be modelled with this model. The time fractional-step method is used in here which is suitable means to solve advection-diffusion equation. Curvilinear coordinate system was used to account for the variations occurring in velocity, depth, and channel curvature. Stream tubes are then divided into variable length elements so as to have a Courant number for the grid space always equal to unity. This way problem of numerical diffusion and dispersion in computing stream wise advection is totally avoided.

This model was verified with analytical solutions for the cases of simple advection, continuous line source and instantaneous injection. Dispersion experiments were carried out in a sinuous channel with irregular bottom topography, using a slug injection and variable rate injection of the tracer. Measured time-concentration data agree quite well with predictions using MABOCOST.

The fact that the different physical processes are programmed as separate modules means that future improvements can be made conveniently. The model was tested first for three simple cases for which analytical solutions exist. Results of these tests show that the model produces stable, non-dispersive solutions that compare very favorably with the analytical solutions. The model was then tested for the more general case of a time-varying pollutant input. It requires controlled experiments in laboratory in which time-concentration measurements were made at multiple locations in a test channel. It was shown that the model's performance was quite satisfactory. The MABOCOST model requires a considerable amount of input data. Depth across a number of cross sections must be provided. Velocity measurements are also required but can be estimated using discharge and depth measurements. Value of the transverse dispersion coefficient also required, which is not an easy parameter to obtain. A means of predicting *Ez* accurately still does not exist and the most dependable method is to obtain *Ez* from a field test, which can sometimes be quite costly. However, these difficulties were unavoidable as carrying out two-dimensional modelling in natural streams.

Jeremy Rivord J. et al. (2014) has applied one-dimensional solute transport model (OTIS) to the Truckee River. The river Originates at Lake Tahoe, provides 85% of drinking water for the Reno/Sparks metropolitan area. Due to Major highways and a railroads being adjacent to the river, increases risk of a contaminant spill into the river that could have detrimental effects on drinking water supplies. Data from dye (Rhodamine WT (RWT) dye; 10 μg/L) studies on the river were used so as to determine a relationship to estimate dispersion coefficients for the River and to calibrate the model. Two sizes of hypothetical contaminant spills from 9 locations under 13 flow scenarios were simulated. Travel times to the first water intake for a train spill of 130,000 L ranged from 3 to 46 h and maximum simulated concentrations of a conservative water soluble contaminant at the intake which is from 340 to 4,800 mg/L. Model output was influenced by some uncertainties in the equation for longitudinal dispersion, so model runs were executed with estimated dispersion values that were a factor of 1.5 greater and less than the equation-estimated value of dispersion. It was assumed that the value of geometry characterized by one cross-sectional value was homogeneous, which in reality was homogeneous. It caused error in the time of arrival. In the end, the assumptions which were made to address these uncertainties in the Truckee River spill model provided the most conservative estimate of time of arrival .so it was concluded that In the event of any spill situation, these model estimates would primarily be used to determine the time available to mobilize for treatment options. Also Model predictions of peak concentrations or duration of impact was not considered to be a critical criteria for making decisions about how to address the situation.

Wang P. et al (1997) In this study developed a mass balance model and applied the model to Sacramento River in northern California during the July 1991 Sacramento River metam-sodium (MS) spill. The transport and reactions of metam-sodium, a soil fumigant, and the volatile and toxic methyl isothiocyanate (MITC) were simulated during the two-and-ahalf days of movement along a 68-km stretch of river. Results from modelling were compared with field data for MITC, which is the only product measured downriver after the spill. Agreement between the simulated and measured values of MITC concentrations were found at Doney Creek (65.9 km downstream). For the 68-km section of the river from source of the spill site to the entrance to Lake Shasta is shallow. It has depths ranging from 0.5 to 1.8 m with an average width of 15 m.

Results illuminated the complexities and unique characteristics associated with the multiple kinetic processes of the chemical plume in the river. In particular, the photolysis of metam-sodium which followed zero-order kinetics for high concentrations. It followed first-order kinetics for low concentrations, which was a unique phenomenon consistent with the finding reported in a laboratory study. Concentrations of metam-sodium for transition from zero- to first-order, obtained by calibration and model sensitivity analyses, were in the same range as those in the reported laboratory results. It stated that model performance was quite satisfactory.

Halaj, P. et al. (2014) has done comparison of some aspects of one dimensional and two-dimensional models (water quality models) used for the modelling of contaminant dispersion in the rivers. Mainly two models which are HEC-RAS & MODI compared to their usage in contaminant dispersion studies using modelling. It was found that HEC-RAS can only give good results and can only be used if the pollutant is completely dispersed in transverse axis. Whereas MODI can work in both the condition when pollutant is completely dispersed or not in the transverse direction. From the study it was concluded that both model can give reasonable support for decision making in the case water quality management of river.

2.2 OBSERVATIONS FROM LITERATURE SURVEY

From the above literature survey, I observed that for the modelling study of effluent transport in rivers, first a little knowledge of physical transport phenomenon like advection, dispersion and diffusion is necessary. Also use of different variable to form an equation on which modelling is to based on the variable must be chosen such that the solving of equation is easy and simulation based on model formula becomes fast and should be less complex. It was evident from above literatures that the models made cannot be 100% accurate but can give fairly good results based on the choices of variables. Also these models can be used as contingency model and can also be used for risk assessment.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 GENERAL

The objective of this study is to code the TWODIFIN model based on the 2-d convective-dispersion equation in MATLAB, so that it is more accessible and to be easily used. Also when coded in MATLAB the model developed will be faster, so consuming less time. Also it works more efficiently. In this chapter the formula used and its variables are discussed. Also the methodology of work and different case studies are also discussed.

The main condition is the instantaneous spill condition which is to be calculated using a governing equation and its analytical solutions. These equations are:

The 2-d convective-dispersion equation for a non-conservative material in the Far field region of the mixing zone can be written in the form:

$$(\partial C/\partial t) + u*(\partial C/\partial x) = e_x*(\partial^2 C/\partial x^2) +u*D_y*(\partial^2 C/\partial q^2) - K_d*C \text{ ------- (equation 3.1)}$$

Where,

- K_d = first order decay rate coefficient (1/s)
- C = concentration at point (x, q) at time (t)
- x = longitudinal co-ordinate (m)
- Q = lateral co-ordinate (m^3/s)
- T = time (s)
- U = velocity of flow in the x direction (m/s)
- e_x = longitudinal dispersion coefficient (m^2/s)
- D_y = lateral diffusion factor (m^5/s^2)

The solution to the equation 1 under a release of pollutant of instantaneous spill and concentration is:

C_i =((W_i*u*exp((u*x)/2*E_x))/(2*pi*sqrt(E_x*E_Q)))*((exp((-a/t)-b*t))/t------- (equation 3.2)

