STUDY OF IMPACT OF DOMESTIC SEWAGE AND INDUSTRIAL EFFLUENT ON WATER QUALITY OF RIVER BHARALU

A DISSERTATION

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

of

MASTER OF TECHNOLOGY

in

CONSERVATION OF RIVERS AND LAKES

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By

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JUNE, 2006

CANDIDATE'S DECLARATION

I hereby certify that the work, which is being presented in this dissertation, entitled **'STUDY OF IMPACT OF DOMESTIC SEWAGE AND INDUSTRIAL EFFLUENT ON WATER QUALITY OF RIVER BHARALU'** in partial fulfillment of the requirement for the award of the Degree of Master of Technology in **CONSERVATION OF RIVERS AND LAKES,** submitted in Alternate Hydro Energy Centre, Indian Institute of Technology, Roorkee, is an authentic record of my own work carried out during the period from July 2005 to June 2006 under the supervision and guidance of Dr. Renu Bhargava, Professor, Department of Civil Engineering, Indian Institute of Technology, Roorkee and Shri M. K. Singhal, Senior Scientific Officer, Alternate Hydro Energy Centre, Indian Institute of Technology, Roorkee.

The matter covered in this dissertation has not been submitted by me for the award of any other degree.

Dated 29-06-2006

(RAJESH BARUAH)
Candidate's signature

This is to certify that the above statement made by the candidate is correct to the best of our knowledge.

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ABSTRACT

The river Bharalu is a left bank tributary of river Brahmaputra in Assam, which passes through Guwahati city. It adds an aesthetic value for the beautification of Guwahati city. The river water is used for washing clothes, bathing and other uses. It also acts as a natural drain for carrying industrial and domestic waste water generated from Guwahati city. The discharge of untreated municipal waste water causes degradation of water quality of river Bharalu in lower stretches of the river. The DO in lower stretches of the river becomes zero during winter, producing foul smell and rendering the water body unsuitable for uses. However during summer, the effect of dilution due to the rainfall is remarkable. In this present study, the pollution load of river Bharalu in post monsoon and premonsoon season has been studied

Eight sampling stations were selected for collection of water sample from river Bharalu. The collected water samples were analyzed in Environmental Laboratory of Assam Engineering College, Jalukbari, Guwahati-13, Assam for various water quality parameters. Some of the samples were brought to Institute Instrumentation Centre, IIT Roorkee for testing of heavy metals. The observed values of various water quality parameters were discussed and compared with the prevailing standards, corresponding to use of the water body. For the development of BOD and DO model, the water samples from 53 drains were collected near outfall of each drain. The BOD and DO of the drains water and flow of drains have been determined. Further, the velocity, depth, width of flow and temperature of the river near outfall of each drain has been measured. These hydrodynamic parameters of the river were used to determine the reaeration rate and deoxygenation rate. The saturation concentration of oxygen in river water was determined from temperature values. The study covers about 13.93 km stretch of river starting from Natun Bazar Sluice gate at Basistha to Bharalumukh, from where the river enters the city. For convenience of study, a reference point is assumed near Natun Bazar Sluice Gate. The distances of each drain outfall from reference point were measured. The travel time in respective reaches were calculated on the basis of reach length and velocity. These data were used in BOD and DO model to predict the BOD and DO values throughout the stretch of the river. The predicted values of BOD and DO are then compared with the observed value of BOD and DO in eight sampling stations of the river. The comparison showed the variation

of predicted and observed values of BOD is about 8.8% in station 2 - 4. The predicted and observed values of BOD and DO match well throughout the stretch. After validation of the model, the various options, such as flow augmentation, zero discharge from industries and combined effect of flow augmentation coupled with waste water treatment were evaluated to improve the water quality of the water body for usable purposes.

The analysis of water samples show that the river is grossly polluted with high BOD. The DO decreases gradually as soon as the river enters the city and reduces to zero at about 3.7 km d/s from reference point. Thereafter it remains zero for the whole stretch till the confluence of river Bharalu and Brahmaputra. Moreover, the water body is highly polluted with faecal coliform, which indicates the discharge of untreated domestic sewage and is unsafe for bathing and primary contact recreational activities. The water quality index at different sampling stations has been calculated by using NSF WQI. The variation of WQI values and decreasing trends of DO towards d/s clearly indicate that the river water quality degrades while passing through the city. The values of WQI indicate that, the water quality as "Bad" in descriptive. The model was simulated for various u/s conditions to predict the impact on d/s stretches. To make the water quality conforming to DBU, various alternative solutions have been considered and out of all the solutions, the flow augmentation from river Basistha combined with provision of STP has been found to be most suitable. Moreover, result of simulation of zero discharge from industries, shows least impact on d/s stretch of the river. Hence, it may be established that the degradation of water quality of river Bharalu is primarily because of the municipal waste water. The study is useful in determining the water quality responses of the water body against various control measures and will help to evaluate low cost best management practices for the EMP.

NOTATIONS / ABBREVIATIONS

NOTATIONS / ABBREVIATIONS	DESCRIPTIONS	DIMENSION
^0C	Degree Centigrade	
APHA	American Public Health Association	
B	Benthic Oxygen Demand	ML^{-3}
BOD	Biochemical Oxygen Demand	ML^{-3}
C	Concentration of DO	ML^{-3}
C_0	Concentration of DO at X=0	ML^{-3}
CBOD	Carbonaceous Biochemical Oxygen Demand	ML^{-3}
CEQ	Council of Environmental Quality	
COD	Chemical Oxygen Demand	ML^{-3}
C_s	Saturation Concentration of DO in water	ML^{-3}
D	is the oxygen deficit of water (g O_2/m^3)	ML^{-3}
D_0	is the initial oxygen deficit of water (g O_2/m^3)	ML^{-3}
DO	Dissolved Oxygen	ML^{-3}
D_x, D_y, D_z	Coefficient of dispersion in x, y and z direction	L^2T^{-1}
EEC	European Environment Commission	
EMP	Environmental Management Plan	
EPA	Environmental Protection Agency	
I_i	Sub index of *i*th parameter	
JTU	Jackson Turbidity unit	
K_1	Deoxygenation rate	T^{-1}
K_2	Reaeration rate coefficient	T^{-1}
K_3	Sedimentation rate constant	T^{-1}
K_r	River decay rate	T^{-1}
L	BOD in the water	ML^{-3}
L_0	Initial BOD in the stream (below waste water discharge)	ML^{-3}
m. s. l	Mean Sea Level	
M_1, M_2	Coefficients for temperature and obvious pollution	
MME	Mean multiplication error	
n	Number of parameter	

NAS	National academic Sciences	
NSF WQI	National Sanitation Foundation Water Quality Index	
NTU	Nephelometric Turbidity Unit	
P	Photosynthesis	
pH	Negative log of hydrogen ion concentration	
PIIP	Prati's Implicit Index of Pollution	
ppb	Parts per billion	
ppm	Parts per million	
Q	Flow or discharge	L^3T^{-1}
q_i	Sub index (quality rating) of *i*th parameter	
q_i	Sub index (quality rating) of *i*th parameter	
R	Respiration	
RPI	River Pollution Index	
S	River bed slope	
S(x, y, z, t)	Denotes external sources and sinks of the substance in concern that may vary in both time and space	$M L^{-3} T^{-1}$
$S_{internal}$	Denotes the internal sources and sinks of the substance,	$M L^{-3} T^{-1}$
SOD	Sediment Oxygen demand	
SPC	Specific Conductivity	Ohm^{-1}
STP	Sewage Treatment Plant	
t	Time	T
TRPI	Taiwan River Pollution Index	
TS	Total Solids	
TSS	Total Suspended Solids	
U	Velocity of flow	LT^{-1}
V	Volume	L^3
v_x, v_y, v_z	Flow velocity in spatial directions x, y, and z	$L T^{-1}$
w_i	Weight of *i*th parameter	
WQI	Water Quality Index	
X	Observed value of *i*th parameter	
X_n	Normal value of *i*th parameter	

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CHAPTER-1

INTRODUCTION

1.1 GENERAL

Water, a basic necessity of life is needed for drinking, domestic uses, for irrigation of crops, production of different goods and for recreation purposes. About 97% of the water on Earth is salt water and not suitable for drinking, domestic and other uses. Of the remaining 3% that is fresh water, about two thirds is ice at the North and South poles. Therefore, only 1% of the total water on Earth is liquid fresh water. Now, of the total liquid fresh water, about 98% is ground water and 2% is surface water. So all of our lakes and flowing water, which provide most of the water for our uses make up about 0.02% of the total water found on earth.

Global studies show a challenging future and a chaotic view when considering total use and water availability, in third millennium. Projection of per capita all purpose water availability will droop from 1000-5000 m^3/year today to less than 1000 m^3 of water/year by 2030 in many developing countries. Most Asian countries will have severe water problem by the year 2025. Discharge of sewage and industrial effluents into the river water without any treatment causes alarming pollution. They cause damage histologically, physiologically and behaviourally to the human being and to the aquatic organisms. The natural balance of the wetland ecosystem is disturbed.

Indian cities have been growing at an alarming rate over the past few decades leading to the environmental problems, such as shortage of water supply, lack of sanitation, polluted air and water and problem of refuse disposal etc. These problems have led to the contamination of watercourse and river passing through or nearby all the cities which are grossly polluted due to sewage, sullage, solid waste leaches and industrial wastes. This problem of wastewater disposal from various sources, have aroused due to inadequacy of sewage treatment systems. As a result, discharge of all the industrial and domestic sewages, most of which are toxic are thrown into rivers, streams, lakes, canals etc. without bothering their deleterious effects on the water quality. If the water bodies are properly managed and exploited with scientific techniques, water borne diseases could be controlled over apart from using them for many other useful purposes. Such typical problem arises in the case of river Bharalu, which is grossly polluted by domestic sewage and industrial effluent generated from Guwahati city.

1.2 STUDY AREA AND DATA COLLECTION

1.2.1 Origin of River Bharalu

The River Bharalu is a left bank tributary of the River Brahmaputra originating from Phamjila, Khasi hills of Meghalaya, India (Figure 1.1) some 503 metres above mean sea level with the name of river Bahini. The river flows through the Mylliem Estate Protected Forest and Merdu hills. The stream Umtasu joins river Bahini at Murilmi pahar, which is 12 km from its source. Then it flows another 12.5 km and another stream from Zoo-Narengi, joining it at Jonali, R.G. Baruah Road. After that, the river Bahini is known as river Bharalu.

The river traverses a course of 30.82 km before meeting River Brahmaputra and has a total catchment area of about 109.4 sqkm. Out of the total catchment area about 62 sqkm falls in the Khasi hill district of Meghalaya covered by dense forest and rest 47.4 sqkm lies in Guwahati city of Assam, covered with built-up area with thick population. Municipal waste and industrial waste are important factors contributing to pollution of the river water. The river quality has been continuously degrading due to ignorance in control and management of water quality aspect. The river has a significant socio-economic value to nearby areas, e.g. the river water is used for drinking, for washing clothes, for bathing at upper reach as well as a carrier for municipal and industrial wastes.

1.2.2 Physiographic and Geographic Features

The study area is a part of the Brahmaputra basin in the Brahmaputra valley and Meghalaya plateau composed of Laterite and new alluvium and lies between 91°44' to 91°51' East longitude and 26°0' and 26°12' North latitude. The basin area lies between the elevation of 503m to 45.82m above m.s.l. with undulating topography comprising 65% hills & 35% plain area. Major land use in Bharalu basin is forestry (reserved forest) having an area of 62sqkm and urban built-up area of 47.4 sqkm. The soil of the area is laterite loamy silt in hills and sandy to clay loam in plain and is normally free from carbon. The catchment area is covered in Survey of India Toposheet No.78 N/16 and 78 N/12 of 1:50,000 scales. River Bharalu passes through the Guwahati city and due to this proximity of site, it was possible to generate a large amount of field data including the data from local interaction with the people residing the riverside and authorities.

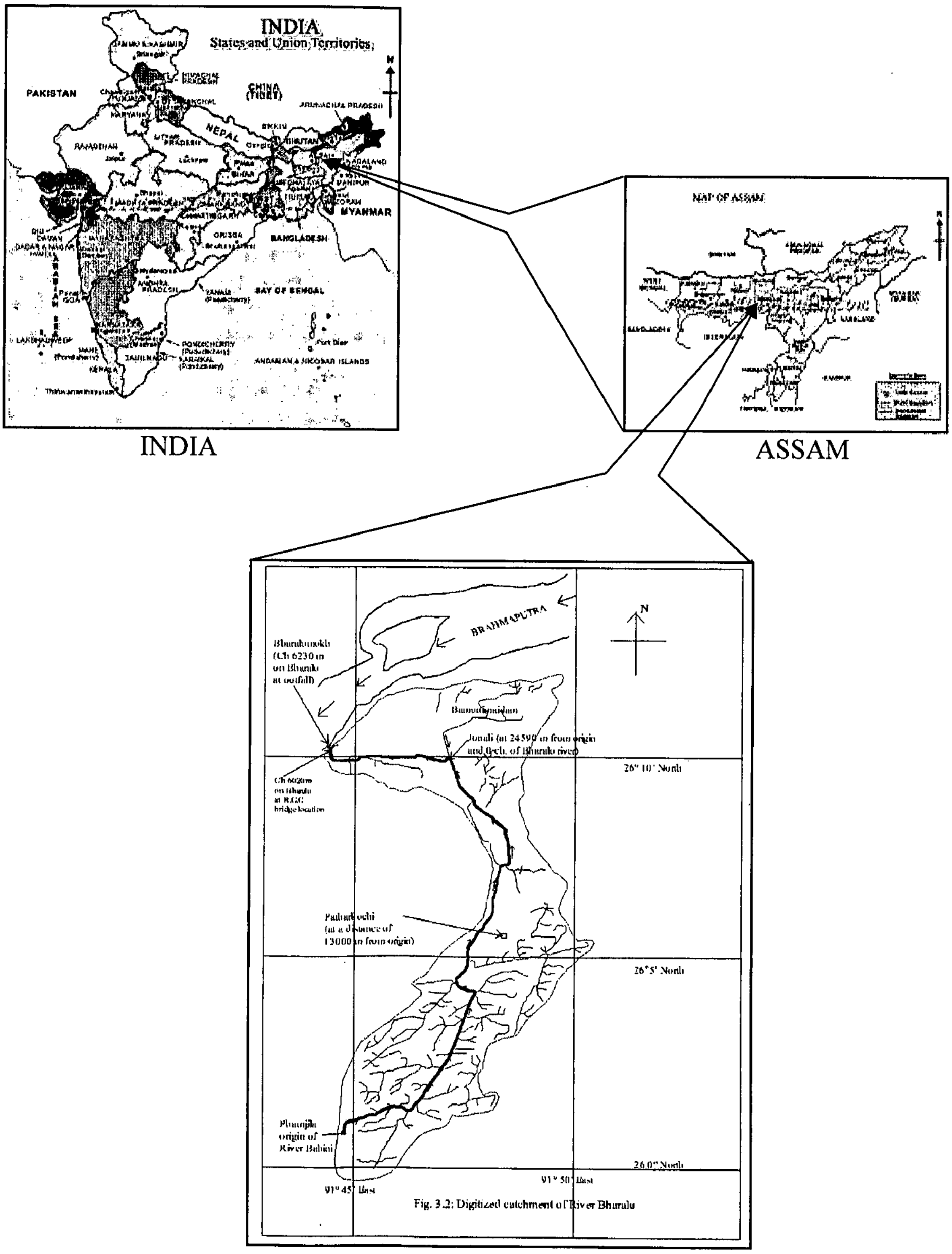

Fig 1.1 Location of River Bharalu in India

1.2.3 Climate

Climate of a place refers to weather conditions prevailing over it for a number of years. Climatic factors (e.g. rainfall) have direct bearing on flow variation of a river, which effect pollutant concentration. The critical period occurs, when the rainfall is lowest during winter. Man has little control over the climate. Therefore, pollution control measures suiting a particular climate have to be identified and adopted.

1.2.3.1 *Rainfall*

The daily rainfall data in the last week of July 2001 for the Guwahati city is shown in Table 1.1. The monthly rainfall data for the period of August 2001 to June 2005 is shown in Table 1.2. The average annual rainfall in the given drainage area (Guwahati city) for the year 1980 to 2003 is shown in Table 1.3. The mean rainfall over the basin is 1600mm, which occurs mainly during the monsoon period (June to October).