Where,

- C_i = concentration at point (x,q) at time 't'. (unit in mg/m^3)
- W_i =total mass of the material or waste discharged instantly(unit in milligram or mg)
- u = velocity of flow in x direction. (unit in m/s)
- exp = exponential also denoted by 'e' =2.718; (unit less quantity)
- x = longitudinal coordinates or distance downstream from source of spill. (unit in meter or m)
- E_x =e_x= longitudinal dispersion coefficient (unit in m^2/s)
  - $E_x = (7.05*10^6 *(u*h))/R_n^{0.762}$
  - <u>Here : </u>u=velocity as mentioned earlier ; h= given effective depth of water (units in m); R_n = Reynolds no. and is calculated as: R_n=(u*h)/v_{T1} ;
  - V_{T1}= kinematic viscosity of water at given temperature 'T_1' (units are in m^2/second).
  - $V_{T2} = v_{T1} * 1.029^{(T2-T1)}$
  - Here T_1 and T_2 are different temperature of the river water.
- Pi = Greek letter Π =3.1419.
- sqrt= function calculating square root of any value.
- E_Q = transverse dispersion coefficient
    - E_Q =(β*Q*u)/b
  - <u>Here:</u> β= dimensionless factor (ranges from 0.005 to 0.01) normally taken as <u>0.01 .</u>
    - Q= given total discharge (unit in m^3/s)
    - u=velocity as mentioned earlier
    - b=(u^2/4*E_x) +$K_{d(T2)}$;
    - $K_{d(T2)}$ =given decay rate constant at temperature T_2 . (to be input by user)

- T_2 =given temperature of water at the point of calculation .(to be input by user)

- for K_d at temperature T_2 ;
  - $K_{d(T2)} = K_d*\theta^{(T2-T1)}$; θ=1.047; T_1=20 °c
- a=constant ; a = $x^2/4*E_x$.(Here considered that $q_s = q$)
- b= constant =
  - b= $(u^2/4*E_x) + K_{d(T2)}$;
  - K_d =given decay rate constant at temperature T_1 for K_d at temperature T_2 ; $K_d(T_2) = K_d*\theta^{(T2-T1)}$; θ=1.047.

➢ For the case of a conservative substance the governing equation remains almost the same, the only difference being the value of decay rate constant (K_d) is taken as zero.

So then equation 1 becomes:

$$(\partial C/\partial t) + u*(\partial C/\partial x) = e_x*(\partial^2 C/\partial x^2) + u*D_y*(\partial^2 C/\partial q^2) - 0*C \text{------- (equation 3.3)}$$

The analytical solution remains almost the same, the only difference being wherever value of decay rate constant is required it is taken equal to zero.

3.2 METHODOLOGY FOLLOWED

The work done in this study is a coding and data based.

So to start with the work first the source code for TWODIFIN model will be written in MATLAB (as shown in appendix B). Any other data for any other situation can be added to itand the output can be taken. For the coding of the model various parameter are used and the modelling is done based on the solution to the governing equation, which is done for the cases of instantaneous discharge spill condition. So for this project study for making the model various parameters are used, some of which are to be entered directly as measured in the environment and some are to be calculated using various measure values and constants. One of these calculated parameter is longitudinal dispersion coefficient (e_x), which in this case is calculated using Bansal's equation (see Appendix A).

After coding is done model will be checked for calibration through comparing the example situation's variation of max concentration at different transect with the variation of max concentration at different transect in 1-d graph of TWODIFIN used in tritium spill incident in Ottawa River. The example used is shown in 3.1. As model is calibrated, different case studies, which may be hypothetical or real life, for instantaneous discharge spill situation for conservative and non-conservative material will be taken and data from these situations will be run in the model and an analysis will be made for contingency approach if any such condition arises on the basis of comparison of the calculated maximum concentration value and the effluent standards given by central pollution control board of India. After how much time the calculated concentration goes below the standard safe value basing on that contingency approach will be made.

3.2.1 Example:

To illustrate data input for the TWODIFIN model and the output as result for the case of instantaneous spill situation an hypothetical example is considered. The code in interactive mode for this situation with some data statistics is presented in Appendix B. The salient aspects for this illustrative example are given below.

The number of transect are five (not including x=0). The stream flow rate is 493.10 m^3/s. The depth taken is 19.7 m and considered same throughout. The longitudinal dispersion coefficient is calculated using equation A.3 and average velocity is taken 0.018 m/s. The temperature is 20°c and the viscosity of water for this temperature is $1.004*10^{-6}$ m^2/s. For this example the spill material is considered to be conservative, so the decay rate constant is zero. Mass of the spill is $8*10^{10}$mg. The time is taken from 0 to 5184000 seconds (60 days) with time intervals of 43200 seconds (12 hours). The reach of 60km is divided into 4 transects(x_1, x_2, x_3, x_4) The output concentration versus Time plot is shown in figure 4.2 of chapter 4.

3.3 CASE STUDIES

In this research 4 different case study on 2 different rivers is taken. The rivers considered for the case studies are Pavana River flowing in Maharashtra and Krishna River flowing in Karnataka and Andhra Pradesh.

Pavana River is a small river flowing in the state of Maharashtra. It originates from Western Ghats about 6 km south of Lonavala. Initially it flows eastward it turns south then crossing through pimpri-chinchwad, Pune and ultimately meeting Mula River near the place Sangvi. It is about 58 km in length. Krishna river is one of the longest river in india about 1400 km in length. Originating from Jor village near mahabaleshwar in Maharashtra and it meets sea in the Bay of Bengal in Hamsaldeevi in Andhra Pradesh. (Source: Wikipedia)

In these case studies the places taken are real but the situation is hypothetical to some extent which considers that there is an instantaneous spill of certain amount. Some suitable data about the river is taken from internet and if not available some suitably assumed data is taken. One such suitably assumed data is that the velocity of the river flow in the reach taken is constant.

Assumption

1. In all of the cases it is assumed that there is no pollution before the effluent spill occurs i.e. river is considered to be pure upstream of the spill location, diluted if previously any pollutants entered the water.

These different case studies are as follows:

Case 1: Hindustan antibiotic limited, pimpri (Maharashtra); Pavana river (non-conservative)

In this case study the industry is antibiotics pharmaceutical industry making medicines like Penicillin, Amoxylin, Gentamycin etc., so the effluent is non-conservative in nature. In this case average and minimum flow of Pavana River is considered. The distance of the spillage point which is considered near outlet is at the distance of 18000m upstream from the water supply intake in Pune. So the output of concentration curve at 18000m is necessary to assess the situation of the spill concentration at point of water supply inlet, so as to assess the risk to the populace. In this case we considered two discharge of Pavana River, average and minimum which is 455.6 &45 m^3/s respectively. 7 different transects($x_1,x_2,x_3,...,x_7$) at the distance of 0m, 5000m, 10000m, 15000m, 18000m, 21000m, 25000m are taken. Velocity is considered constant throughout the stretch and is 0.20m/s. The kinematic viscosity is $0.886*10^{-6}m^2/s$ as the temperature of river water is found out to be 26 ^{0}C(as kinematic viscosity is temperature dependent, table showing the relation between these two is shown in C.1, Appendix C) in natural state and when effluent mixed, it is

30 ^{0}C. Decay rate constant is 0.1 day^{-1}. Total waste discharged instantly is 4.4*10^{9}mg (which is taken on the basis of its effluent generation per day) and beta value is taken to be 0.007. The time is taken from 0 to 2160000 seconds (25days) with the intervals of 43200 seconds(12 hours). The depth of river water in case of average flow is 20m and 10m in case of minimum flow.

The result output graph of concentration versus time for this case after running the model is shown in figure 4.3 & 4.4 of chapter 4.