1.2.3.2 *Temperature*

Temperature controls the bacterially mediated process of biodegradation. The atmospheric temperature is the major regulating factor for determining the temperature of water body. The maximum temperature recorded at Guwahati in the summer, winter and rainy seasons are 38° C, 29° C, and 35° C respectively. Whereas minimum temperature recorded in summer, winter and rainy seasons is 23° C, 10° C and 22° C respectively.

1.2.4 Drainage Systems

The Guwahati city has open drainage system. These drains carry domestic sewage and industrial effluent from various location of the city and finally discharge it to river Bharalu. It has no separate storm water drainage, so during monsoon these drains also carry the surface runoff generated by rainwater. The reference point is taken near Natun bazar sluice gate at Beltola and chainage of this point is assumed as 0.0m. The name, location and size of drains joining river Bharalu are given in Table 1.4 and shown in Fig 1.2. The conceptual linearize diagram of the river and the drains are shown in Fig 1.3.

Table1.1 Daily rainfall of Guwahati

Sr. No.	Date	Rainfall (mm)
1	24/7/2001	12.7
2	25/7/2001	Nil
3	26/7/2001	Nil
4	27/7/2001	6.6
5	28/7/2001	2.5
6	29/7/2001	27.9
7	30/7/2001	25.4
8	31/7/2001	3.3

Table1.2 Monthly rainfall of Guwahati

Months	Monthly Rainfall in (mm)				
	2001	2002	2003	2004	2005
Jan		15.5	Nil	Nil	22.9
Feb		7.4	35.6	16.5	
Mar		84.5	75.1	1.5	93.4
April		285.3	223.9	315.9	228.75
May		189.1	102.8	125.3	299.5
June		323.2	308.1	263.2	87
July		326.5	308.1	331.9	
Aug	137.1	114.5	180.2	155.3	
Sept	149.5	130.8	95	70.3	
Oct	119.9	44.9	122.6	312.3	
Nov	16.2	38.1	6.6	8.2	
Dec	0	7.6	7.1		

1.2.5 Industries Located at Guwahati

A number of industries are set up in and around Guwahati. The major industries are Guwahati Oil Refinery, which was commissioned in the 1962; India Carbon and Railway workshop are located in the eastern part of the City (Noonmati). Other types of industries include rice, oil and flour mills, tea factory, manufacturer of wooden furniture, motor and engineering workshops, textile cotton spinning and weaving mills, brass products, steel works, cycle manufacturing, carbon products, leather works, bamboo and cane industries, gas factory, metal products, candle industries, ayurvedic products, printing and paper binding industries.

Table 1.3 Yearly rainfall of Guwahati

Year	Yearly Rainfall (mm)	Remarks
1980	1392.11	Jan - Dec
1981	1413	Jan - Dec
1982	1457.17	Jan - Dec
1983	1815.4	Jan - Dec
1984	1920	Jan - Dec
1985	1470.1	Jan - Dec
1986	1438.8	Jan - Dec
1987	1597.4	Jan - Dec
1988	2173	Jan - Dec
1989	1163.6	May-Sept
1990	2799.8	Jan-Oct
1991	1726.5	May-Oct
1992	1732.1	Jan-Sept
1993	1796.6	May-15thOct
1994	1037.2	May-Oct
1995	2425.2	15th May-15th Oct
1996	1453.4	15th May-15th Oct
1997	1357.1	Jan - Dec
1998	1393.9	Jan - Dec
1999	1791.7	Jan - Dec
2000	1804.2	Jan - Dec
2001	1763.6	Jan - Dec
2002	1673.5	Jan - Dec
2003	2065.3	Jan - Dec

Table 1.4 Name of drains, location, size and its discharge

Drain No.	Date of Survey	Dist. From Ref. point (m)	Location	Name of drain	Size of drain	Flow, Q_i (m^3/sec)
1	24-1-06	100	Natun Bazar	R/B drain from Patarkuchi	1.2x2.1	0.108
2	24-1-06	1650	Beltola Bazar	L/B drain from Beltola Bazar Road	(1.2+1.0)x1.5/2	0.005
3	24-1-06	1700	Saurav Nagar road, Beltola	R/B drain of Saurav Nagar Road	0.8x 1.0	0.0008
4	24-1-06	1850	Near Dehang Apt, Beltola Bazar	R/B drain near Dihang Apartment, Beltola	(1.5+1)x2.1/2	0.045
5	24-1-06	2000	R.C.C. bridge,Beltola	R/B drain at u/s of R.C.C. br.,Beltola	(1.5+1)x2.1/2	0.018
6	24-1-06	2030	R.C.C. bridge,Beltola	R/B drain at d/s of R.C.C.br	(1.5+1)x2.4/2	0.073
7	24-1-06	2030	R.C.C. bridge,Beltola	L/B drain at d/s of R.C.C.br	(1.5+1)x2.4/2	0.02
8	25-1-06	3600	R.C.C. bridge, Rukminigaon,G.S. Road	R/B drain at u/s of R.C.C.br.Rukminigaon	(1.5+1)x2.2/2	0.001
9	25-1-06	3700	R.C.C. bridge, Rukminigaon,G.S. Road	R/B drain at d/s of R.C.C.br.Rukminigaon	(1.5+1)x2.2/2	0.0015
10	25-1-06	4400	Near Down Town Hospital, Saru Mataria	R/B drain at u/s of R.C.C.br.Down Town Hospital	1x1.2	0.0025
11	25-1-06	4410	Near Down Town Hospital, Saru Mataria	R/B drain at d/s of R.C.C.br.Down Town Hospital	1x1.2	0.0025
12	25-1-06	4700	Sarumataria road, Super Market, Dispur	R/B drain u/s of Sarumatoria Road, Supermarket	1x2.4	0.003
13	25-1-06	4710	Sarumataria road, Super Market, Dispur	R/B drain d/s of Sarumatoria Road, Supermarket	0.6 m dia pipe	0.002
14	25-1-06	4780	Super Market, Dispur	R/B drain from LPGas agency, Dispur	0.8x1.8	0.001
15	25-1-06	5250	Near Janata Bhawan, Dispur	L/B drain from Capital complex, Dispur	2.5x2.4	0.075
16	25-1-06	5850	Hengrabari	L/B drain from Ganeshguri market, Hengrabari Rd	3.0x2	0.144
17	28-1-06	5850	R.C.C. bridge, Hengrabari Road	R/B drain u/s of R.C.C.bridge, Hengrabari Road	2.5x2.0	0.09
18	28-1-06	6050	SPT bridge, Japorigog path, Nayanpur	R/B drain u/s of SPT bridge, Nayanpur road	1.5x2.0	0.24
19	28-1-06	6060	SPT bridge, Japorigog path, Nayanpur	R/B drain d/s of SPT bridge, Nayanpur road	1.5x2.0	0.24
20	28-1-06	6060	SPT bridge, Japorigog path, Nayanpur	L/B drain d/s of SPT bridge, Nayanpur road	0.3x1.5	0.0015
21	28-1-06	6300	Jayanta Hazarika Path, Nursery	R/B drain u/s of Jayanta Hazarika Rd, Nursery	0.5x21.0	0.003
22	28-1-06	6300	Jayanta Hazarika Path, Nursery	L/B drain u/s of Jayanta Hazarika Rd, Nursery	1.5x2.0	0.075
23	28-1-06	6308	Jayanta Hazarika Path, Nursery	R/B drain d/s of Jayanta Hazarika Rd, Nursery	0.5x1.0	0.003
24	28-1-06	6308	Jayanta Hazarika Path, Nursery	L/B drain d/s of Jayanta Hazarika Rd, Nursery	1.5x2.0	0.075
25	28-1-06	6410	Manik Nagar Path,Nursery	R/B drain u/s of Manik Nagar Rd., Nursery	0.5x1.5	0.0075

Contd...

...Contd. **Table 1.4**

26	28-1-06	6416	Manik Nagar Path,Nursery	R/B drain d/s of Manik Nagar Rd., Nursery	0.5x1.5	0.0075
27	28-1-06	6580	Rangpur path,Nursery	R/B drain d/s of Rangpur Road, Sundarpur	0.5x 1.5	0.0013
28	28-1-06	6750	East byelane No.18 road, Sundarpur	R/B drain u/s of East Byelane Road, Sundarpur	0.4x1.5	0.0013
29	28-1-06	6756	East byelane No.18 road, Sundarpur	R/B drain d/s of East Byelane Road, Sundarpur	0.4x1.5	0.0025
30	28-1-06	6902	Sundarpur Road,Sundarpur	R/B drain u/s of Sundarpur Road, Sundarpur	0.6x1.5	0.06
31	28-1-06	6908	Sundarpur Road,Sundarpur	R/B drain d/s of Sundarpur Road, Sundarpur	0.6x1.5	0.06
32	28-1-06	7018	Shiv Mandir path, Nandanpur	R/B drain of Shiv Mandir Road, Sundarpur	0.5x0.6	0.001
33	28-1-06	7208	Nandanpur path, Nandanpur	R/B drain of Nandanpur Road, Nandanpur	0.5 m dia	0.005
34	28-1-06	7274	Progoti girls hostel road	R/B drain of Pragati Girl's Hostel Rd., Nandanpur	0.3x1.5	0.003
35	28-1-06	7322	Sarathi path, Nandanpur	R/B drain u/s of Sarathi Road, Nandanpur	0.5x0.4	0.000083
36	28-1-06	7382	Japorigog Road, State Zoo	R/B drain u/s of Japorigog Road	0.6x1.0	0.0024
37	28-1-06	7388	Japorigog Road, State Zoo	R/B drain d/s of Japorigog Road	0.6x1	0.0024
38	28-1-06	7412	State Zoo, R.G.B. Road	R/B drain from State Zoo Entrance Road	0.6x1.5	0.0018
39	28-1-06	7510	Jyoti path, Near State Zoo	R/B drain u/s of Jyoti Path	0.6 m dia pipe	0.0001
40	28-1-06	7516	Jyoti path, Near State Zoo	R/B drain d/s of Jyoti Path	0.6 m dia pipe	0.0002
41	1/2/2006	7590	Namghar path, R.G.B. Road	R/B drain u/s of Namghar Path	0.6 m dia pipe	0.0015
42	1/2/2006	7596	Namghar path, R.G.B. Road	R/B drain d/s of Namghar Path	0.6 m dia pipe	0.0012
43	1/2/2006	7620	Jurani path, R.G.B. Road	R/B drain u/s of Jurani Path	0.6 m dia pipe	0.0013
44	1/2/2006	7626	Jurani path, R.G.B. Road	R/B drain d/s of Jurani Path	0.4x0.6	0.0015
45	1/2/2006	7700	R.C.C. bridge , Jonali, R.G.B.road	R/B drain u/s of Jonali bridge	5x2.6	0.792
46	1/2/2006	7720	R.C.C. bridge , Jonali, R.G.B.road	R/B drain d/s of Jonali bridge	(1.5+1)x2/2	0.015
47	1/2/2006	7720	R.C.C. bridge , Jonali, R.G.B.road	L/B drain d/s of Jonali bridge	0.9 m dia pipe	0.0039
48	3/2/2006	8870	R.C.C. bridge, Nabin Nagar, Rajgarh road	R/B drain 50m u/s of bridge	1.8x2.4	0.27
49	3/2/2006	11300	R.C.C. bridge, Cherap Bhati	R/B drain u/s of R.C.C. bridge,	1.8x2.4	0.2268
50	9/2/2006	11775	Chabipul L.P. School, Athgaon	R/B drain from Chalabeel, Chabipol	(6+3)x2.6/2	0.81
51	9/2/2006	12350	Fatasil Ambari	L/B drain , MoraBharalu, Fatasil Ambari	(4+10)x1.5/2	0.08
52	9/2/2006	12400	Narayan Nagar	R/B drian from Narayan Nagar	1.2x2.4	0.0036
53	9/2/2006	13050	Goenka Nursing home, Santipur	L/B drain from Durga Sarobar	1.2x2.4	0.0072