Case 2: Bajaj auto limited, Akurdi, Pune (Maharashtra); Pavana river (conservative)

In this case study the industry is automobile manufacturing industry and the effluent spill mainly consist of zinc and chromium from plating and painting processes. These metal and are generally conservative in nature, also very toxic and lethal in small quantity to humans and animal alike. In this case also average and minimum flow of Pavana River is considered. In this case the distance of the spillage point which is considered near outlet is at the distance of 5000m upstream from the water supply intake in before Pimpri. So the output of concentration curve at 5000m is necessary to assess the situation of the spill concentration at point of water supply inlet, so as to assess the risk to the populace. In this case we considered two discharge of Pavana River, average and minimum which is 455.6 &45 m^3/s respectively. 7 different transects(x_1,x_2,x_3,...,x_7) at the distance of 0m, 5000m, 10000m, 15000m, 18000m, 21000m, 25000m are taken. Velocity is considered constant throughout the stretch and is 0.20m/s as shallow and slow moving river. The kinematic viscosity is 0.886*10^{-6}m^2/s as the temperature of river water is found out to be 26 ^{0}C in natural state and when effluent mixed, it is 29 ^{0}C. Decay rate constant is 0 day^{-1} as effluent spill is of conservative in nature. Total waste discharged instantly is 6.31*10^{8}mg (which is taken on the basis of its effluent generation per day) and beta value is taken to be 0.007. The time is taken from 0 to 2160000 seconds (25days) with the interval of 43200 seconds (12 hours). The depth of river water in case of average flow is 20m and 10m in case of minimum flow.

The result output graph of concentration versus time for this case after running the model is shown in figure 4.5 & 4.6 of chapter 4.

Case 3: Raichur thermal plant, Shaktinagar (Karnataka); Krishna river. (Conservative)

In this case study the industry type is thermal power plant and the effluent spill mainly consists of zinc and chromium from fly ash. These metal and are generally conservative in nature, also very toxic and lethal in small quantity to humans and animal alike. In this case also average and minimum flow of Krishna River is considered. In this case the distance of the spillage point which is considered near outlet is at the distance of 21000m upstream from the water supply intake in before Raichur. So the output of concentration curve at 21000m is necessary to assess the situation of the spill concentration at point of water supply inlet, so as to assess the risk to the populace. In this case we considered two discharge of Krishna River, average and minimum which is 2100 & 1000 m^3/s respectively. 7 different transects(x_1,x_2,x_3,...,x_7) at the distance of 0m, 5000m, 10000m, 15000m, 18000m, 21000m, 25000m are taken. Velocity is considered constant throughout the stretch and is 0.44m/s. The kinematic viscosity is $0.884*10^{-6}m^2/s$ and $0.801*10^{-6}m^2/s$ as the temperature of river water is found out to be 27 ^{0}C as average and maximum temperature is 30 ^{0}C in natural state and when effluent mixed, it is 38 ^{0}C & 42 ^{0}C respectively. Decay rate constant is 0 day^{-1} as effluent spill is of conservative in nature. Total waste discharged instantly is $1.21*10^{10}$mg (which is taken on the basis of its effluent generation per day) and beta value is taken to be 0.007. The time is taken from 0 to 259200 seconds (3days) with the interval of 7200 seconds (2 hours). The depth of river water in case of average flow is 20m and 10m in case of minimum flow.

The result output graph of concentration versus time for this case after running the model is shown in figure 4.7 & 4.8 of chapter 4.

Case 4: Krishna district milk producers co-operation union limited Lambadipet, Vijayawada (Andhra Pradesh); Krishna river(non-conservative)

In this case study the industry type is dairy industry and the effluent spill mainly consists of nitrogen and phosphorus which can create pollution. Phosphorus and ammonia products formed from nitrogen can be harmful for human health. These are metal and are generally conservative in nature. In this case also average and minimum flow of Krishna River is considered. In this case the distance of the spillage point which is considered near outlet is at the distance of 10000m upstream from the water supply intake in before Vijayawada. So the output of concentration curve at 10000m is necessary to assess the situation of the spill concentration at point of water supply inlet, so as to assess the risk to the populace. In this case we considered two discharge of Krishna River, average and minimum which is 1600 & 100 m^3/s in Vijayawada area respectively(source:

Wikipedia). 7 different transects($x_1, x_2, x_3, ..., x_7$) at the distance of 0m, 5000m, 10000m, 15000m, 18000m, 21000m, 25000m are taken. Velocity is considered constant throughout the stretch and is 0.44m/s. The kinematic viscosity is $0.884*10^{-6}m^2/s$ and $0.724*10^{-6}m^2/s$ as the temperature of river water is found out to be 27 ^{0}C as average and maximum temperature is 36 ^{0}C in natural state and when effluent mixed, it is 30 ^{0}C & 37 ^{0}C respectively. Decay rate constant is 0.25 day^{-1} as effluent spill is of conservative in nature. Total waste discharged instantly is $3.75*10^8$mg (which is taken on the basis of its effluent generation per day) and beta value is taken to be 0.007. The time is taken from 0 to 259200 seconds (3days) with the interval of 7200 seconds (2 hours). The depth of river water in case of average flow is 50m and 15m in case of minimum flow.

The result output graph of concentration versus time for this case after running the model is shown in figure 4.9 & 4.10 of chapter 4

CHAPTER 4: RESULTS AND DISCUSSION

4.1 RESULTS

The result graphs for example and four different cases are shown as follow:

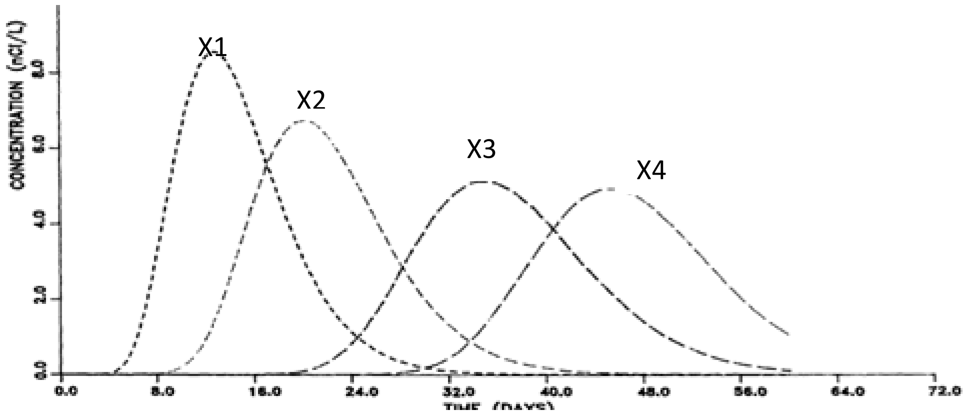

Figure 4.1: A typical 1-d concentration versus time graph by TWODIFIN.