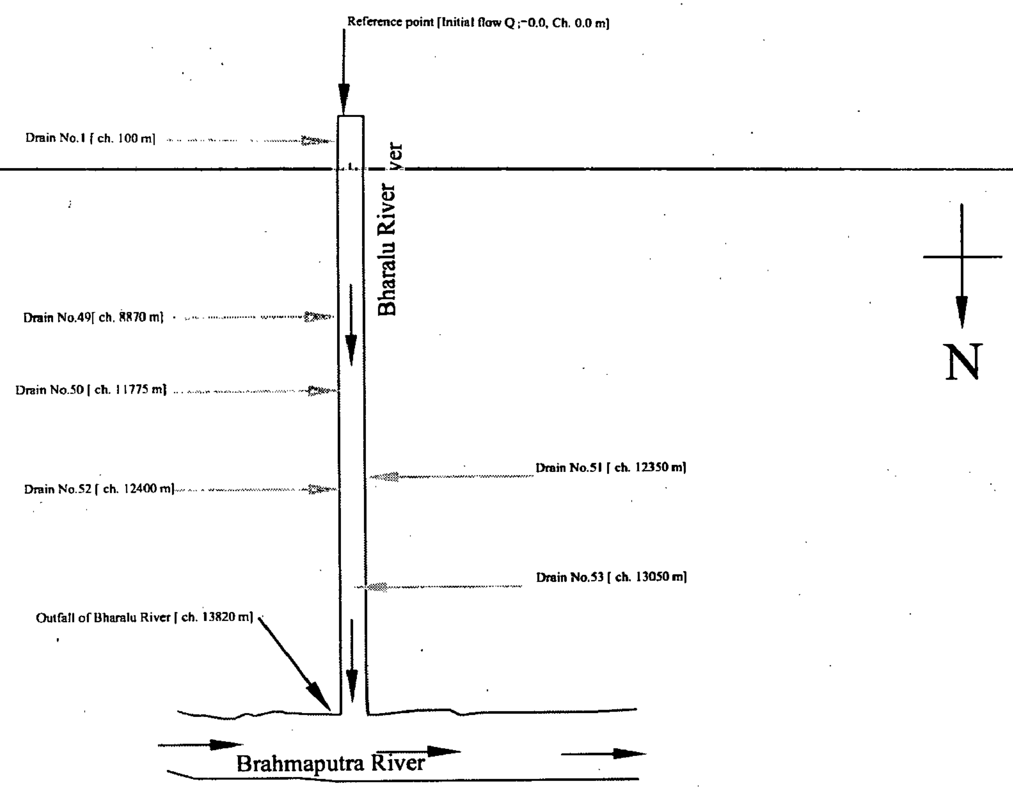

Fig.1.3 Conceptual linearize diagram of Bharalu river and its drain

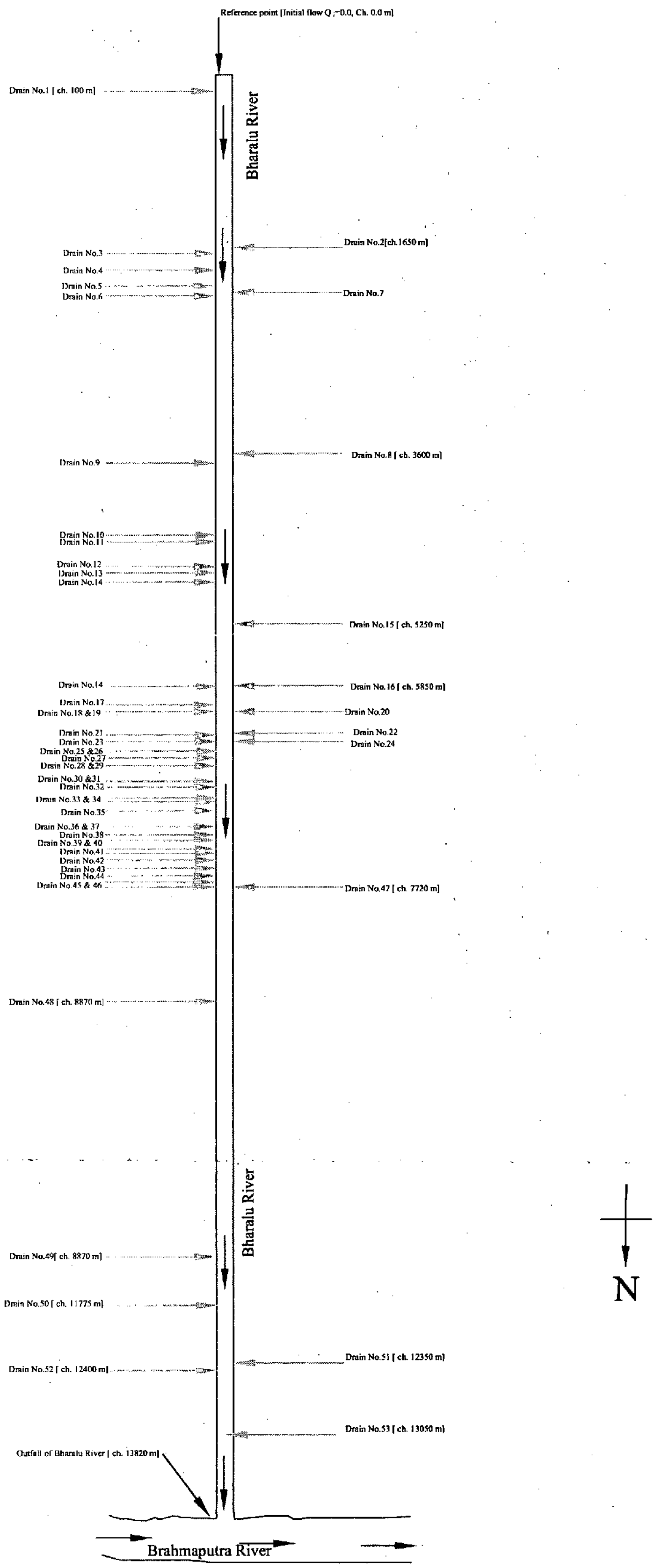

Fig.1.3 Conceptual linearize diagram of Bharalu river and its drain

1.2.6 Sources of Pollution

The sources of water pollutants of the river Bharalu can be classified as domestic, industrial and agricultural wastewater. A brief survey of the river and its surroundings was conducted before the samples were collected to have a preliminary idea on pollution of the Bharalu river. During the survey, it was found that the colour of the river water turns gradually dark from Beltola bazaar area and darkest in the Bharalumukh area. There is an unpleasant smell from Bhangagarh to Bharalumukh. There are many service latrines on the bank of the river, which discharges faeces to the river directly. There are about fifty-three numbers of drains on both bank of the river, which carries semi treated and untreated domestic sewage and industrial effluent from various localities of the city to discharge into the Bharalu River. They joins river Bharalu at various point as shown in Fig.1.2. At present Guwahati refinery discharges its wastewater into Brahmaputra near Saraighat Bridge through a pipeline. However, occasionally they discharge the waste into Bharalu and clean water of the refinery into the open drain connecting the river Bharalu near Kamrup ice factory at Jonali, R. G. Baruah Road. Moreover, there are more than hundred numbers of motor garages and automobile servicing centers including the Railway diesel workshop at Bamunimaidam and ASTC workshop at Paltanbazar, which drains their wastewater into the river Bharalu. The semi treated wastewater generated from the toilet and numbers of other sources contribute greatly to the pollution of Bharalu River. According to Nellist (1973), if the heavy metal and cyanide are not removed from the effluent of metal finishing and electroplating industries, discharges of such effluent into rivers causes excessive acidity or alkalinity in the water of the river.

1.3 STATEMENT OF THE PROBLEM

Most of the waste products of the Guwahati city, industrial effluents of some industries and almost all the pollutants in air, which are washed down by rain, finally find their way to the river Bharalu that passes through Guwahati city. It serves as a natural drain for various pollutants. As a result, the clear water has become blackish in colour and fish population has vanished completely. On many occasions, foul smells are emitted towards the lower reaches of the river. The river water is used for bathing, washing clothes and other useful purposes in upper reaches. The water body of the river is grossly polluted with high biochemical oxygen demand (BOD) and low dissolves oxygen (DO) as soon as it entered the city till it discharges its pollution load to river Brahmaputra. So it becomes necessary to restore the water quality of the river Bharalu to bring back to the usable purposes as the water demand is ever increasing with the increase of population.

Till now many studies has been carried out to ascertain the pollution of the water body of river Bharalu by analyzing water quality parameter at various sampling stations. These studies only depict the level of pollution of the water body and are not sufficient to give enough information to set up control measures for the treatment of the wastewater and the subsequent water quality responses of the water body. For this purpose detailed study has to be done regarding the quality and quantity of wastewater carried by the drains, their location and hydrodynamics parameter of the river for the development of BOD and DO profile of the river. Then only necessary control measures such as setting up of localized sewage treatment plant (STP) with its location, Zero discharge from industries and flow augmentation can be simulated for the water quality responses of the water body for different conditions.

Keeping in view of the seriousness of the problem and its relevance to the present situation, an attempt has been made in the present study to quantify the pollution load to assess the impact of domestic sewage and industrial effluent on water quality of river Bharalu (i.e. changing of water quality of the river when it enters the city till it goes out of the city), Guwahati, District- Kamrup, Assam, in pre-monsoon and post–monsoon seasons. Moreover, an attempt is also made to develop a model for the BOD and DO profile of the river for helping in evaluation of effectiveness of control measures for the environmental management plan.

1.4 AIMS AND OBJECTIVES OF THE STUDY

The objectives of these studies are:

- To investigate the quantity and quality of domestic and industrial wastewater generation in Guwahati city as well as spatial distribution of drains meeting the Bharalu River.
- Preparation of the schematic linearize diagram of point load sources to develop the BOD and DO profile of the river.

- Simulation of BOD and DO model with respect to flow augmentation, zero discharge and setting up of localized STP.
- To assess the water pollution loads vis-à-vis present status of surface water environment of River Bharalu and to develop water quality index for the river Bharalu.
- To evaluate the various control measure for environmental management plan.

1.5 SCOPE OF STUDY

The study has been carried out for the river stretch from Natun Bazar Sluice Gate, Basistha to Bharalumukh (i.e. confluence of river Bharalu and Brahmaputra) with a length of about 13.95 km. The impact of industrial effluent and municipal/domestic sewage discharged into the river through 53 drains has been studied. BOD and DO model shall be formulated. Sediment oxygen demand, nonpoint source pollution shall not be considered in modeling. Water quality analysis and flow measurements were restricted within the period from Oct'05 to Apr'06.

1.6 ORGANISATION OF THE WORK

The whole study is incorporated into six chapters. The first chapter includes the problem, brief description of the study area and objectives of the present study. The second chapter includes literature survey for different case studies of river pollution, BOD and DO modeling for streams/rivers and water quality index. The third chapter describes the quality based classification of river Bharalu and has been compared with the DBU standard. The fourth chapter includes the methodology for water quality analysis and development of BOD and DO model. The fifth chapter includes results and discussion for water quality analysis and determination of water quality index at different sampling stations of the river. This chapter also includes the development of BOD and DO model, model validation and simulation of various u/s load conditions to predict the d/s impact. Various alternative solutions are suggested to improve the quality of the river as well as their numerical analysis is incorporated in this part. Lastly, general conclusions and further scope of study are given in chapter six.

CHAPTER-2

LITERATURE REVIEW

2.1 GENERAL

The growth of civilization and subsequent needs for better living standard of human being has caused great impact on the environment. The various issues and challenges before the mankind for utilization of natural resources for a sustainable development have compelled to look back at various environmental problems at different levels. One of the major environmental problems is the pollution of surface water body due to discharge of domestic and industrial effluent. According to Odum (1971), "Pollution is an undesirable change in the physical, chemical or biological characteristics of our air, water and land that may or will harmfully affect human life or that of desirable species or industrial processes, living conditions and cultural assets, or that may or will waste or deteriorate our material resources".

Human waste was historically the first pollution problem. In ancient times, people naturally settled near source of water and thus, communities grew besides lakes, along rivers, and in areas where spring or well water was available. During the Industrial Revolution of the 19^{th} century, cities in the United States and Western Europe grew at a tremendous rate. Refuse of all kinds including great quantities of horse manure ended up in the streets, open sewers and nearby rivers. Devastating epidemics of water borne diseases such as cholera, typhoid and dysentery were common in large cities.

By the early part of the 20^{th} century, the connection between diseases and sewage-borne microorganisms had been recognized. Luis Pasteur (1822-1895) and Robert Koch (1843-1910) postulated the Germ theory of disease. This focused attention of the scientific community to the safe disposal of domestic sewage and need to practice sanitation. Accordingly, safe water supplies were established in most industrialized nations. As a result, water borne diseases have been virtually eliminated in those countries; however, those are still very common in less developed countries, where waste disposal systems are often inadequate or non-existent. In industrialize nations, contamination with hazardous chemicals has become the main threat to the surface water body.

Therefore, it becomes necessary to assess and monitor the water quality of the surface water body to determine its acceptability for the different uses as well as pollution status of the water body. If the level of pollution increases above the acceptance level, then necessary control measures have to be established. However, before setting any control measure, we should know the effectiveness of such measures and for this, water quality model has to be developed for the surface water body. Water quality model will help in predicting water quality responses of the water body in different load condition and allow us to choose alternative option.

The literature has been reviewed under two headings namely (1) Study of pollution status of river and (2) Development of BOD and DO model (3) Water Quality Index.

2.2 STUDY OF POLLUTION STATUS OF RIVER

A number of studies have been carried out in connection with pollution of river water. Grande (1964) studied the water quality of river Otra, Norway. He studied the conductivity, colour, COD, organic suspended solids and pH of different water samples of pulp and paper mill wastes on fish population of the river. Similar works were carried out in the river Yodo, Japan (Shoji, 1966); in the river Holme (Brown et al., 1979); in the river Isumi, Japan (Mori et al., 1979) and in Glatt River, Switzerland (Gunten et al., 1986). Schroesfer (1963) carried out some research works in the Mississipi River.

Rajagopalan et al. (1973) studied pollution of Subarnrekha River at Rachi. Chattopadhyay et al. (1984) studied the pH, alkalinity, chloride, sulphate, phosphate, nitrogen in different forms, DO, BOD, and COD of the Ganga river water in the Kanpur region and found that the river water in Kanpur region has become highly polluted. Similar works on the Ganga River was carried out in Varanashi region (Sing, 1985).

Agarwal et al. (1986) studied the DDT residues in the river Jamuna, Delhi and found that the river contains moderate to high levels of DDT residues. The concentration of total DDT residues ranges from 0.04 to 3.42 milligram per litre in water, 0.007 mg per kg in bottom sediments, 0.05 to 15.24 mg per kg in various invertebrates and 0.54 to 56.31 mg per kg of fishes. Anderson and Peterson (1969) showed by experiments that DDT has sub lethal effects on the nervous system of Brook Trout.

Tirath et al. (1982) studied the water quality of Gomti River, Lucknow (U.P.). They studied DO, BOD, nitrogen in different forms, TDS, TSS and turbidity and found that the river water is polluted. Raina et al. (1984) studied the pollution status of the river Jhelum-1. Das et al (1987) studied pollution status in river Ib (physico-chemical characteristics). Ajmal et al. (1988) studied pollution of Hindon and Kali nadi. Sankaran (1988) studied pollution on Cauvery and Adyar rivers in Tamil Nadu. Shah (1988) studied physico-chemical aspects of pollution in river Jhelum (kasmir). Sinha (1988) studied effect of waste disposal on water quality of river Damodar in Bihar with special reference to physico-chemical characteristics. Khan et al. (1994) studied water quality parameter (physico-chemical characteristics) in river Ganga between Narora and Kannauj, U.P.

Ghose et al. (1990) studied the water pollution due to the surface and underground mining activity in Satgram Underground Coal Project. Kakoti (1990) studied physico-chemical characteristics of municipal wastewater of Guwahati city flowing through 9 major drains in different areas of the city. Pophali et al. (1990) studied the pollution load in pre monsoon and post monsoon seasons in Patra River, Bhopal, Madhya Pradesh. Katariya (1994), studied water quality of Kalisot River, Mandideep, Bhopal. Angelidis et al. (1995) studied the impact of point (domestic and industrial effluent) and non-point (agricultural land run off) pollution sources on the quality of the receiving waters of the Evrotas River (Laconia, Greece). Vutukuru et al. (2002) studied the impact of domestic and industrial wastes on the water quality structure of Gostani and Velpur canal, Tanku, West Godavari district, Andhra Pradesh. The canal was subjected to organic pollution, indicated by high BOD and COD values besides poor microbial water quality. Nagaraj et al. (2005) studied the impact of industrial effluents and domestic sewage on ground water pollution in Vrishabavathi river basin, Karnataka.

The State Pollution Control Board, Assam has made some water quality measurements in the Brahmaputra River and its other tributaries, bur their experimental results are not available. Das (1977) studied the pH, DO, BOD, oil and phenol in the water of the Bharalu River. He found that amounts of these parameters were considerably high in comparison to the standards. Sharma et al. (1994) studied the physico-chemical parameters of Bharalu River water. The results showed high pollution status with values of some parameter beyond the permissible limits DO (1.0 mg/l), Alkalinity (430 mg/l), BOD (12.2 mg/l) and COD (62.0 mg/l) etc.

2.3 DEVELOPMENT OF BOD AND DO MODEL

2.3.1 History of Development

The mathematical modeling of water quality in a river has progressed from the pioneering work of Harold Streeter and Earle Phelps (1925) who developed the relationship between the decay of an organic waste measured by the biochemical oxygen demand (BOD) and dissolved oxygen (DO) resources of the river, producing the classic dissolved sag model. These two counteracting processes, (BOD and DO), are considered in the traditional BOD-DO model of Streeter and Phelps (1925) in the mathematical form. Subsequent to Streeter and Phelps (1925), several BOD-DO models and several concepts were introduced in the past (Theriault, 1927; Camp, 1963; Li, 1972; Gundelach and Castillo, 1976; Van Genuchten and Alves, 1982; Bhargava, 1983; Thomman and Muller, 1987; Jolankai, 1997, Yu et al., 1991; Adrain et al., 1994). Most of these models have gradually increased in terms of the number of variables representing the variation of BOD as well as DO concentrations. However, some of the models are different in functional forms and don not transform to the widely used Streeter and Phelps model.

To assess the changes in water quality of rivers in spatial and temporal scales, very limited modeling efforts have been made in India in recent years (Bhargava 1983; Choudhary et al., 1990; Ghosh, 1993; Jain, 1998; Sharma et al., 2000). Abbasi et al., (2002) studied the modeling of Bukingham canal water quality, Chennai, India by using the QUAL2E-UNCAS software.

2.3.2 Computer Automated Tool

Numbers of software are available for water quality modeling of river and stream. They are QUAL2K, QUAL2E, WASP, CE-QUALM-ICM, HEC5Q, MIKE11, ATV MODEL, SALMON-Q, DUFLOW, AQUSIM and DESERT etc. These softwares have been developed for the Environmental Protection Agency (EPA) of United States of America. QUAL2K is a modeling Framework for simulating river and stream water quality developed by Steve Chapra, Greg Pelleties and Hua Tao, which are explained in following paragraphs.

2.3.2.1 *Assumption*

The following assumptions were made while developing the model.

- One-dimensional. The channel is well mixed vertically and laterally. The variation in water quality is along the flow.
- Branching. The system can consist of a mainstream river with branched tributaries.
- Steady state hydraulics. Non-uniform, steady flow is simulated.
- Diel heat budget. The heat budget and temperature are simulated as a function of meteorology on a diel time scale.
- Diel water-quality kinetics. All water quality variables are simulated on a diel time scale.
- Heat and mass inputs. Point and non-point loads and withdrawals are simulated.

2.3.2.2 *Framework*

The QUAL2K framework includes the following new elements:

- Software Environment and Interface. Q2K is implemented within the Microsoft Windows environment. Numerical computations are programmed in Fortran 90. Excel is used as the graphical user interface. All interface operations are programmed in the Microsoft Office macro language: Visual Basic for Applications (VBA).
- Model segmentation. Q2E segments the system into river reaches comprised of equally spaced elements. Q2K also divides the system into reaches and elements. However, in contrast to Q2E, the element size for Q2K can vary from reach to reach. In addition, multiple loadings and withdrawals can be input to any element.

- Carbonaceous BOD speciation. Q2K uses two forms of carbonaceous BOD to represent organic carbon. These forms are slowly oxidizing form (slow CBOD) and a rapidly oxidizing form (fast CBOD).
- Anoxia. Q2K accommodates anoxia by reducing oxidation reactions to zero at low oxygen levels. In addition, denitrification is modeled as a first-order reaction that becomes pronounced at low oxygen concentrations.
- Sediment-water interactions. Sediment-water fluxes of dissolved oxygen and nutrients are simulated internally rather than being prescribed. That is, oxygen (SOD) and nutrient fluxes are simulated as a function of settling particulate organic matter, reactions within the sediments, and the concentrations of soluble forms in the overlying waters.
- Bottom algae. The model explicitly simulates attached bottom algae. These algae have variable stoichiometry.
- Light extinction. Light extinction is calculated as a function of algae, detritus and inorganic solids.
- pH. Both alkalinity and total inorganic carbon are simulated. The river's pH is then computed based on these two quantities.
- Pathogens. A generic pathogen is simulated. Pathogen removal is determined as a function of temperature, light, and settling.
- Reach specific kinetic parameters. Q2K allows you to specify many of the kinetic parameters on a reach-specific basis.