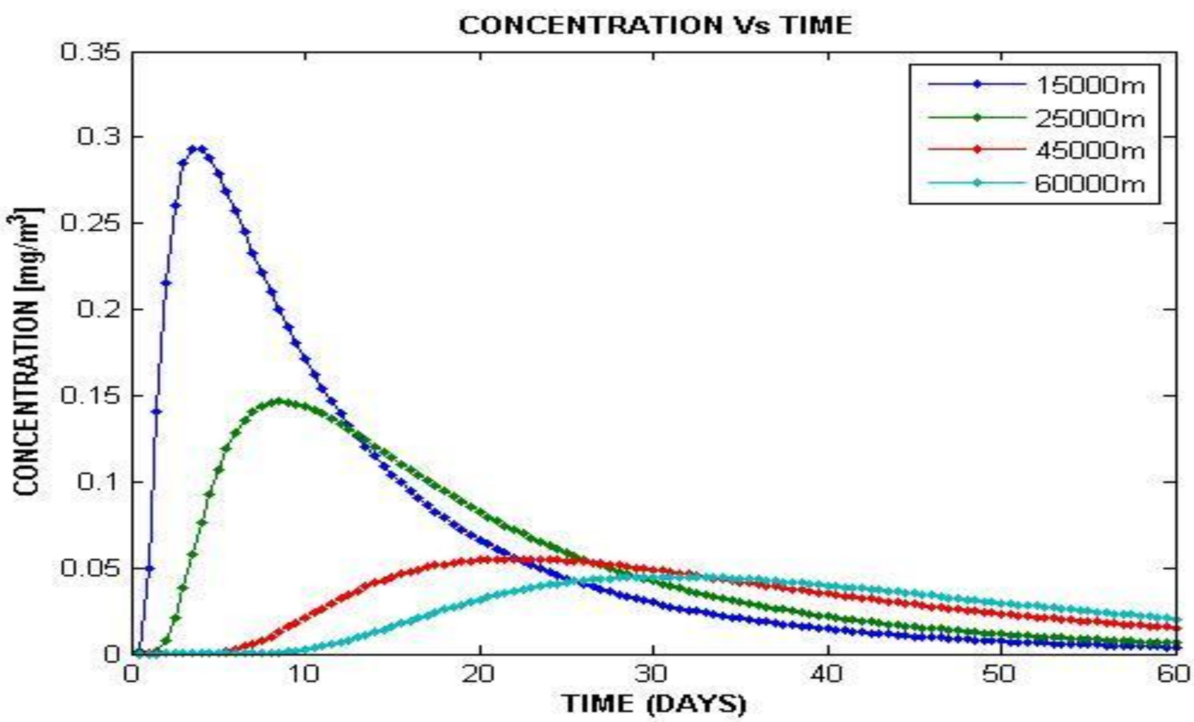

Figure 4.2: 1-d Concentration versus time graph for example by coded program.

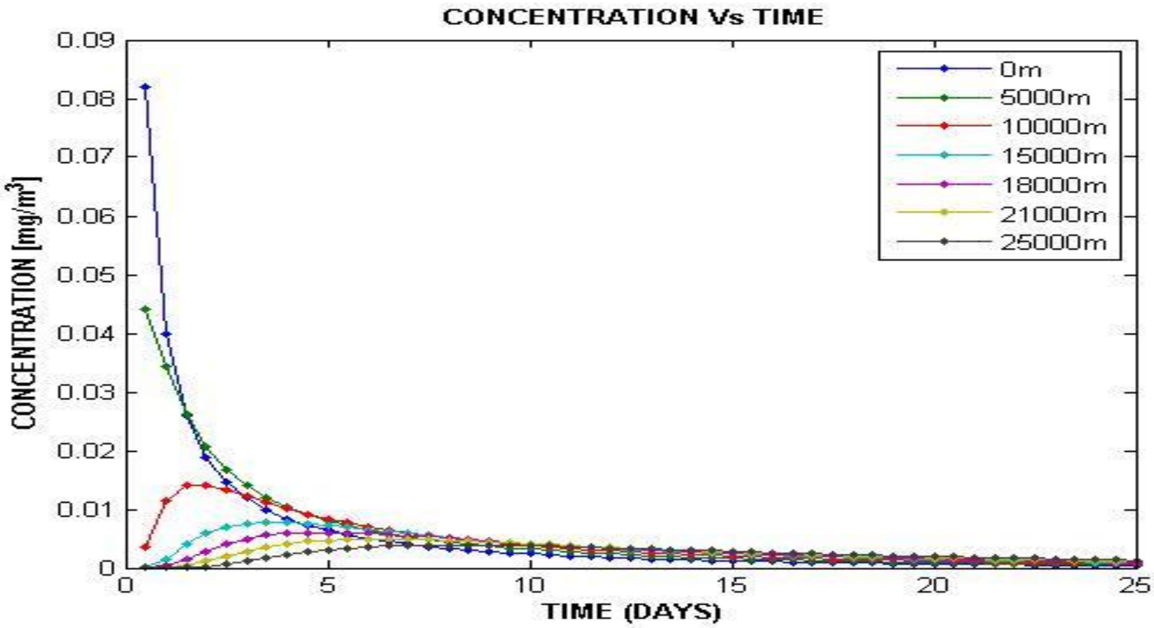

Figure 4.3: Concentration vs. time graph for case 1 by coded program. (Pavana river; average flow [455.6 cumec])

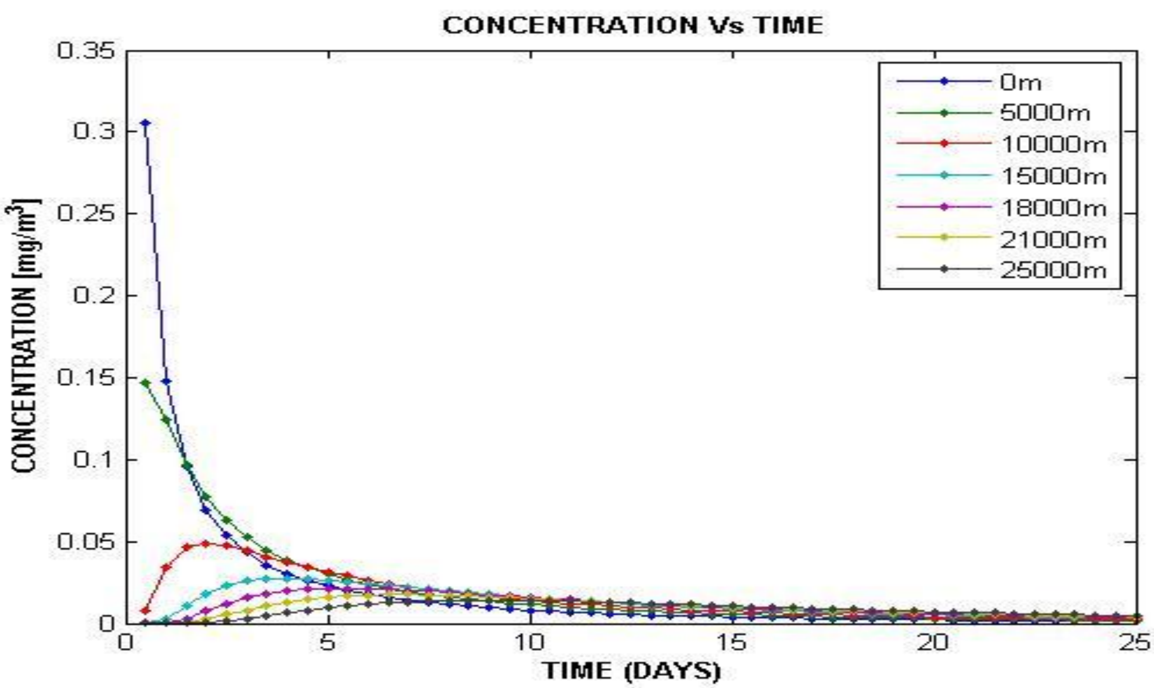

Figure 4.4: Concentration vs. time graph for case 1 by coded program. (Pavana river; minimum flow [45 cumec])