2.3.2.3 *Segmentation and hydraulics*

The model represents a river as a series of reaches. These represent stretches of river that have constant hydraulic characteristics (e.g., slope, bottom width, etc.). The reaches are numbered in ascending order starting from the headwater of the river's main stem. Notice that both point and non-point sources and point and non-point withdrawals (abstractions) can be positioned anywhere along the channel's length.

2.3.3 Governing Equation for BOD-DO Modeling

There are several models for BOD-DO simulation. Some of models that are used in the developed decision support system (DSS) are described below. In general, river water quality models, and thus the BOD-DO models, can be derived from the general basic water quality model equation as given below.

$$\frac{\partial c}{\partial t}+v_x\frac{\partial c}{\partial x}+v_y\frac{\partial c}{\partial y}+v_z\frac{\partial c}{\partial z}=\frac{\partial}{\partial x}\left(D_x\frac{\partial c}{\partial x}\right)+\frac{\partial}{\partial y}\left(D_y\frac{\partial c}{\partial y}\right)+\frac{\partial}{\partial z}\left(D_z\frac{\partial c}{\partial z}\right)+S(x,y,z,t)\pm S_{internal}$$

..............(2.1)

Where,

C - is the concentration, the mass of the quality constituent in a unit volume of water (mass per volume, $M\ L^{-3}$);

D_x, D_y, D_z - are the coefficients of dispersion in the direction of spatial co-ordinates x, y, and z, (surface area per time, L^2T^{-1});

v_x, v_y, v_z - are the components of the flow velocity in spatial directions x, y, and z, (length per time, $L\ T^{-1}$);

t - is the time (T);

S(x, y, z, t) - denotes external sources and sinks of the substance in concern that may vary in both time and space (mass per volume per time, $M\ L^{-3}\ T^{-1}$);

$S_{internal}$ - denotes the internal sources and sinks of the substance, ($M\ L^{-3}\ T^{-1}$);

2.3.3.1. *Streeter and Phelps (1925) model*

The water quality modeling in a river has progressed from the pioneering work of Streeter and Phelps (1925). Streeter and Phelps (1925) established the relationship between the decay of an organic waste measured by BOD and DO resources of the river producing the classical dissolved oxygen sag model.

The developed equation for BOD and DO model are given in Eqs. (2.2) and (2.3) respectively.

$$L = L_0 e^{(-K_1 t)}$$ ....(2.2)

Where,

L - BOD in the water ($g\ O_2/m^3$)

L_0 - initial BOD in the stream (below waste water discharge)

K_1- is the rate coefficient of biochemical decomposition of organic matter (T^{-1}, usually day^{-1})

t - is the time, that is the time of travel in the river interpreted as t =X/U, where X is the distance downstream of the point of effluent discharge (T, given usually in days). And U is the velocity of flow (m/s).

$$D = D_0 e^{-K_2 t} + \frac{K_1 L_0 \left(e^{-k_1 t} - e^{-K_2 t}\right)}{\left(K_2 - K_1\right)} \qquad \text{................ (2.3)}$$

Where,

D_0 - is the initial oxygen deficit of water (g O_2/m^3)

D - is the oxygen deficit of water (g O_2/m^3)

K_2 - is the reaeration rate coefficient (T^{-1})

2.3.3.2. *Camp model (1963)*

Camp (1963) developed expanded BOD and DO models. The model involves the following processes in addition to the decay of organic matter and reaeration process:

- Sedimentation of biodegradable organic matter;
- Benthic oxygen demand (e.g. the diffuse source of BOD represented by the decay of organic matter that had settled out earlier onto the channel bottom)
- Internal oxygen source represented by the photosynthesis and respiration activity of aquatic plants.

There are four new parameters in this model, the sedimentation rate constant, K_3, the benthic oxygen demand (B) and the photosynthesis (P) and respiration(R). The developed equation for BOD and DO model are given in Eqs. (2.4) and (2.5) respectively.

$$L = L_0 e^{-(K_1+K_3)t} + \frac{B\left(1 - e^{-(K_1+K_3)t}\right)}{\left(K_1 + K_3\right)} \qquad \text{........(2.4)}$$

$$D = D_0 e^{-K_2 t} + \frac{K_1 L_0 \left(e^{-(K_1+K_3)t} - e^{-K_2 t}\right)}{\left(K_2 - (K_1 + K_3)\right)} + \frac{K_1 B\left(1 - e^{-K_2 t}\right)}{K_2\left(K_1 + K_3\right)} - \frac{K_1 B\left(e^{-(K_1+K_3)t} - e^{-K_2 t}\right)}{\left(K_2 - (K_1 + K_3)\right)\left(K_1 + K_3\right)} - \frac{(P - R)\left(1 - e^{-K_2 t}\right)}{K_2} \qquad \text{......(2.5)}$$

2.3.3.3 *Thomman and Muller model (1987)*

Thomman and Muller (1987) include the changes in BOD and DO concentration due to distributed sources (non-point sources) within the stream. Given a constant magnitude of the distributed source which originates at x=0, and given a river with reasonably constant parameters (flow, area, depth) over a given length, the mass balance equation at steady state was developed. Thomman and Muller model (1987) stated that in addition to the other sources and sinks (photosynthesis, respiration and sediment oxygen demand) of DO, there may be distributed sources of BOD in a given reach of river. Such a source of BOD may result from:

(1) Degradation products of sediment decomposition and subsequently, by their diffusion from the sediment into the overlying water, products are exerted as a BOD from the bed of the river.

(2) From the contributing catchments area including BOD leaching from a landfill along the length of the river.

The equation developed by Thomman and Muller (1987) for BOD and DO are given in Eqs. (2.6) and (2.7) respectively.

$$L = L_0 e^{-k_1 t} + \frac{L_d \left(1 - e^{-k_1 t}\right)}{k_1} \qquad \text{............(2.6)}$$

$$D = D_0 e^{-K_2 t} + \frac{K_1 L_0 \left(e^{-K_1 t} - e^{-K_2 t}\right)}{(K_2 - K_1)} + \frac{K_1 L_d \left(1 - e^{-K_2 t}\right)}{K_2 K_1} + \frac{K_1 L_d \left(e^{-(K_1 + K_3)t} - e^{-K_2 t}\right)}{(K_2 - K_1) K_1} \qquad \text{......(2.7)}$$

Where,

L_d – Distributed source of BOD [M/L^{3}-T]

2.3.3.4 *Bhargava (1983) model*

The classical Streeter-Phelps (1925) models for BOD and DO with the inclusion of bioflocculation and settling of the organic matter, has been modified by Bhargava (1983). Bhargava (1983) applied the settling concept in addition to the first order decay concept in large rivers of India having high discharges. The equations for BOD and DO are given in equation (2.8) and (2.9) respectively.

$$L = \begin{bmatrix} L_0 e^{-(k_1+k_3)t} + (1-p_f)\left[L_1 e^{-k_1 t} + L_2 e^{-k_1 t_{t1-t}} + L_3 e^{-k_1 t_{t2-t}} + \ldots\ldots\ldots\ldots + L_n e^{-k_1 t_{(n-1)-t}} \right] \\ + p_f \begin{bmatrix} L_1\left(1-\left(\frac{1}{T}\right)t_{0-T}\right) + L_2\left(1-\left(\frac{1}{T}\right)t_{t1-(t1+T)}\right) + L_3\left(1-\left(\frac{1}{T}\right)t_{t2-(t2+T)}\right) + \ldots \\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots + L_n\left(1-\left(\frac{1}{T}\right)t_{tn-(tn-1+T}\right) \end{bmatrix} \end{bmatrix} \quad \ldots..(2.8)$$

$$\frac{dD}{dt} = K_1 \begin{bmatrix} L_0 e^{-(k_1+k_3)t} + (1-p)\left\{ L_1 e^{-k_1 t} + L_2 e^{-kt_{t1-t1}} + L_3 e^{-k_1 t_{t2-t}} + \ldots\ldots\ldots + L_n e^{-k_1 t_{t(n-1)-t}} \right\} \\ + p_f \begin{Bmatrix} L_1\left(1-\left(\frac{1}{T}\right)t_{0-T}\right) + L_2\left(1-\left(\frac{1}{T}\right)t_{t1-(t1+T)}\right) + L_3\left(1-\left(\frac{1}{T}\right)\right)t_{t2-(t2+T)} + \ldots \\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots + L_n\left(1-\left(\frac{1}{T}\right)t_{tn-(tn+T}\right) \end{Bmatrix} \end{bmatrix} \quad \ldots(2.9)$$

Where,

P_f - is the fraction of settleable BOD

$L_1, L_2, \ldots L_n$ - are the influx of BOD at different sections of a river

$t_{t1-t}, t_{t2-t} \ldots\ldots\ldots t_{t(n-1)-t}$ - are the travel times of different river reaches

2.3.4 Governing Equation for K_2 Estimation

K_2 is the reaeration rate coefficient. K_2 is defined as the rate at which streams uptakes oxygen across the water surface due to the turbulent motion of water and due to molecular diffusion. K_2 depends upon velocity, depth of flow, slope, and Froude number. Many Investigators gives different formula for K_2 estimation, which is shown in Table 2.1.

Table 2.1 Some empirical reaeration equation

Sr. No.	Investigators	Re-aeration equation
1.	O'Connor & Dobbins (1958)	$K_2 = 3.90V^{0.5}H^{-1.5}$
2.	Churchill et al. (1962)	$K_2 = 5.010V^{0.969}H^{-1.673}$
3.	Krenkel & Orlob (1962)	$K_2 = 173(SV)^{0.404}H^{-0.66}$
4.	Owens et al. (1964)	$K_2 = 5.35V^{0.67}H^{-1.85}$
5.	Langbein & Durum (1967)	$K_2 = 5.14VH^{-1.33}$
6.	Cadwallader & McDonnell (1969)	$K_2 = 186(SV)^{0.5}H^{-1}$
7.	Thackston & Krenkel (1969)	$K_2 = 24.9(1 + F_r^{0.5})V_*H^{-1}$
8.	Parkhurst & Pomeroy (1972)	$K_2 = 23(1 + 0.17F_r^2)(SV)^{0.375}H^{-1}$
9.	Tsivoglou & Wallace (1972)	$K_2 = 31200SV$ for $Q < 0.28\ m^2\ s^{-1}$ $K_2 = 15200SV$ for $Q > 0.28\ m^3\ s^{-1}$
10.	Smoot (1988)	$K_2 = 543S^{0.6236}V^{0.5325}H^{-0.7258}$
11.	Moog & Jirka (1998)	$K_2 = 1740V^{0.46}S^{0.79}H^{0.74}$ for $S > 0.00$ $K_2 = 5.59S^{0.16}H^{0.73}$ for $S < 0.00$
12.	Jha et al. (2001)	$K_2 = 5.79V^{0.5}H^{-0.25}$
13.	Thackston & Dawson (2001)	$K_2 = 0.000025(1 + 9F_r^{0.25})(9.81SD)^{0.5}H^{-1}$
14.	Jha et al. (2004)	$K_2 = 0.603286V^{0.4}S^{-1.0}H^{0.154}$ (MME=1.76) Fr≤1 $K_2 = 866.307V^{1.393}S^{-0.173}H^{0.8}$ (MME=1.2) Fr>1

2.4 WATER QUALITY INDEX

2.4.1 History of Development

It is reported that attempts were made in Germany as early as 1848 to relate the level of water pollution to the occurrence of certain biological organism (Landwehr-1974). Since then, various European countries have developed and applied different system to clarify the quality of surface water. Indices, which use a numerical scale to represent the gradation in water quality levels, were first introduced by Horton (1965). In India, Bhargava (1985) has suggested a water quality index for river Ganga for zoning and classification with respect to specific use.

2.4.2 Water Quality Index (WQI)

Public awareness and consciousness about pollution in general and pollution of water in particular has increased over the recent years. Emergences of International Organization like Green Peace are testimony to this fact. However, in spite of awareness of water quality and water pollution, the general public is at loss to understand the actual level of water quality as it is explained in technical parameters. In such circumstances, if the water quality is expressed in terms of numbers, the public as well as technologists and administrators can better understand it.

An index is a mean device to reduce a large quantity of data down to a simplest form. First the term environmental indicator or sub-index function is calculated which refers to a single quantity derived from one or two polluted variables/characteristic parameters (Ott-1978). It is used to reflect some environmental attribute. Water Quality Index (WQI) is then calculated by a mathematical aggregation of two or more indicators in some fashion. It is simply a numerical value having no units. WQI is a comparison of water quality or status to a prescribed base or to a scientific arbitrary standard. Various ranges of WQI may be used to classify the quality of water for a given use into various classes such as excellent, good, satisfactory, poor and unacceptable etc.

2.4.3 Uses of WQI

The planning Committee of National Academy of Sciences (NAS) 1975 has indicated that the Environmental indices perform an important role in formulating policy, judgment of effectiveness of environmental protection programmes, designing such programmes, and communicating with the public concerning conditions of the environment and progress towards its enhancement.

Ott (1978) identified six basic uses of indices as:

(i) Resource Allocation – Indices may be applied to environmental decisions to assist managers in allocating funds and determining priorities.

(ii) Ranking of Locations - Indices may be applied to environmental data at different locations or geographical areas.

(iii) Enforcement of Standards – Indices may be applied to specific locations to determine the extent to which legislative standards and existing criteria are being met or exceeded.

(iv) Trend Analysis – Indices may be applied to environmental data at different points in time to determine the change in environmental quality (degradation or improvement), which have occurred over the period.

(v) Public information – Indices may be used to inform the public about environmental conditions.

(vi) Scientific Research – Indices may be applied as a means for reducing a large quantity of data to a form that gives insights to the researcher conducting a study of some environmental phenomenon.

2.4.4 Classification of WQI

There are two general types of water quality index forms.

a) Increasing scale form – those in which the index numbers increase with increasing pollution level.
b) Decreasing scale form – those in which the index numbers decrease with increasing pollution level.

Some specialists in the field refer to the former as "Water Pollution Indices" and later as "Water Quality Indices". In an increasing scale form, an index of zero indicates no pollution, while, in a decreasing scale form, index of zero indicates maximum polluted or 100% polluted water. Both the terms are inter-related and, therefore, in practice both type of indices are called "Water Quality Indices".

To present many indices found in the literature in an orderly fashion, Ott (1978) has classified them into four general categories;

1. General Water Quality Indices – Water has a variety of different uses, viz. public drinking water supply, irrigation, recreational etc. Water quality requirements vary depending upon the intended use. Some indices, however, are based on the assumption that "water quality" is a general attribute of surface water irrespective of the use to which the water is put. Such indices are termed as general water quality indices.
2. Specific Use Indices – Indices developed in consideration of the specific use of water are classified as per specific use indices.
3. Planning Indices – Indices designed specially for management decision-making are called planning indices. These indices usually don't depict ambient water quality or related conditions but often incorporate variables other than those routinely measured by water pollution monitoring programmes. For examples, a planning index designed for allocating water pollution abatement funds might include the cost of wastewater treatment facilities.
4. Indices based on Statistical Approach - These approaches usually employ some standard statistical procedure with the water quality data. The statistical approaches have the advantage that they incorporate fewer subjective assumptions than the traditional indices: however, they are more complex and often more difficult to apply.

One more type of water quality index does exist in literature, i.e. "Biological Water Quality Indices". These are generally developed after evaluating water quality in terms of its impact on aquatic life in some form. The biological indices are entirely dissimilar in approach to other categories.

2.4.5 General conditions to be satisfied by WQI

(a) It should change with the changes in the values of each of the water quality variables.

(b) The change should be greater due to a variable, which produces the more important quality impact.

(c) It should approach the poorest designated value when a critical variable, whose concentration beyond the permissible levels cannot be compromised, exceeds the permissible limits.

(d) It should remain unchanged when a variable's concentration changes within its permissible limits.

Criteria for formulation of WQI as given by Council of Environmental Quality (CEQ) are:

(a) It should facilitate communication of environmental quality information to the public.

(b) It should be readily derived from available monitored data.

(c) It should strike a balance between over simplification and complex technical conceptualization.

(d) It should impart an understanding of significance of data represented.

(e) It should be objectively designed but amenable to comparison with expert judgment so that their validity can be assed.

2.4.6 Different WQIs

Some selected WQIs are discussed below.

2.4.6.1 *Horton water quality index*

Horton (1965) proposed first water quality index formulated on the following criterion

- Number of variables should be limited
- Variables should be of significance
- Variables should reflect the availability of data.

Although Horton developed the index using 10 selected variables, it was suggested that any number of variables could be selected in accordance with the convenience and criteria indicated. Horton's WQI is given by the following equation

$$WQI = \frac{\sum_{i=1}^{n} w_i q_i}{\sum_{i=1}^{n} w_i} \times M_1 M_2 \qquad \text{..............(2.10)}$$

Where,

w_i is the weight of *i*th parameter,

q_i is the subindex (quality rating) of *i*th parameter,

n is the number of parameters (variables), and,

M_1 and M_2 are coefficients for temperature and obvious pollution and take the values either 1 or ½.

If temperature > critical level M_1= ½ otherwise M_1= 1

Similarly, if obvious pollution is present M_2 = ½ otherwise M_2= 1

The weights for parameters are given in Table 2.2.

Table 2.2 Parameter and their weight for Horton's water quality index

Sr. No.	Variables	Weights (w)
1.	Dissolved Oxygen	4
2.	Sewage treatment	4
3.	PH	4
4.	Coliform	2
5.	Specific Conductance	1
6.	Carbon chloroform extract	1
7.	Alkalinity	1
8.	Chloride	1

2.4.6.2 *National Sanitation Foundation water quality index*

Brown et al. (1970) presented a water quality index similar in structure to Horton's index. It is also called National Sanitation water Quality Index. It is calculated after aggregating the sub-indices for 11 parameters as weighted sum, using the following equation.

$$NSF\ \ WQI = \sum_{i=1}^{n} w_i q_i \qquad \text{..............(2.11)}$$

Weights for 9 parameters are listed in Table 2.3.

Table 2.3 Parameters and their weights for NSF WQI

Sl. No.	Parameters	**Weights**
1.	Dissolved Oxygen	0.17
2.	Feacal coliform	0.15
3.	PH	0.12
4.	5 day BOD	0.10
5.	Nitrates	0.10
6.	Phosphates	0.10
7.	Temperature	0.10
8.	Turbidity	0.06
9.	Total solids	0.08

As in the case of Horton's index, a decreasing scale, 0-100, is used for expressing the WQI. The sub-index functions of all parameters are shown in Fig.2.0 to Fig.2.8. A different approach was adopted for remaining two parameters i.e. pesticides and toxic elements. In case of these parameters exceeding the specified limits, the water quality index shall be termed as zero.

Although the above form of additive index has been tested in the field and applied, an alternative geometric (multiplicative) form, NSF WQI_g, was proposed subsequently to overcome the eclipsing, which occurs, when a single pollutant variable shows extremely poor water quality. In the geometric form, which is a product aggregation function, the same weights become powers of sub indices.

$$NSF\ \ WQI_g = \prod_{i=1}^{n} q_i^{w_i} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(2.12)$$

In this form if any one sub-index approaches zero, the over all index approaches zero. A system of reporting NSF WQI which relates the index values to 5 words and colours was also suggested by MeClelland et al. (1976) as shown in Table 2.4.

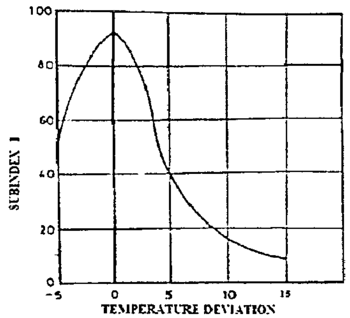

FIG.2.0: SUBINDEX FUNCTION FOR TEMPERATURE DEVIATION FROM EQUILIBRIUM (dT) IN THE NSF WQI (FOR dT> 15 0C, I = 5)

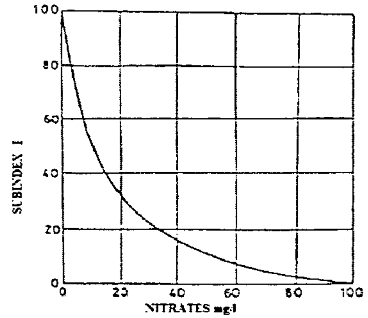

FIG.2.1: SUBINDEX FUCTION FOR NITRATES IN THE NSF WQI (FOR NITRATES > 100 MG/L, I = 1

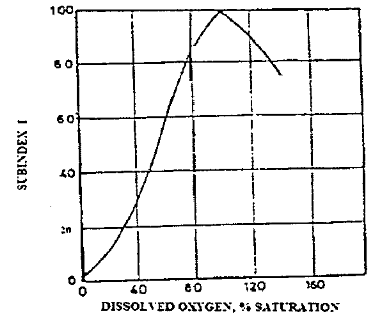

FIG.2.2: SUBINDEX FUNCTION FOR DISSOLVED OXYGEN IN NSF WQI (FOR DO > 140%, I = 50)

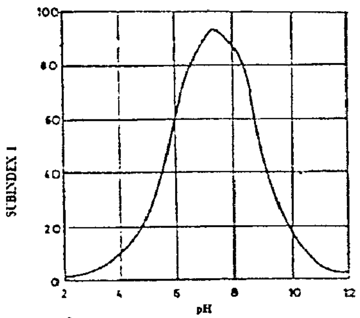

FIG.2.3: SUBINDEX FUNCTION FOR pH IN THE NSF WQI (FOR pH > 12 AND pH < 2, I = 0)

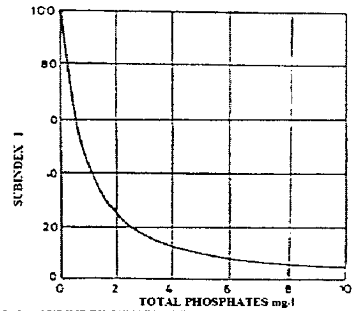

FIG. 2.4: SUBINDEX FUNCTION FOR TOTAL PHOSPRATES IN THE NSF WQI (FOR TOTAL PHOSPHATES > 10 mg/l, I = 2)

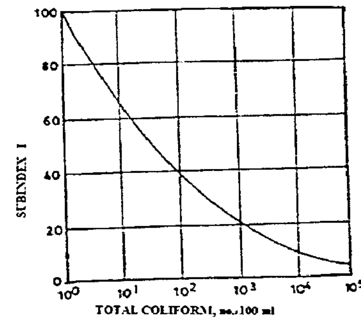

FIG. 2.5: SUBINDEX DUNCTION FOR TOTAL COLIFORMS (AVERAGE NUMBER OF ORGANISMS PER 100ml) IN THE NSF WQI (FOR TOTAL COLIFORMS > 100000/100 ml, I = 2)

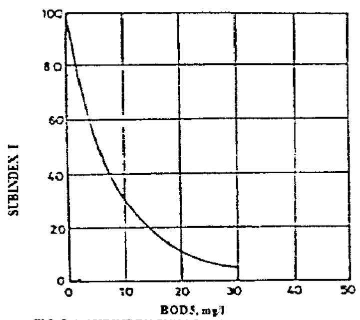

FIG.2.6: SUBINDEX FUNCTION FOR BOD5 IN THE NSF WQI (FOR BOD5 > 30 mg/l, I = 2)

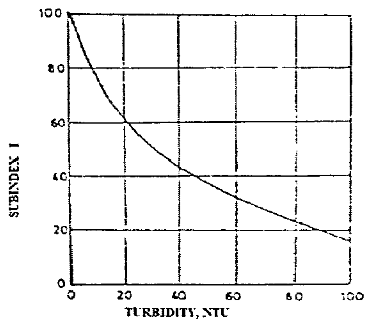

FIG. 2.7: SUBINDEX FUNCTION FOR TURBIDITY NTU IN THE NSF WQI (FOR TURBIDITY > 100 NTU, I = 5)

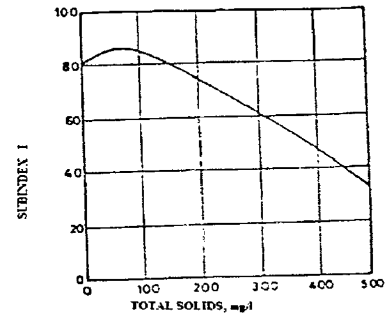

FIG.2.8: SUBINDEX FUNCTION FOR TOTAL SOLIDS IN THE NSF WQI (FOR TOTAL SOLIDS > 500, I = 20)

Table 2.4 Descriptor words and colours suggested for reporting NSF WQI

Descriptor words	Very bad	Bad	Medium	Good	Excellent
Numerical range of index	0-25	26-50	51-70	71-90	91-100
Colour	Red	Orange	Yellow	Green	Blue

2.4.6.3 *Prati's implicit index of pollution*

Prati et al. (1971) proposed an index for surface water based on the water quality classification system given as under. They considered 13 pollutant variables as summarized in Table 2.5.

$$PIIP = \frac{1}{n}\sum_{i=1}^{n} q_i \qquad \text{..................(2.13)}$$

2.4.6.4 *Dinius social accounting system*

Dinius (1972) proposed a water quality index as a first step towards designing a 'rudimentary social accounting system', which would measure the costs and impact of pollution control efforts. This WQI includes 11 parameters. Like Horton's index and NSF WQI, it has a decreasing scale with values ranging from 0-100. Each sub-index was developed from a review of the published literature and represented by explicit mathematical functions. The overall WQI is calculated as a weighted sum of indices as in NSF WQI and is given by the equation as under;

$$I = \frac{1}{21}\sum_{i=1}^{11} w_i q_i \qquad \text{....................(2.14)}$$

The 11 pollutant variables with the weights assigned to each parameter and sub index functions, are shown in Table 2.6. Some descriptive language was suggested to enable a single WQI to be applied to different water uses as shown in Table 2.7.

Table 2.5 Sub index function for PIIP

Sl. No.	Parameter	Sub- index	Range
1.	Dissolved Oxygen (%)	$I = 0.00168X^2 - 0.249X + 12.25$ $I = -0.08X + 8$ $I = 0.08X - 8$	$0 \le X < 50$ $50 \le X < 100$ $100 \le X$
2.	pH (Units)	$I = -0.4X^2 + 14$ $I = -2X + 14$ $I = X^2 - 14X + 49$ $I = -0.4X^2 + 11.2X - 64.4$	$0 \le X < 5$ $5 \le X < 7$ $7 \le X < 9$ $9 \le X < 14$
3.	5 day BOD (mg/l)	$I = 0.666667X$	
4.	COD (mg/l)	$I = 0.1X$	
5	Permagnate, Kubel test (mg/lO$_2$)	$I = 0.4X$	
6.	Suspended solids (mg/l)	$I = 2^{[2.1\log(0.1x-1)]}$	
7.	Ammonia (mg/l)	$I = 2^{[2.1\log(10x)]}$	
8.	Nitrates (mg/l)	$I = 2^{[2.1\log(0.25x)]}$	
9.	Chlorides (mg/l)	$I = 0.000228X^2 + 0.0314X$ $I = 0.000132X^2 + 0.0074X + 0.6$ $I = 3.75(0.002X - 5.2)0.5$	$0 \le X < 50$ $50 \le X < 300$ $300 \le X$
10.	Iron (mg/l)	$I = 2^{[2.1\log(10x)]}$	
11.	Manganese (mg/l)	$I = 2.5X^2 + 3.95X$ $I = 5.25X^2 + 2.75$	$0 \le X < 0.5$ $0.5 \le X$
12.	Alkyl Benzene Sulfonates (mg/l)	$I = -1.2X + 3.2\sqrt{X}$ $I = 0.8X + 1.2$	$0 \le X < 1$ $1 \le X$
13.	Carbon Chloroform Extract (mg/l)	$I = X$	

Table 2.6 Sub-index functions & their weights for Dinius WQI

Sr.No.	Parameters	Sub Index function	Weights assigned
1.	Dissolved Oxygen	$I = X$	5
2	5 day BOD (mg/l)	$I = 107X^{-0.642}$	2
3.	Total coliforms (MPN/100)	$I = 100X^{-0.30}$	3
4.	Feacal coliforms (MPN/100)	$I = 100(5X)^{-0.30}$	4
5.	Specific conductance (μmho/cm at 25^0C)	$I = 535X^{-0.3565}$	1
6.	Chlorides (mg/l)	$I = 125.8X^{-0.207}$	0.5
7.	Hardness ($CaCO_3$, ppm)	$I = 10^{1.974-0.00132x}$	1
8.	Alkalinity($CaCO_3$, ppm)	$I = 108X^{-0.178}$	0.5
9.	pH	$I = 10^{0.2335x+0.440}\ for X < 6.7$ $I = 100 \quad 6.7 \le X \le 7.58$ $I = 10^{4.22-0.293x}\ for\ X > 7.58$	1
10.	Temperature (^{0}C)	$I = -4(X_a - X_s) + 112$ $X_a = actual\ temperature$ $X_s = s\tan dard\ temperature$	2
11.	Colour (C units)	$I = 128X^{-0.288}$ *X is C units measured after all suspended matter, evaluated by turbidity, is removed.*	1
	Total		21

2.4.6.5 *McDuffie's river pollution index*

McDuffie et al. (1973) presented a WQI, which they called the River Pollution Index (RPI). Although 8 pollutant variables are discussed in their paper, either fewer or more than 8 variables can be included depending on the available data.

The sub-index for each variable is based on the ratio of the measured value to the natural level. To make the sub indices vary from 10 ('natural' level) to 100 ('highly polluted' level), the ratio of the observed value to natural level is multiplied by a

Table 2.7 Descriptive language suggested by Dinius to enable a single water quality index to be applied to different water uses.

<table>
<tr><th>PERCENT</th><th>PUBLIC WATER SUPPLY</th><th>RECREATION</th><th>FISH SHELLFISH AND WILDLIFE</th><th>INDUSTRIAL AND AGRI-CULTURAL</th><th>NAVIGATION</th><th>TREATED WASTE TRANS-PORTATION</th></tr>
<tr><td>100–90</td><td>PURIFICATION NOT NECESSARY</td><td rowspan="3">ACCEPTABLE FOR ALL WATER SPORTS</td><td rowspan="3">ACCEPTABLE FOR ALL FISH</td><td>PURIFICATION NOT NECESSARY</td><td rowspan="7">ACCEPTABLE</td><td rowspan="9">ACCEPTABLE</td></tr>
<tr><td>90–80</td><td>MINOR PURIFICATION RREQUIRED</td><td rowspan="2">MINOR PURIFICATION NECESSARY FOR INDUSTRY REQUIRING QUALITY WATER</td></tr>
<tr><td>80–70</td><td rowspan="3">NECESSARY TREATMENT BECOMING MORE EXTENSIVE</td></tr>
<tr><td>70–60</td><td>BECOMING POLLUTED</td><td>MARGINAL FOR TROUT</td><td rowspan="2">NO TREATMENT NECESSARY FOR NORMAL INDUSTRY</td></tr>
<tr><td>60–50</td><td>STILL ACCEPTABLE BACTERIA COUNT</td><td>DOUBTFUL FOR SENSITIVE FISH</td></tr>
<tr><td>50–40</td><td>DOUBTFUL</td><td>DOUBTFUL FOR CONTACT WATER</td><td>HARDY FISH ONLY</td><td rowspan="2">EXTENSIVE TREATMENT FOR MOST INDUSTRY</td></tr>
<tr><td>40–30</td><td rowspan="4">NOT ACCEPTABLE</td><td>ONLY BOATING NO WATER CONTACT</td><td>COARSE FISH ONLY</td></tr>
<tr><td>30–20</td><td>OBVIOUS POLLUTION APPEARING</td><td rowspan="3">NOT ACCEPTABLE</td><td>ROUGH INDUSTRY USE ONLY</td><td>OBVIOUS POLLUTION APPEARING</td></tr>
<tr><td>20–10</td><td>OBVIOUS POLLUTION</td><td rowspan="2">NOT ACCEPTABLE</td><td>OBVIOUS POLLUTION</td></tr>
<tr><td>10–0</td><td>NOT ACCEPTABLE</td><td>NOT ACCEPTABLE</td><td>NOT ACCEPTABLE</td></tr>
</table>

scaling factor (usually 10). Thus, many of the sub-indices are of the general linear form;

$$I_i = 10\left[\frac{X}{X_n}\right]_i \qquad \text{................(2.15)}$$

Where, I_i is the sub index of the *i*th parameter, X is the observed value of *i*th parameter, and,

X_n is the normal value of *i*th parameter.