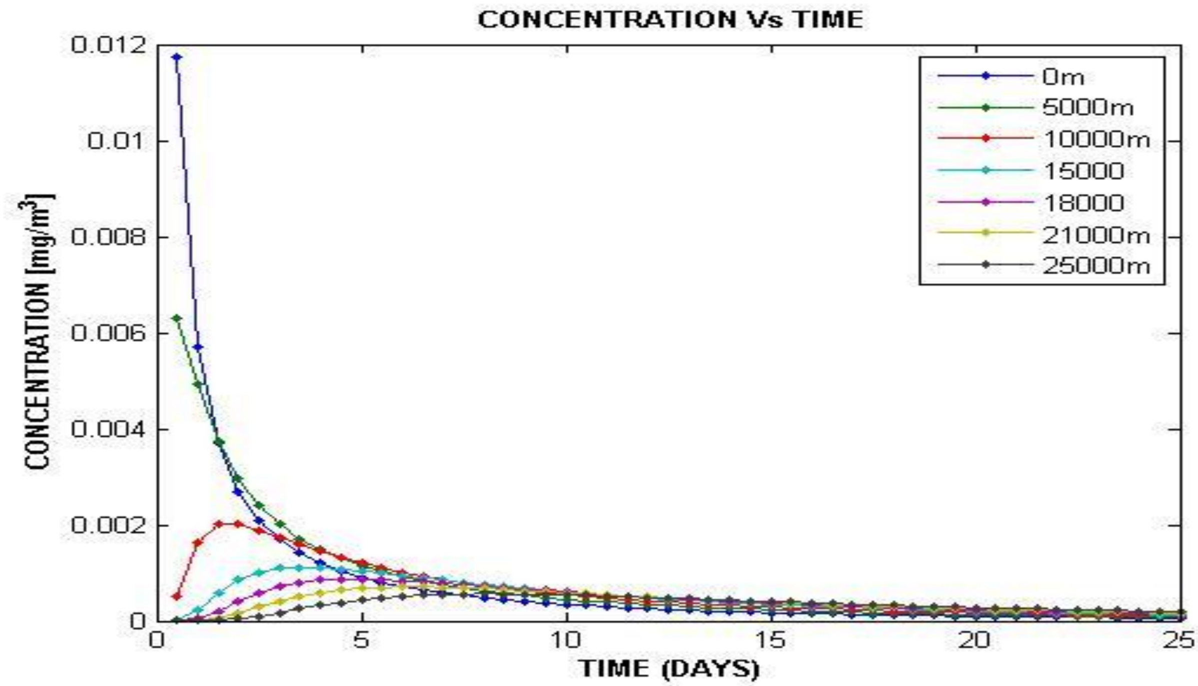

Figure 4.5: Concentration vs. time graph for case 2 by coded program. (Pavana river; average flow [455.6 cumec])

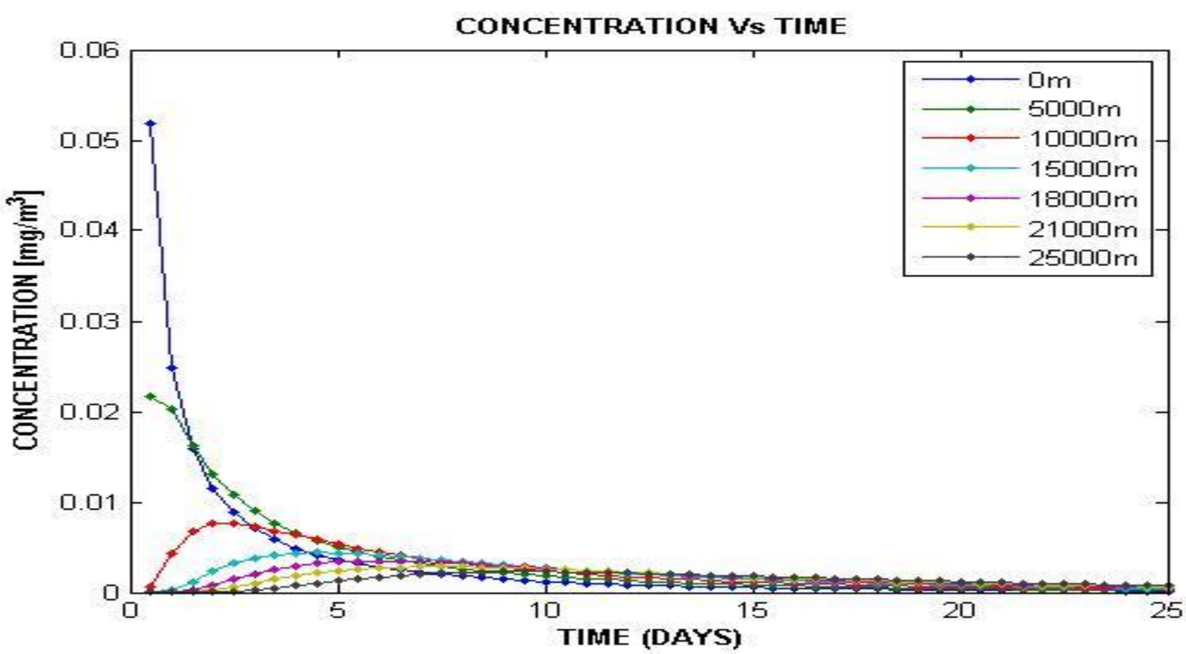

Figure 4.6: Concentration vs. time graph for case 2 by coded program. (Pavana river; minimum flow[45 cumec])

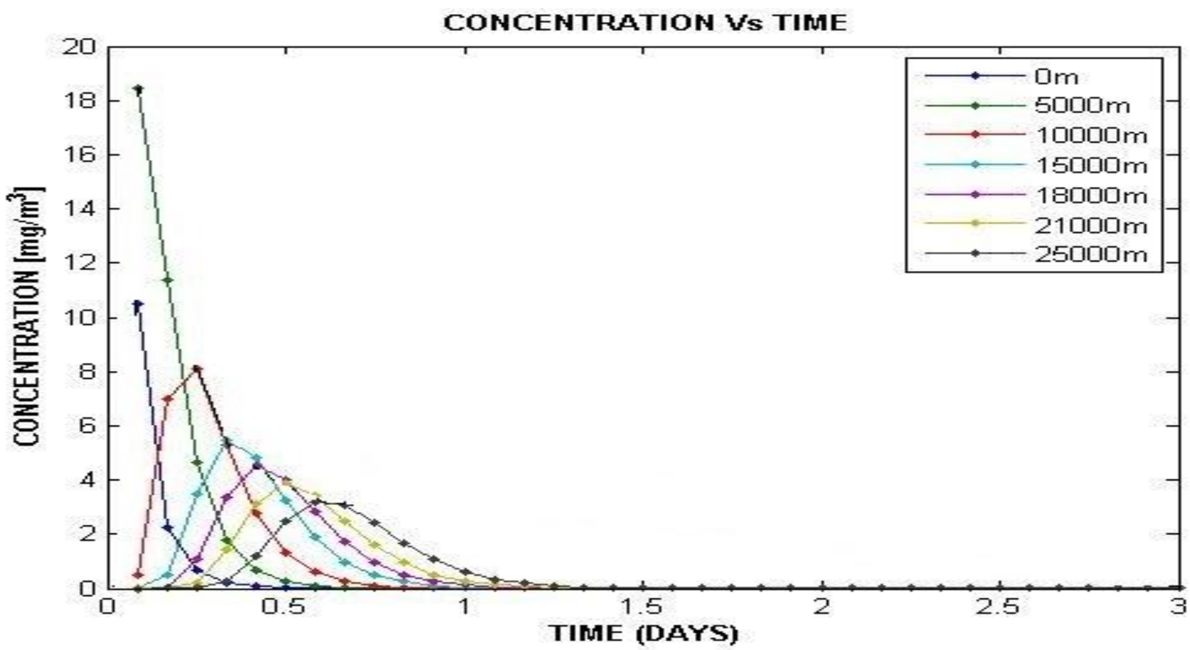

Figure 4.7: Concentration vs. time graph for case 3 by coded program. (Krishna river; average flow [2100 cumec])

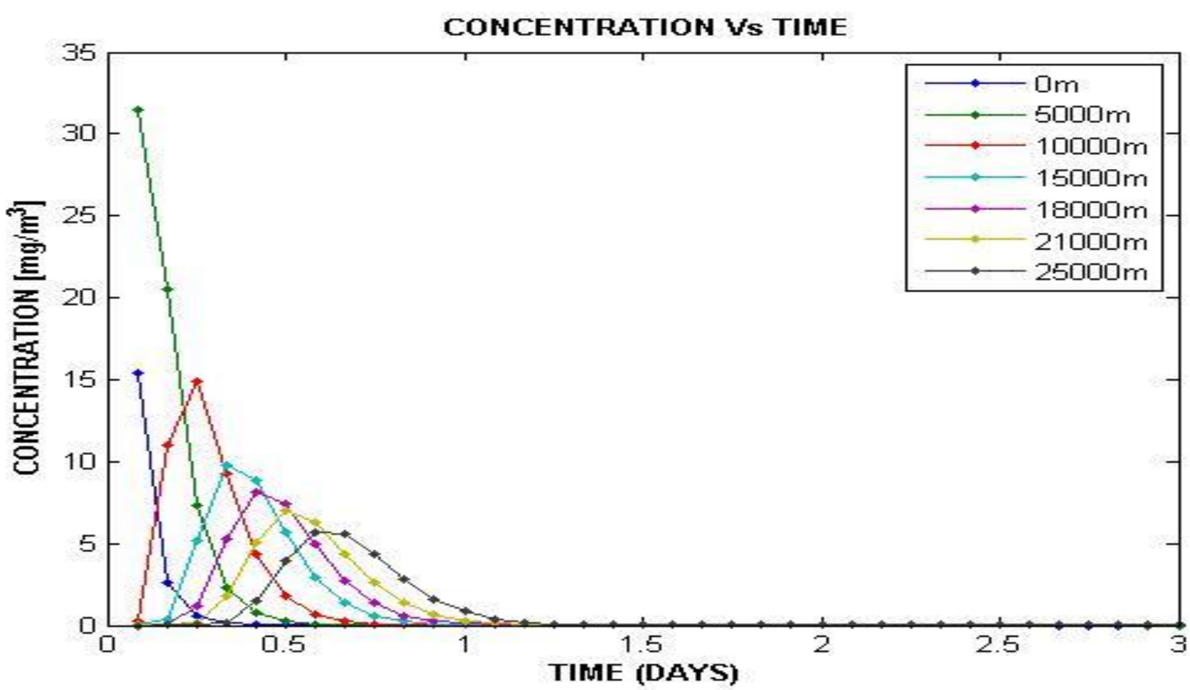

Figure 4.8: Concentration vs. time graph for case 3 by coded program. (Krishna river; minimum flow [1000 cumec])

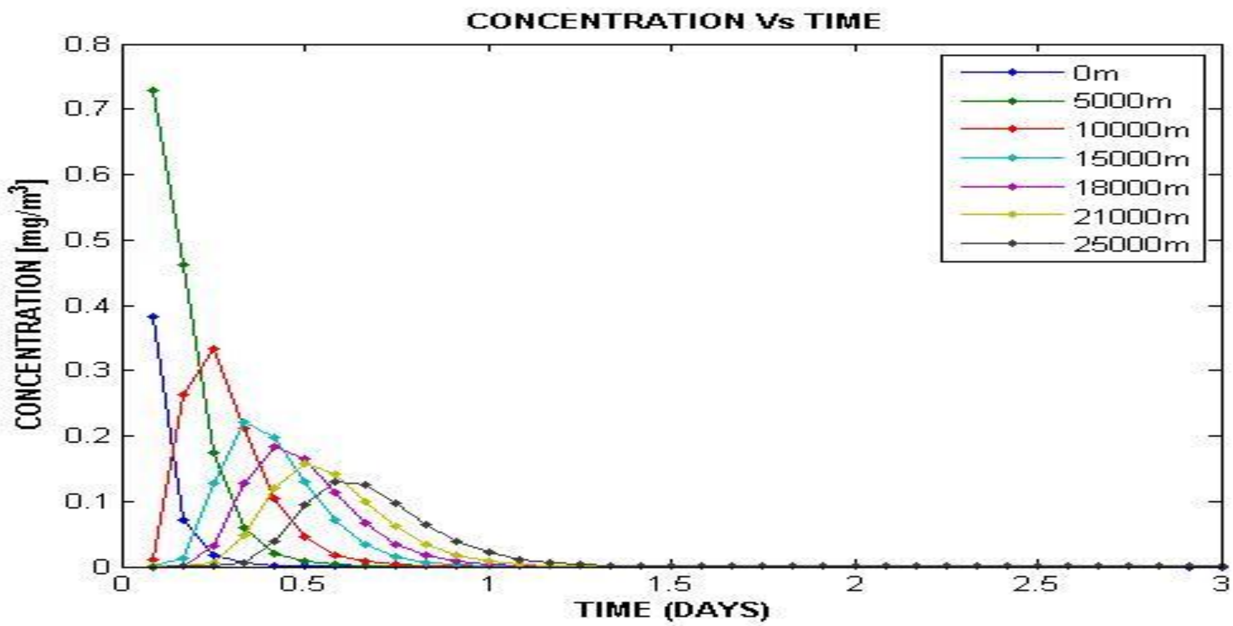

Figure 4.9: Concentration vs. time graph for case 4 by coded program. (Krishna river; average flow [1600 cumec])