The 8 parameters and their calculated simplified sub-index functions, incorporating the scaling factors and recommended limits, are shown in Table 3.7. The RPI is calculated according to the equation.

$$RPI = \frac{10}{n+1}\sum_{i=1}^{n} I_i \qquad \text{...................(2.16)}$$

The index has an increasing scale varying approximately from 100 (natural level) to approximately 1000 (highly polluted).

Table 2.8 Parameters and their sub-index functions considered in river pollution index

Sl.No.	Parameters	Sub-Index function	Remarks
1.	Percent oxygen deficit	I = 100- X	X = DO (%)
2.	'Biodegradable' organic matter	I = 10X	X = BOD_5 (ppm)
3.	'Refractory' organic matter	I = 5(X-Y)	X = COD (ppm) Y = BOD_5 (ppm)
4.	Coliform count (no./100ml)	$I = 10\left[\frac{\log X}{\log 3}\right]$	
5.	Nonvolatile suspended solids (ppm)	I = X	
6.	Average nutrient excess	$I = 5\left[\frac{X}{0.2} + \frac{Y}{0.1}\right]$	X=Total N (ppm) Y=Total PO_4(ppm)
7.	Dissolved salts	I = 0.25X	X = Specific conductance
8.	Temperature	$I = \frac{X^2}{6} - 65$	

2.4.6.6 *Taiwan river pollution index (TRPI)*

A water quality index for Taiwan Rivers was suggested by Yen (1979) on the same pattern as was done by Brown et al. (1970). Parameters with their importance (weights) have been shown in Table 2.9. This is given by equation

$$TRPI = \frac{1}{100}\left[\sum_{i=1}^{n} q_i w_i\right]^2 \qquad \text{..............(2.17)}$$

Where, $\sum_{i=1}^{n} w_i = 1$

Table 2.9 Parameters and their weights for TRPI

Sl. No.	*Parameters*	*Weights*
1.	DO	0.18
2.	Feacal Coliform	0.18
3.	pH	0.11
4.	BOD_5	0.13
5.	Temperature	0.07
6.	Turbidity	0.07
7.	Carbon Chloroform extract	0.07
8.	Phenol	0.10
9.	Radioactivity (β)	0.09
	Total	1.0

2.4.6.7 *Walski and Parken's recreational water quality index*

It is specifically intended for the recreational use of water, such as swimming and fishing etc. A total of 12 different pollutant variables were used in this index. The sub indices consist of non-linear and segmented non-linear explicit functions as shown in Table 2.10. Except for the unimodel variables pH and temperature, all other sub indices are represented by negative exponential equations. The pH and temperature sub indices are represented by parabolic equations. For each sub-index, value of I = 0.01 corresponds to "intolerable", I = 0.1 "poor", I = 0.9 "good" and I = 1.0 as 'perfect' water quality. The weights of sub-indices are not given in the published article. The index is given by the equation

$$WPR\ \ WQI = \left[\prod_{i=1}^{12} I_i^{w_i}\right]^{\frac{1}{12}} \qquad \text{..................(2.18)}$$

This has an advantage if any sub-index approaches zero, then the whole index becomes zero.

Table 2.10 Sub-index functions for index proposed by Walski and Parker

Sl. No.	*Pollutant Variable*	*Equation*	*Range*
1.	DO (mg/l)	$I = e^{[0.3(x-8)]}$ $I = 1$	$0 < X \le 8$ $X > 8$
2.	pH (standard units)	$I = 0$ $I = 0.04\left[25-(X-7)^2\right]$	$2 > X > 12$ $2 \le X \le 12$
3.	Total Coliform (no./100ml)	$I = e^{-0.0002X}$	
4.	Temperature (^{0}C) Actual Deviation	$I = 0.0025\left[400-(X-20)^2\right]$ $I = 0$ $I = 0.01\left[100-(\Delta X)^2\right]$	$0 \le X \le 40$ $-10 > \Delta X > 10$ $-10 \le \Delta X \le 10$
5.	Phosphates (mg/l)	$I = e^{-2.5X}$	
6.	Nitrates (mg/l)	$I = e^{-0.16X}$	
7.	Suspended solids (mg/l)	$I = e^{-0.02X}$	
8.	Turbidity (JTU)		
9.	Colour (C units)	$I = e^{-0.001X}$	
10.	Grease Thickness (μ) Concentration (mg/l)	$I = e^{-0.002X}$ $I = e^{-0.35X}$	
11.	Odour (TON)	$I = e^{-0.016X}$ $I = e^{-0.1X}$	
12.	Sacchi Disk Transparency (m)	$I = \log_{10}(X+1)$ $I = 1$	$X \le 9$ $X > 9$

2.4.6.8 *Other WQI*

In addition to the above, some agencies have developed their own indices with variation in parameters, ratings, weights and the form of aggregation of sub-indices. Some of them may, however, not fall exactly under the category of general WQI. These indices include (1) The Trend Monitoring Index (TMI) of Georgia's Department of Natural Resources (Environmental Pollution Division), (2) Pollution Index (PI) of Illinois' Department of Transportation (Division of water Resources Management), (3) Nevada Water Quality Index, (4) Water Quality Index developed by Oregon's Department of Environmental Quality (DEQ), etc. (Ott-1978).

2.4.7 Comparison of different Water Quality Indices

WQI's show considerable variation in terms of number of variables, scales, ranges and aggregation method. This may be seen from Table 2.11.

NSF WQI met all the five CEQ criteria referred in para 2.3.5. Out of the many General water quality indices developed so far, the NSF WQI is the most widely accepted water quality Index. It has got the effectiveness and flexibility, while it is simple to formulate.

Table 2.11 Different WQIs at a glance

Sl. No.	Index name	No. of variables	Type of Scale	Range of index value
1.	**General Water Quality Indices**			
	Horton's Quality Index (HQI)	10	Decreasing	0 to 100
	NSF Water Quality Index (NSF WQI)	9	Decreasing	0 to 100
	Prati's Implicit Index of Pollution (PHP)	13	Increasing	0 to 15+
	McDuffie's River Pollution Index (RPI)	8	Increasing	0 to 1000+
	Dinius Social Accounting System (SAS)	11	Decreasing	0 to 100
2.	**Specific-Use Water Quality Indices**			
	O'Conner Fish & Wildlife (FAWL) Index	9	Decreasing	0 to 100
	O'Conner Public Water Supply (PWS)	13	Decreasing	0 to 100
	Index	11/13	Decreasing	0 to 100
	Deininger's Index for Public Water Supply	12	Decreasing	0 to 1
	Walski and Parker's Index for Reccreation	31	Decreasing	-100 to
	Stoner's Index for Dual Water Uses*	14	Increasing	100
	Nemero's Index for Three Water Uses			0 to 1+
3.	**Planning Indices**	Any number	Increasing	
	Prevalence Duration Intensity (PDI) Index	Any number	Increasing	0 to 1
	National Planning Priorities Index (NPPI)	Any number	Increasing	0 to 1
	Priority Action Index (PAI)	78	Decreasing	0 to 1
	Environmental Evaluation System (EES)	Any number	Increasing	0 to 1,000
	Canadian National Index	3	Increasing	0 to 1
	Potential Pollution Index (PPI)	Any number	Increasing	0 to 1,000+
	Johanson's Pollution Index (JPI)			0 to 100+
4.	**Statistical Approaches**	18	Increasing	
	Composite Pollution Index (CPI)	5	Decreasing	-2 to 2
	Index of Partial Nutrient	5	Decreasing	0 to 100
	Index of Total Nutrient	Any number	Increasing	0 to 100
	Harkin's Index (Kendall ranking)	Any number	Increasing	0 to 1,000
	Beta Function Index			0 to 1

* Index may be less than -100 and may become a large negative number

CHAPTER- 3

WATER QUALITY BASED CLASSIFICATION OF RIVER BHARALU

3.1 GENERAL

The term "water quality" is widely used expression that has an extremely broad spectrum of meanings. Each individual has vested interests in water for his particular use. The term "quality", therefore must be considered relative to the proposed use of water. From the user's point of view, the term "water quality" is defined as " those physical, chemical or biological characteristics of water by which the user evaluates the acceptability of water". For example for the sake of man's health the water should be pure, wholesome and potable. For agriculture, we require that, the sensitivity of different crops to dissolved minerals and other toxic materials is known and water quality for other type of crops is controlled accordingly. For Textiles, Brewing, Paper and other industries using water, should meet their specific water quality needs.

For management of the water quality of a water body, one has to define the water quality requirements or water quality objectives for that water body. As mentioned above, each water use has specific water quality need. Therefore, for setting water quality objectives of a water body, it is essential to identify the uses of water in that water body. Normally each stretch is used for various purposes. Out of these, the use which demands highest water quality is termed as Designated Best Use and accordingly the water body is classifies. The CPCB has identified five such "designated best use" as given in Table 3.1. Water, being a best solvent available on earth, is seldom found in pure state, it exists as a mixture. In nature, the most nearly pure state of water is in its evaporation state. For water to condense, it requires a surface or a nuclei, thus water may acquire impurities at the very moment of condensation. In the hydrological cycle, water comes in contact with various gases and particulate matter in the atmosphere, soils, rocks and other materials on land and various minerals underground. During this contact, water acquires impurities. The characteristics of water of a particular place depend on the types and quality of the materials it has come into contact with. Human activities contribute further impurities to the water. Industrial and mining wastes, domestic wastes, agricultural chemicals and other contaminants added by humans have greatly affected the quality of water bodies.

Table 3.1 Classification of water body based on "designated best use"

Sr. No.	Designated Best Use	Quality Class	Primary quality criteria
1	Drinking water source without conventional treatment but with disinfections	A	PH 6.5–8.5; DO≥6.0; BOD< 2; MPN< 50
2	Organized outdoor bathing	B	PH 6.5–8.5; DO≥ 5.0:BOD≤3.0; MPN<500
3	Drinking water source with conventional treatment followed by disinfections	C	PH 6.5-8.5; DO≥6.0; BOD≤5.0; MPN<5000
4	Propagation of wildlife and fisheries	D	PH 6.5–8.5; DO≥6.0; NH_4^+≤ 1.2
5	Irrigation, Industrial cooling and controlled water disposal	E	PH 6.5–8.5; cond 2250μ: Na absorption ratio max 20

3.2 COMPONENTS OF WATER QUALITY

As water is the best solvent available on earth, thus it is made up of several components. They are (1) Chemical Components -Water dissolves several gases and other materials, which influence its chemical properties. (2) Physical properties - Thermal stability, viscosity, vapour pressure and other processes constitute the physical properties of water. (3) Hydrological properties -Water has several hydrological properties like velocity, flow regime; bed characteristics etc. (4) Biological properties - All forms of natural water contains some life forms inhabiting it. (5) Pollutants - Pollutants are the most important components of a water body, because their presence may lead to several adverse effects to the either the water body or the users of the water. Some of the important pollutants are listed below.

3.2.1 Pathogenic Microorganisms

These are present in large numbers in the faeces of sick individuals. When this comes in contact with water, either through surface runoff or leaching, the pathogens propagate and the water becomes unsafe for users. These pathogenic micro-organisms causes several diseases to humans, some are even terminal, e.g. virus cause hepatitis and poliomychitis; bacteria cause cholera, typhoid; protozoa cause amoebic dysentery; helminthes cause hookworms, etc. The summary parameter used as an indicator of faecal pollution is coliform bacteria. It is present in large numbers in the faecal matter of both healthy and sick individuals. It can be easily determined in laboratories by using methods like Total Plate Count, Dilution Tube Method and is expressed as most probable number (MPN/100ml).

3.2.2 Organic Matter

The common sources of organic pollution in water include sewage from domestic and animal sources, industrial wastes from food processing, paper mills, tanneries, distilleries, sugar and agro-based industries. These organic wastes get oxidized in the water through microbial activities and consume dissolved oxygen. Since water has limited availability of oxygen, if consumption exceeds the availability, oxygen gets depletion, which leads to the disappearance of aquatic life. Organic matter pollution is measured by the summary parameters such as BOD and COD. Standard testing methods have been developed and these parameters are expressed in mg/l.

3.2.3 Nutrients

Nutrients are always present in water and thus it support aquatic life. The discharge of domestic waste water, agricultural return water and many industrial effluents contribute nutrients, which promote the growth of algae at the microscopic level and larger aquatic weeds at the macro-scopic level and can result in an environmental damage called "eutrophication". This leads to a case of oxygen super saturation in the daytime and its gross depletion at night. Nutrient pollution is monitored by measuring the amount of dissolved oxygen in water, expressed in mg/l.

3.2.4 Dissolved Solids

These are the inorganic dissolved material found in water generally in the ionized form. Major cations are sodium, potassium, calcium, magnesium and anions are chloride, sulphate, carbonate, bicarbonate and nitrate. These dissolved salts are essential for living organisms but if present in excess in water, they may lead to the impairment of physiological process in humans and in agriculture, their gradual accumulation leads to increased salinity of the soil, thus rendering it non productive. The summary parameter for measuring Total Dissolved Solid is electrical conductivity of the water sample. The measured electrical conductivity multiplied by a factor between 0.55 to 0.9 gives the TDS in the sample.

3.2.5 Micro Pollutants or Trace Compounds

Trace compounds found in water are mainly due to effluent discharge from industrial activity, excess use of agro-chemicals and leachate from domestic wastewater. They include heavy metals like cadmium, copper, chromium, mercury, lead, nickel, zinc etc; organic compound like polyaromatic hydrocarbons (PAH), polychlorinated biphenyls (PCB) and pesticides; and also naturally securing pollutants like Arsenic, Fluoride and Iron. These pollutants are present in small concentration but they are highly toxic. These toxics accumulate in the body and get magnified at each tropic level of the food chain (biomagnifications). However, these compounds are not monitored on regular basis because their determination require sophisticated instrument and highly trained personal.

3.3 PAST AND PRESENT SCENARIO OF THE WATER USE OF THE RIVER BHARALU

The whole stretch of river Bharalu may be divided into three parts according to the water use by the people residing nearby area of the river as shown in Fig. 3.1.

Stretch No.1: The river water is used for drinking, bathing, washing clothes and other useful purposes in upper stretch of the river and till now the water quality in this stretch is not deteriorated due to less anthropogenic activities. This upper basin is characterized by forest Cover Mountain; only few human settlements are taking place in this area due to inaccessibility and poor infrastructure (road, electricity and communication). The water body of this stretch of the river can be classified as class 'A' on the basis of DBU. This stretch has a length of about 12.5 km from the origin. The clear water of this stretch is shown in Plate No. 3.1 and 3.2.

Stretch No.2: The river water in this stretch is also used for drinking, bathing, washing clothes and other purposes. However due to the growth of the city in the eastward direction, i.e. in the upstream side and settlement of people in that locality, the river water gets polluted due to the discharge of domestic sewage. It leads the water body unsuitable for drinking purposes and is used for washing clothes, bathing and other purposes. This stretch has a length of about 4.37 km and can be classified as class 'B' on the basis of DBU. The water quality in this stretch is slightly turbid and shown in Plate No. 3.3 and 3.4.

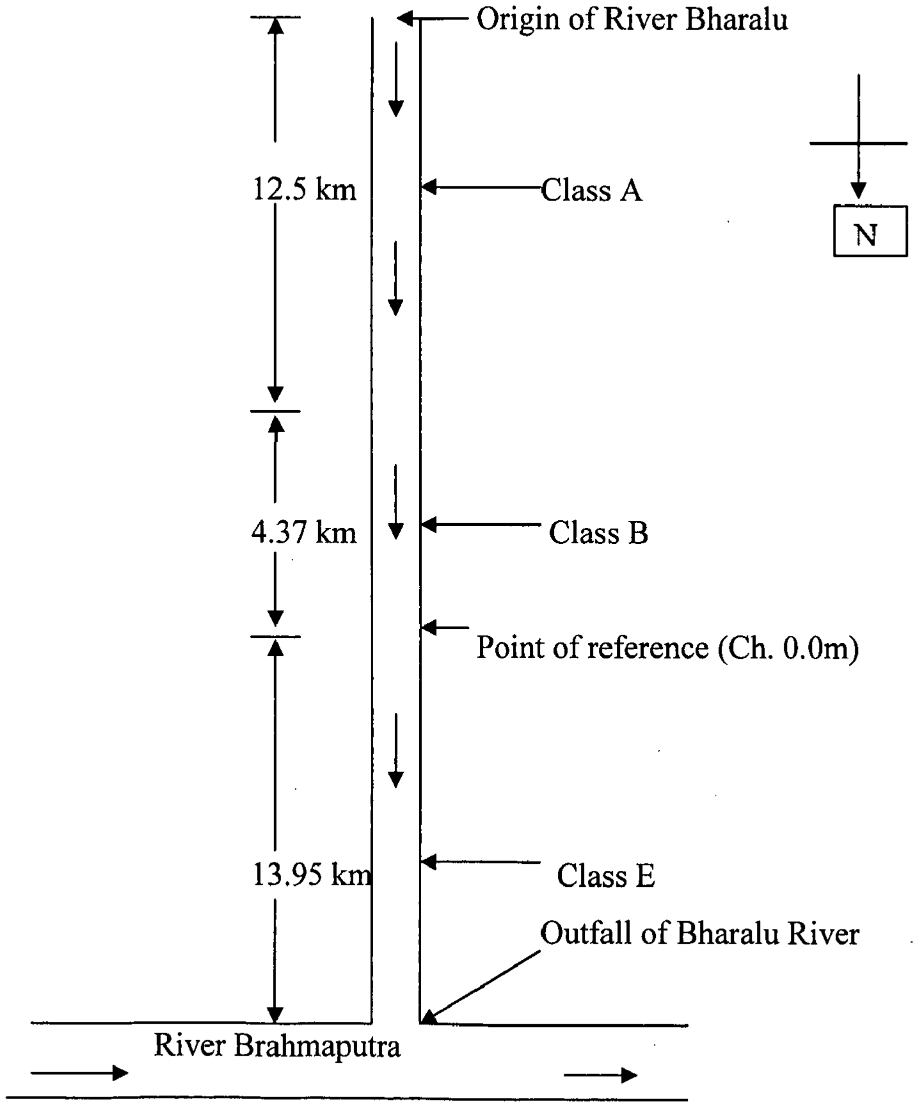

Fig. 3.1 Water quality based classification of river Bharalu

Stretch No.3: In this stretch, the river water was used for bathing, washing clothes & other useful purposes till mid sixties. However, at present the river water in this stretch is grossly polluted with high BOD and low DO. This stretch starts from Natun

Bazar sluice gate at Basistha, which is taken as point of reference and ends at the outfall. The river enters the city from this point and carries domestic sewage and industrial effluent of the city, which is finally discharged to river Brahmaputra. The length of this reach is about 13.95 km. The water body in this reach can be classified as class 'E' and shown in Plate No. 3.5 and 3.6. Although on the basis of DBU this should be class 'B', hence an attempt has to be made to restore this water body to class 'B'.

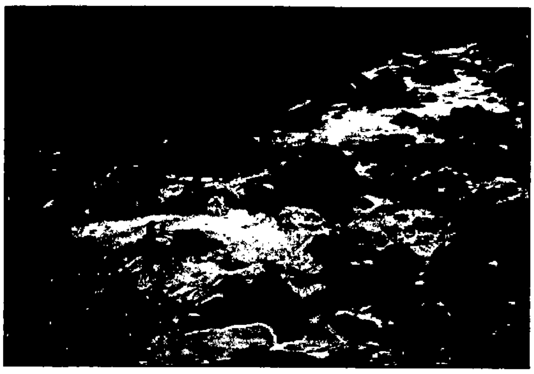

Plate No. 3.1 Clear water of Bharalu at reach no.1

Plate No. 3.2 Clear water even after bank erosion at reach no.1

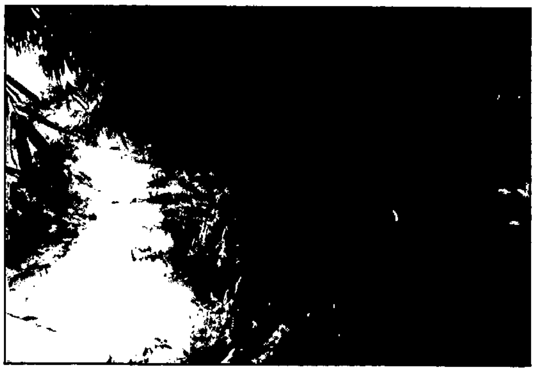

Plate No. 3.3 Slightly turbid water of Bharalu at reach no.2

Plate No. 3.4 Showing turbid water at reach no.2 of Bharalu

Plate No. 3.5 River near Natun Bazar Sluice Gate (Ch. 0m)

Plate No. 3.6 Showing the river at Beltola Bazar in reach no.3

CHAPTER-4

METHODOLOGY

4.1 GENERAL

Indiscriminate disposal of sewage and industrial waste in rivers has led to serious river pollution in India. Effective monitoring of quality parameters is an important initial step in abatement of river pollution. Monitoring of water quality through physical senses, general appearance, taste and odour, is a very old practice. Modern monitoring techniques could be classified as conventional, automatic recording and remote sensing techniques. In present study, river Bharalu was monitored conventionally (i.e. samples were collected manually) for three months. After conducting reconnaissance survey, eight sampling stations (river point) were chosen. Water samples were collected from these sampling stations in the month of October 2005, January 2006 and April 2006, transported to laboratory and tested for various water quality parameters at Environmental Laboratory of Assam Engineering College, Guwahati-13, Assam. Some samples were brought to Institute Instrumentation Centre (IIC) at IIT Roorkee for testing of heavy metal after proper filtration and preserving the sample in nitric acid medium (pH<2). Simultaneously, the discharge from all drains joining river Bharalu were measured. Moreover, water sample from all drains (fifty-three) were collected for determination of BOD and DO of the wastewater. The hydrodynamic data of the river i.e. velocity of flow, flow depth, bed slope, side slope and discharge of the river were also collected near the outfall of each drain for development of BOD and DO model.

For the convenient of discussion, the methodology has been divided into two parts:

(I) Methodology for water sample collection and analysis

(II) Methodology for development of BOD and DO model

4.2 METHODOLOGY FOR WATER SAMPLE COLLECTION & ANALYSIS

4.2.1 Reconnaissance Survey

The sampling schedule, locations and frequency of sampling was decided after the reconnaissance survey was made. Data pertaining to the catchment activities, significant from the view of having an impact on river system, was collected from Guwahati and nearby areas. During reconnaissance survey, a preliminary strategy was made about the sampling programme to carryout the study in a convenient manner according to available resources and time.

The criteria for selection of sampling stations were made on the basis of the following consideration.

- It should be accessible in all seasons of the year.
- It should have proper mixing of pollutants thus representing water quality of the river at that particular stretch.
- Facilities to take water samples are available there.
- It should affect the quality of water (I) before the river enters the city (II) inside the city where maximum pollution is observed

4.2.2 Selection of Sampling Station

For assessment of water quality of river Bharalu eight locations were selected. The general layout of the sampling stations is shown in Fig.4.1 and locations of sampling stations are given in Table 4.1. The study covers about 13.93 km stretch of river starting from Natun Bazar sluice gate to Bharalumukh.

The details of these sampling stations are given as below.

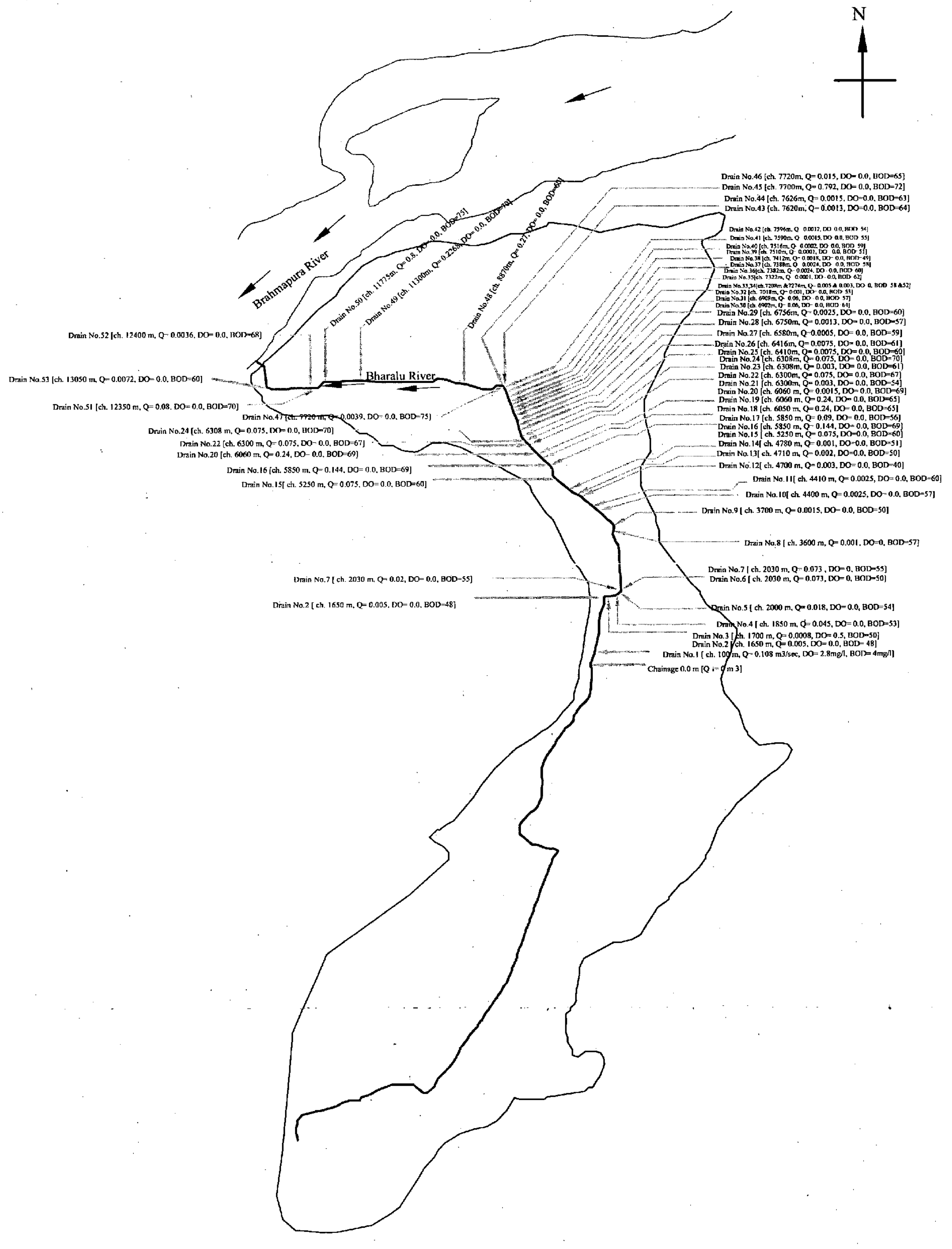

Fig. 1.2 Location of drains on river Bharalu

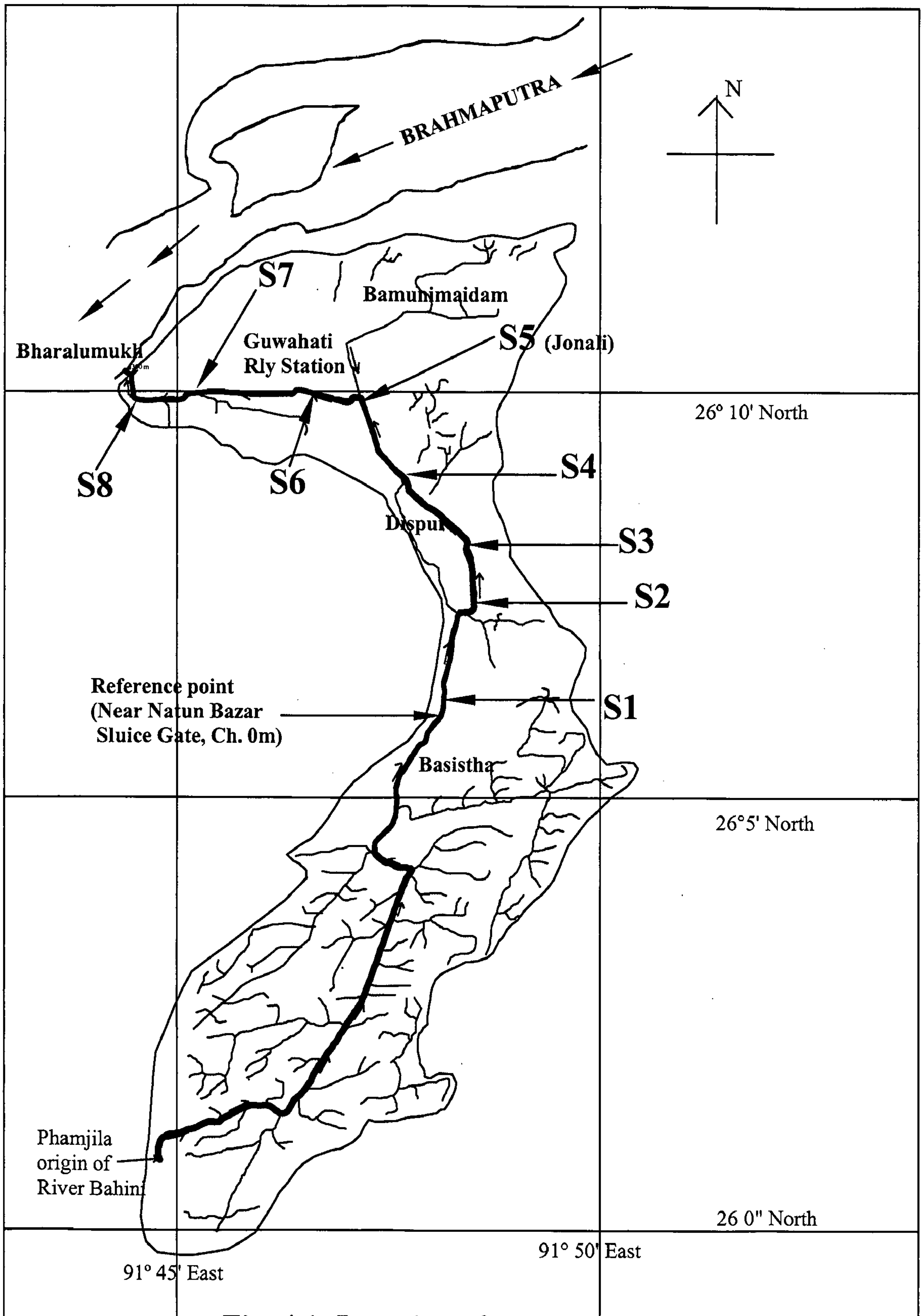

Fig. 4.1: Location of sampling stations

Table 4.1 Location of sampling stations

Sr. No.	Category	Sampling station	Location
1	River Point	S_1	Near Natun Bazar Sluice Gate, Basistha, Guwahati-28
2	River Point	S_2	Near R.C.C. Bridge, Beltola Bazar, Guwa-hati-28
3	River Point	S_3	Near R.C.C. Bridge,. Rukminigaon, G.S. Road Guwahati-6
4	River Point	S_4	Near R.C.C. Bridge, Hengrabari Road Ganeshguri, Guwahati-5
5	River Point	S_5	Near R.C.C. Bridge, Jonali, R.G.Baruah Road, Guwahati-24
6	River Point	S_6	Near R.C.C. Bridge, Bhangagarh, Rajgarh Road
7	River Point	S_7	Near R.C.C. Bridge, Rehabari, Arabindra Bidya Mandir Path, Guwahati-7
8	River Point	S_8	Near R.C.C. Bridge AT Road, Bharalumukh, Guwahati-8

The detailed descriptions of above sampling stations are given as follows.

4.2.2.1 *Station 1 (Natun Bazar)*

This sampling station is selected because it represents the clear water zone. This station is located about 100m d/s from the reference point. At reference point, the river water may be diverted through cross regulator consisting of gates to river Basistha to avoid flood in the downstream areas. In this area, no remarkable industries or motor workshop are situated. Natun Bazar Sluice Gate is assumed as reference point, from where the city starts and designated as 0.0 m chainage as shown in Fig. 4.1.

4.2.2.2 *Station 2 (Beltola Bazar)*

This station is about 2.0 km downstream from the point of reference. The drains carrying domestic sewage from Jawaharnagar, Saurav Nagar and Beltola bazaar area joins river Bharalu in between station 1 and station 2.

4.2.2.3 *Station 3 (G.S.Road, Rukminigaon)*

This station is about 3.6 km downstream from the point of reference. At this point, river Bharalu crosses the G. S. Road. The drains carrying domestic sewage from Six mile and Rukminigaon area join the river at this point.