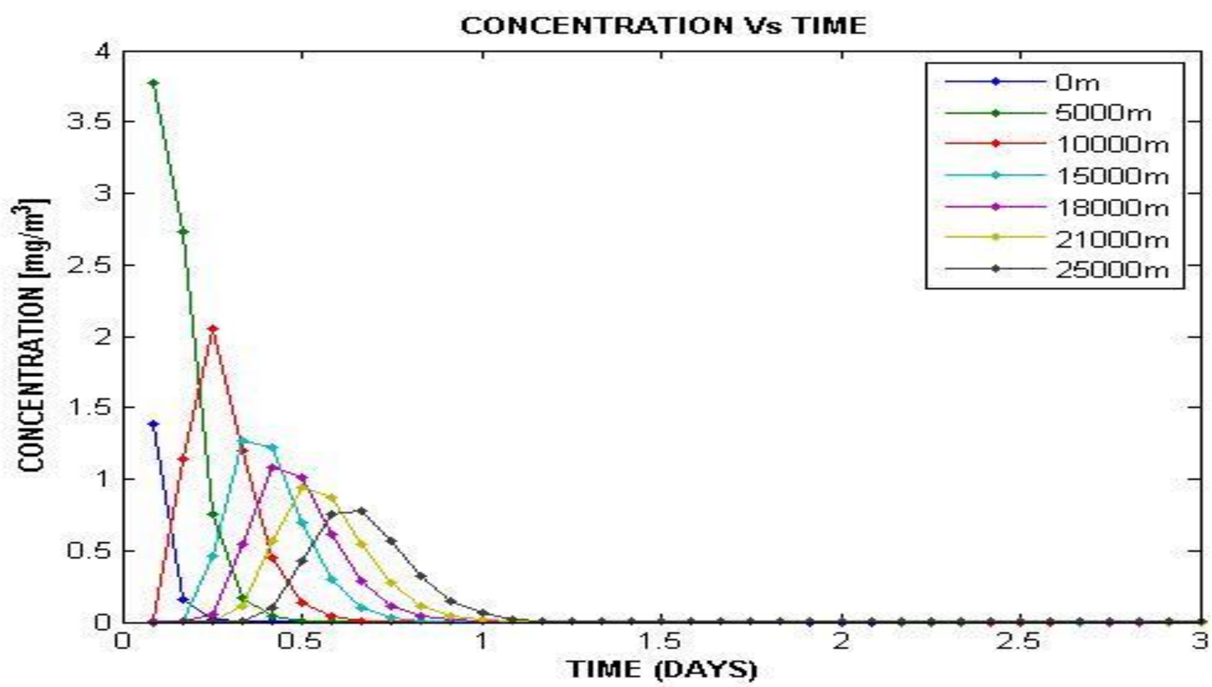

Figure 4.10: Concentration vs. time graph for case 4 by coded program. (Krishna river; minimum flow [100 cumec])

4.2 DISCUSSION

Example:

The result shown above in figure 4.2 shows the same trend of concentration versus Time curves as shown in figure 4.1, which shows curves for different ‘x’ values i.e. different downstream distances where x1<x2<x3 and so on. These figure shows the bell shaped curves, also these figure shows the same kind of dip in the peak concentration values for each consecutive transect point, which shows that the coded program for instantaneous spill condition is quite accurate up to a certain degree. Although it can be said not totally accurate, as with increase in distance of transect from spill its accuracy decreases. It is because of lack full data required for calibration, but as this model is to be used only for quick risk assessment and the preliminary contingency plans, keeping that into the perspective this model shows fairly good results. Also from the graphs it is shown that the concentration level up to peak rises very quickly as the slop is quite steep but it lowers down slowly. It shows that the process of diffusion and dispersion which causes the decrease in concentration due to moving toward the equilibrium state is slow in nature and takes quite long time. As the river velocity is slow and the diffusion process is acting as a major force than advection and dispersion after reaching maximum concentration value.

Case 1:

In this case the maximum ever concentration occurs at the starting point in both average and minimum flow cases which is 0.082 mg/m^3 and 0.31 mg/m^3 .but the concerned region is at 18000 m and there the critical value will be at low flow. The antibiotics consists of nitrogen and sulphide particles which can pollute water, there permissible limit in the inland surface water is 50mg/l & 2mg/l (CPCB guidelines, tableC.2 appendix C) there the concentration is 0.25 mg/m^3 which occur after 5 days.

Even if this value of these chemicals is within the permissible limit but for the extra safety water supply can be halted for 2-3 hours will we ok, although it is not necessary, as the risk to populace is not there.

Case 2:

In this case the maximum ever concentration occurs at the starting point in both average and minimum flow cases which is 0.012 mg/m^3 and 0.053 mg/m^3 .but the concerned region is at 5000 m and there the critical value will be at low flow where the value of maximum concentration is 0.02 mg/m^3. The effluent of this kind consists mainly of zinc and chromium. In this case also the concentration of the effluent chemicals is well within permissible limits (CPCB guidelines, tableC.2 appendix C).

So no halting of supply is required. But as these pollutants are non-conservative and poisonous so halting of the supply for 12 hours should be done, so that these chemicals can pass the critical point without going into water supply system.

Case 3:

In this case the maximum ever concentration occurs at the 5000m point in both average and minimum flow cases which is 18 mg/m^3 and 32 mg/m^3 .but the concerned region is at 21000 m and there the critical value will be at low flow. There the value of maximum concentration along the flow at minimum flow condition is 7 mg/m^3, and even though less than permissible limits (CPCB guidelines, tableC.2 appendix C) but still high in value so supply should be halted for half a day i.e. from half day to 1st day end when the concentration reaches near zero, as the constituents are hazardous metals like zinc and copper. So there is little risk to populace.

Case 4:

In this case the maximum ever concentration occurs at the 5000m point in both average and minimum flow cases which is 0.72 mg/m^3 and 3.75 mg/m^3 .but the concerned region is at 10000 m and there the critical value will be at low flow. The effluent of this kind consists mainly of nitrogen and phosphorus, which are easily biodegradable.

There the value of maximum concentration along the flow at minimum flow condition is 2 mg/m^3 after 6 hours of spill, but the value is very much less than the permissible value (CPCB guidelines, tableC.2 appendix C). So no need to halt water supply as this mix of effluents and water poses no danger to human health

Comparison of all cases:

These four cases can be broadly studied under two case when comparing i.e. Pavana River (low velocity & low flow) and Krishna River (medium velocity & high flow).

For Pavana River cases the bell shape curves are not well defined whereas in case of the Krishna River they are well defined. It shows the model gives more accurate results for the case of medium speed & high flow rivers rather than the low velocity & low flow rivers.

Also in case low velocity river the diffusion is more prominent showing the slow descending of concentration curve, as diffusion is slow process, whereas in case of high velocity river advection and dispersion due to turbulence is prominent causing fast decrease in concentration and steeper slope of concentration curve.

CHAPTER 5: CONCLUSION

5.1 CONCLUSION

From the results shown in chapter 4 it is evident that the results imitate the typical condition up to a certain degree, even if its comparison to real time situation remains to be tested. But as far as comparison to typical condition shows that the model is quite effective and generates satisfactory result, especially in the case of Krishna river i.e. deep river, high flow & medium velocity river. One of the shortcomings of this models come in the case of low flow rivers & shallow river, which maybe the case because of the inaccuracy of the coefficient of longitudinal and transverse dispersion as there accurate values are hard to calculate and various concentration measurement laboratory dye tests may have to be performed for more accurate results. But on the basis of the comparison of concentration value with safe permissible values of parameters we can work the basic plan of action e.g. if value of concentration of effluent constituent goes above standard value water supply can be halted to the point of the concentration going below the permissible limit and if concentration is already less than the permissible value no action is needed as was discussed in previous chapter.

Also this model helps in risk assessment too on the basis of two things , one being comparison to permissible limit, if concentration crosses permissible limit it poses risk to human populace and second being knowing the chemicals nature (conservative or non-conservative or hazardous). Then even if value of concentration is less than permissible value it poses a little risk still and necessary action can be worked out.

On the whole it can be said that this model gives satisfactory results for a basic simulation model.

But still Further coding in future about iso-concentration lines and testing of the code with suitable and more real life data, so as to have even more accurate result is required and recommended.

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APPENDIX A

DETERMINATION OF LONGITUDINAL DISPERSION COEFFICIENTS

A.1 DETERMINATION OF THE LONGITUDINAL DISPERSION COEFFICIENT

The longitudinal dispersion coefficientis denoted as e_x, in the governing equation of the one-dimensional model. The equation is:

$(\partial C/\partial t) + u*(\partial C/\partial x) = e_x*(\partial^2 C/\partial x^2) - K_d*C$ -------- (equation A.1)

In the case of one-dimensional models dispersion coefficients can be entered directly. It also can be calculated by using the Bansal's equation. As in the case of TWODIFIN Bansal's equation for computing the dispersion coefficient is:

$e_{x\ =2.82*10}{}^{6}*(1/K)*\ (u/u_s)\ *((v*h)/((\rho*v*h)/\mu)^{0.762}$-------- (equation A.2)

Typically this formula in simplified form is also written as:

$e_x = (7.05*10^6 *(u*h))/R_n^{0.762}$-------- (equation A.3)

Here:

- u=velocity of flow in the reach (units are in m/s)
- u_s = velocity of plume in the reach (units are in m/s)
- h= effective depth of water (units in m)
- R_n = Reynolds no., and it is calculated as: $R_n=(u*h)/v_{T1}$
- V_{T1}= kinematic viscosity of water at given temperature 'T_1'(units are in m^2/second).
  - $V_{T2} = v_{T1} *1.029^{(T2-T1)}$
- K= regional dispersion factor (generally between 1-3 for shallow rivers)

- ρ = mass density of water (units in kg/m^3)
- μ = coefficient of viscosity of water (units in kg/m*s)

Here T_1 and T_2 are different temperature of the river water

The 'K' is constant. It is also independent of river flow rate, however, is dependent on bottom slope of river and other channel characteristics. Knowing only the time of travel for a specific flow rate, the dispersion coefficient can therefore be calculated. [2]

The dispersion coefficients calculation can also be done using field measurements of concentration for release of a dye plug into a river. Through this concentration-time data, the dispersion coefficients can be calculated. It is calculated for a given section of river by usage of the method of moments. The relationship is given as following:

$e_x = 0.5*u' * \{((\sigma_{t2})^2-(\sigma_{t1})^2)/(t_2' - t_1')\}$ -------- (equation A.4)

Here,

The subscripts 1 and 2 refer to the two measuring stations and,

e_x = longitudinal dispersion coefficient

$(\sigma_t)^2$= variance of the time-concentration data

t' = time of arrival of the centroid of the cloud at the given station

u' = mean river velocity between the two stations

The variances are calculated as follow:

$(\sigma_t)^2 =(\sum^N_{i=1}C_i*(t_i-t')^2)/(\sum^N_{i=1}C_i)$ -------- (equation A.5)

And

$t' =(\sum^N_{i=}(Ci*t_i))/(\sum^N_{i=1}C_i)$ -------- (equation A.6)

Here: C_i = concentration measurement at time

APPENDIX B

CODING OF INSTANTANEOUS SPILL CONDITION

B.1 CODING IN INTERACTIVE MODE

This model calculates concentration and gives the graph between concentration and time.

```
clear;
close all;

%% Set distance and time arrays
% Distance (x) will be denoted as xi, where i= 1,2,3,4
% x1=15000m, x2=25000m, x3=45000m, x4=60000m
x = [15000,25000,45000,60000];

% Time should start from 0 to 5184000 seconds, with a interval of 43200 seconds in it
t = 0:43200:5184000; % Unit-seconds

% Velocity of flow in x-direction
u = [0.018 0.018 0.016 0.017];

%% Initialize constant variables
h = 19.7; % Given depth of water
Vt1 = 1.004*1e-6; % Kinematic viscosity of water at given temperature ‘T1’(units are in
m2/second )
Q = 493.1; % Given total discharge (unit in m3/second)
Kd = 0; % Given decay rate constant at temperature T1 for Kd at temperature T2
Wi = 8e10; % Total mass of the material or waste discharged instantly(unit in milligram or mg)

beta = 0.001; % Dimensionless factor (ranges from 0.005 to 0.01) normally taken as  0.01
theta = 1.047;
```

```
T1 = 20; % T1 Temperature in degree centrigrade
T2 = 20; % Given temperature of water at the point of calculation (to be input by user)
for distIndex = 1:length(x)

%% Calculate Rn = Reynolds number
Rn(distIndex) = (u(distIndex)*h)/Vt1;

%% Calculate Ex = ex = longitudinal dispersion coefficient (unit in m2/second)
Ex(distIndex) = (7.05*1e6 *u(distIndex)*h)/Rn(distIndex)^0.762;

%% Calculate Kd = given decay rate constant at temperature T2
Kd_T2 = Kd*theta^(T2-T1);

%% Calculate constant b
b(distIndex) = (u(distIndex)^2)/(4*Ex(distIndex)) + Kd_T2;

%% Calculate Constant a
a(distIndex) = (x(distIndex)^2)/(4*Ex(distIndex));

%% Calculate EQ = transverse dispersion coefficient
EQ(distIndex) = (beta*Q*u(distIndex))/b(distIndex);

%% Calculate Concentration as a function of distance and time
numeratorCi(:,distIndex) = Wi*u(distIndex)*exp(
(u(distIndex)*x(distIndex))./(2*Ex(distIndex)) )...
*exp( -(a(distIndex)./t) - (b(distIndex)*t) );
denominatorCi(:,distIndex) = 2*pi*sqrt(Ex(distIndex)*EQ(distIndex))*t;
Ci(:,distIndex) = numeratorCi(:,distIndex)./denominatorCi(:,distIndex);

end
```

```
%% Plot results
tInDays = t/(24*60*60);
figure; plot(tInDays,Ci,'.-'); hold on;
xlabel('\bf TIME (DAYS)');
ylabel('\bf CONCENTRATION [mg/m^3]');
title('\bf CONCENTRATION Vs TIME');
% legend(['x = ',num2str(x(1))],['x = ',num2str(x(1))],['x = ',num2str(x(1))],['x =
',num2str(x(1))],['x = ',num2str(x(1))]);
```

APPENDIX C

MISCELLANEOUS TABLES

C.1 TABLE SHOWING DIFFERENT KINEMATIC VISCOSITY AT DIFFERENT TEMPERATURE

S.NO.	TEMPERATURE(^{O}C)	KINEMATIC VISCOSITY(m^2/s)*10^{-6}
1	0	1.787
2	5	1.519
3	10	1.307
4	20	1.004
5	30	0.801
6	40	0.658
7	50	0.553
8	60	0.475
9	65	4415
10	70	4127
11	75	3872
12	80	3643

C.2 TABLE SHOWING SOME OF THE CHEMICALS SAFE PERMISSIBLE VALUES IN INLAND SURFACE WATERS BY CPCB

S. NO.	PARAMETER OR CHEMICAL	INLAND SURFACE WATERS
1	Total Chromium(as Cr), (mg/l), Maximum	2.0
2	Copper (as Cu), (mg/l), Maximum	3.0
3	Zinc (as Zn), (mg/l), Maximum	5.0
4	Dissolved phosphates(as phosphorus(P)), (mg/l), Maximum	5.0
5	Sulphides (as Sulpur(S)), (mg/l), Maximum	2.0
6	Ammonical nitrogen (as N), (mg/l), Maximum	50
7	Total Kjeldahl Nitrogen (as NH3) , (mg/l), Maximum	100