4.2.2.4 *Station 4 (Hengrabari Road, Ganeshguri)*

This station is about 5.85 km downstream from the point of reference. The drains carrying domestic sewage from Dispur Capital Complex, Ganeshguri Bazar and Hengrabari join the river Bharalu in between station 3 and 4.

4.2.2.5 *Station 5 (R.C.C.Bridge at Jonali, R.G.B.Road)*

This station is about 7.7 km downstream from the point of reference. A major drain originating from Guwahati refinery area near Noonmati carrying industrial waste from refinery along with domestic sewage from Bamunimaidam, Jyotinagar and Narikalbasti area join the river Bharalu at this point.

4.2.2.6 *Station 6 (R.C.C.Bridge, Bhangagarh, G.S.Road)*

This station is about 9.35 km down stream from the point of reference. The drain carrying domestic sewage from All India Radio Complex, Chandmari, Rajgarh Road and Nabin Nagar area joins river Bharalu in between station 5 and 6.

4.2.2.7 *Station 7 (R.C.C. Bridge, Arbind Bidya Mandir Path, Rehabari)*

This station is about 10.67 km down stream from the point of reference. The drain carrying domestic sewage from Ullubari, Lachit Nagar and Bora Service area joins the river Bharalu in between station 6 and 7.

4.2.2.8 *Station 8 (R.C.C.Bridge, A.T. Road, Bharalumukh)*

This station is about 13.72 km downstream from the point of reference and near the outfall of river Bharalu at Bharalumukh. The drain carrying wastewater from Ambari, Paltanbazar, Manipuribasti, Gopinath Nagar and Chatribari areas joins river Bharalu through Chalabeel. Another drain carrying wastewater from Lakhtokia, Panbazar joins river Bharalu through Chalabeel.

4.2.3 Sampling Programmes

Sample collection is a very important part of river survey because conclusions drawn are based only on the testing of collected samples. The purpose of taking samples is to obtain information, which in some way typifies the aquatic system from which samples are drawn. Based on the procedure of collection, samples are divided into three types: (i) Grab, (ii) Composite and (iii) Integrated samples. In this study, grab samples were collected from sampling stations since time constraints and manpower available did not permit collection of integrated/composite samples. Sampling was done between October 2005 and April 2006. This period was chosen to study the quality of the stream during rainy and winter seasons. Considering the amount of efforts required, time and resources available, sampling was done at a frequency of approximately two months. The sampling schedule is given in Table 4.2.

4.3. EXPERIMENTAL WORKS

The water quality for a given use depends on the following:

I. Parameters which significantly affect the utility for the use
II. Individual values of each significant parameter
III. The relative importance of various relevant parameters for that particular use

Focus of interest on the present work was primarily to restore the water body to class 'B' as per DBU, which defines the water uses for outdoor bathing, washing clothes and other uses etc. Considering above points in mind, following water quality parameters were determined; temperature, pH, DO, BOD, COD, total solids, total suspended solids, total dissolved solids, turbidity, specific conductivity, nitrate, phosphate, total coliform (MPN), faecal coliform and heavy metals.

Table 4.2 Sampling schedule

Sample from Station No.	Date of sampling		
	Oct'05	**Jan'06**	**April'06**
S_1	19-10-05	20-01-06	7-04-06
S_2	19-10-05	20-01-06	7-04-06
S_3	20-10-05	20-01-06	7-04-06
S_4	20-10-05	23-01-06	10-04-06
S_5	21-10-05	23-01-06	10-04-06
S_6	21-10-05	23-01-06	10-04-06
S_7	24-10-05	24-01-06	11-04-06
S_8	24-10-05	24-01-06	11-04-06
2 km u/s from Reference Point	Not collected	Not collected	21-04-06
5km u/s from Reference Point	Not collected	Not collected	21-04-06

Physico-chemical and bacteriological parameters were evaluated according to methods specified in "Standard Methods for the Examination of water and Wastewater" (APHA-AWWA-WPCF 1995). The techniques, instruments and principles involved in arriving at different water quality parameters are tabulated in Table 4.3 (Mathur 1984, Standard method 1995, Trivedi 1985)

4.4 METHODOLOGY FOR DEVELOPMENT OF BOD AND DO MODEL

4.4.1 Survey of Drains and River

Detailed field survey was carried out to determine the following characteristics of drain and river.

For drain

- Location of drains joining river Bharalu
- Distance of drains outfall from the point of reference [Natun Bazar Sluice Gate ch. 0.0m]
- Size of the drain
- Velocity of flow

- Depth of flow
- Width of flow
- Discharge

Table 4.3 Summary of analytic -methods

Sl.No.	Parameters	Principle	Instrument/ Technique Used
1.	Temperature	Metric	Thermometer
2.	Turbidity	Photometric	Nephlometer or turbidity meter
3	Total solids	Gravimetric	Evaporation in oven at 103^0- 103^0C (24 hrs)
4.	Dissolved solids	Gravimetric	Evaporating of filtrate (Whatman Paper no.44) at 103^0- 103^0C (24 hrs)
5.	Non volatile suspended solids	Gravimetric	Difference of residue of total solids & residue of dissolved solids in muffle furnace at 600^0C (20 minutes)
6.	Specific conductance	Electrometric methods	Digital Conductivity Meter
7.	pH	Electrometric	Digital pH-meter
8.	DO	Volumetric	Modified Winkler's Method Titrant- N/40 Na_2S_2 O_3 Indicator- Starch
9.	BOD	Volumetric	Winkler's Method Incubation for 3 days at 27^0C
10.	COD	Volumetric	Reflux Method Titrant- 0.25 N Ferrous Ammonium Sulphate; Indicator- Ferroin
11.	Amonical Nitrogen	Colorimetric	U. V. Spectrophotometer Nesselerization
12.	Total Nitrogen	Colorimetric	U. V. Spectrophotometer Kjeldahl Method
13.	Nitrate	Colorimetric	U. V. Spectrophotometer, Phenoldisulphonic acid method
14.	Phosphate	Colorimetric	U. V. Spectrophotometer, $Sncl_2$ Method
15.	Total coliform	MPN-index	MeConcey's browth at 35 ± 0.5^0C for 48 hrs.
16.	Heavy metal	Computerized flame photometry	Inductively Couple Mass Spectrometer (ICPMS)

For river

- Velocity of flow of the river
- Flow depth of river
- Flow width at top
- Discharge
- Temperature

Above measurements were taken near the outfall of each drain.

4.4.1.1 *Measurement of width and depth of drains and river*

The measurements of width of drains and river are done manually with the help of measuring tape. The depth of drains and river are measured with the help of specially built ranging rod marked with scale. The depth of river is observed less than 1.5m during the time of survey.

4.4.1.2 *Flow measurement*

A number of methods of measuring flow in streams, drains and pipes carrying wastewater are available. In this study, the flow of wastewater in drain is measured by surface float method.

A float (any piece of wood, thermocol, plastic, etc.) is thrown on water surface. The time required for a float to travel (t), for a known distance (d) is observed with the help of stopwatch and the average velocity is obtained by

$$U = d/(1.2 \times t) \qquad \text{.................(4.1)}$$

The factor 1.2 accounts for the fact that surface velocities are normally about 1.2 times higher. If the cross-sectional area (A) is measured, the discharge Q is computed by using area velocity method.

4.4.2 Model Segmentation

The model represents a river as a series of reaches. The stretch of the river is divided into reaches between the two consecutive drains outfall (discharge point). The river is segmented into fifty-three numbers of reaches. The reaches are numbered in ascending order starting from the headwater of the river's main stem. A typical segmentation of a river into six numbers of reaches is shown in Fig. 4.2.

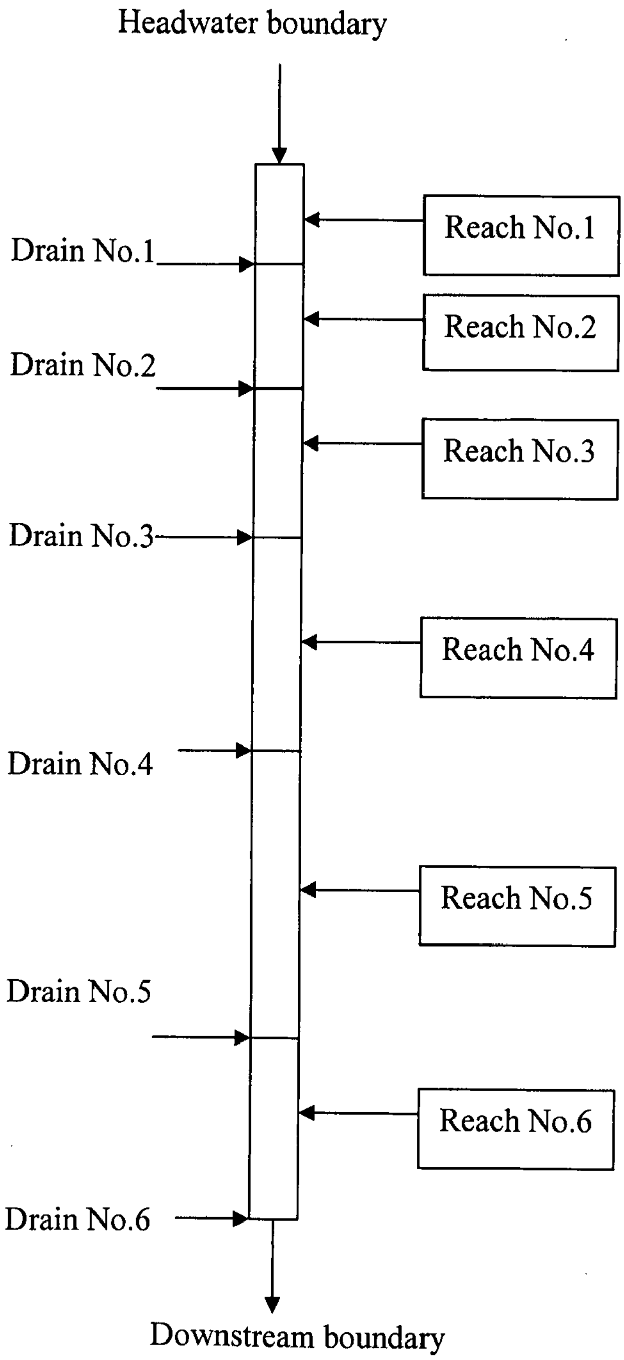

Fig. 4.2 Typical diagram for segmentation of a river

4.4.3 Flow Balance

A steady state flow balance is implemented for each model element as shown in Fig. 4.3.

$$Q_i = Q_{i-1} + Q_{in,i} - Q_{out,I} \qquad \text{.....................(4.2)}$$

Where,

Q_i = Outflow from element *i* into the downstream element i+1 [m^3/d]

Q_{i-1}=Inflow from the upstream element i-1 [m^3/d]

Q in,i = Total inflow into the element due to point and nonpoint sources [m^3/d]

$Q_{out,i}$ = Total outflow from the element due to point withdrawals in [m^3/d]

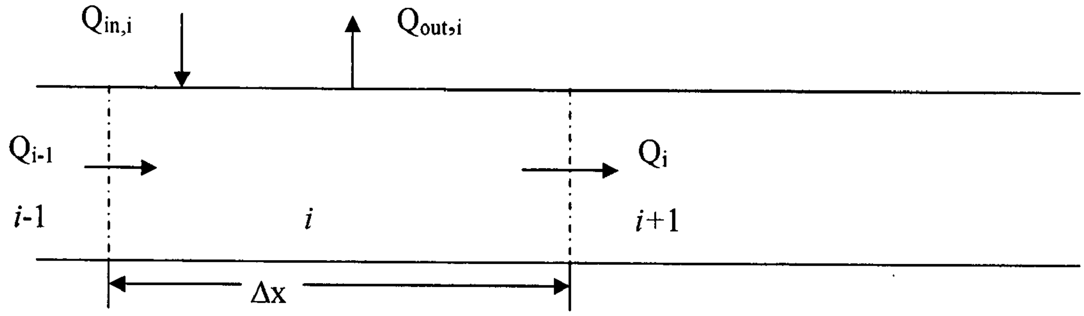

Fig. 4.3 Element flow balance

4.4.4 Rating Curve

Power equation can be used to relate mean velocity and depth to flow.

$$U = a\,Q^b \qquad \text{...................(4.3a)}$$

$$H = \alpha\,Q^\beta \qquad \text{.................. (4.3b)}$$

Where, H = Mean depth (m)

And a, b, α and β are empirical co-efficient that are determined from velocity, discharge and stage-discharge rating curves, respectively. The values of velocity and depth can then be employed to determine the cross-sectional area and width by

$$A_c = Q/U$$

$$B = A_c/H$$

The surface area and volume of the element can then be computed as

$$A_s = B\Delta x$$

$$V = BH\Delta x$$

Where, Δx is elemental length (m)

The exponents b and β typically take on values tabulated in Table 4.4. The sum of b and β must be less than or equal to 1. For rectangular channel the sum of b and β becomes one.

Table 4.4 Typical values for the exponents of rating curves used to determine velocity and depth from flow (Barnwell et al., 1989)

Equation	**Exponent**	**Typical values**	**Range**
$U = a\,Q^{b}$	b	0.43	0.4-0.6
$H = \alpha\,Q^{\beta}$	β	0.45	0.3-0.5

In this study, the values of empirical coefficients are taken as follows,
$\alpha = 0.57$; $a = 0.15$; $\beta = 0.45$ and $b = 0.55$.

4.4.5 Travel Time

The residence time of each element is computed as

$$\tau_k = \frac{V_k}{Q_k} \qquad \text{..................(4.4)}$$

Where,

τ_k = the residence time of the k^{th} element [d]
V_k = the volume of the k^{th} element [m^3]
$A_{c,k}$ = the cross-sectional area of the k^{th} element [m^2]
Δx_k = the length of the k^{th} element [m]

4.4.6 Longitudinal Dispersion

Longitudinal dispersion may be computed by using the following formula

$$E_{p,i} = 0.011\frac{U_i^2.B_i^2}{H_i.U_i^*} \qquad \text{....................(4.5a)}$$

Where,

$E_{p,i}$ = the longitudinal dispersion (based on channel hydraulics) between elements ith and $(i+1)$th [m^2/s]

U_i= velocity [m/s]

B_i = width [m]

H_i= mean depth [m]

U_i^* = Shear velocity [m/s]

$$U_i^* = \sqrt{gH_iS_i} \qquad \text{....................(4.5b)}$$

g = acceleration due to gravity = [9.81 m/Sec^2], S= Channel slope [dimensionless]
After computing or prescribing $E_{p,i}$,, the numerical dispersion is computed as

$$E_{n,,i} = \frac{U_i\Delta x_i}{2} \qquad \text{....................(4.5c)}$$

The model dispersion E_i (i.e. the value used in the model calculation) is then computed as follows:

If $E_{n,i} \le E_{p,i}$, the model dispersion , E_i is set to $E_{p,i}$-$E_{n,i}$.

If $E_{n,i} \ge E_{p,i}$, the model dispersion is set to zero.

For the later case, the resulting dispersion will be greater than the physical dispersion. Thus dispersive mixing will be higher than reality. It should be noted that for most steady-state rivers, the impact of this overestimation on concentration gradients would be negligible. If the discrepancy is significant, the only alternative is to make element lengths smaller so that the numerical dispersion becomes smaller than the physical dispersion. In this model longitudinal dispersion is not studied.

4.4.7 Manning's Equation

Some elements are idealized as a rectangular and some are idealized as trapezoidal channel. Under conditions of steady flow, the Manning's equation can be used to express the relationship between flow and depth.

4.4.8 Constituent Reactions

The mathematical relationships that describe the individual reactions and concentrations of the model state variables are presented as follows.

4.4.8.1 *Oxygen saturation*

The following equation is used to represent the dependence of oxygen saturation on temperature (APHA 1992)

$$\ln C_s(T,0) = -139.34411 + \frac{1.575701\times10^5}{T_a} - \frac{6.642308\times10^7}{T_a^2} + \frac{1.243800\times10^{10}}{T_a^3} - \frac{8.621949\times10^{11}}{T_a^4} \qquad \text{...........(4.6a)}$$

Where,

C_s (T, 0) = the saturation concentration of dissolved oxygen in freshwater at 1 atm [mg O_2/L]

and T_a = absolute temperature [K]

Where, T_a= T + 273.15

The effect of elevation is accounted for by

$$C_s(T,elev) = e^{\ln C_s(T,0)}(1 - 0.0001148elev) \qquad \text{.......(4.6b)}$$

4.4.8.2 *Reaeration*

The reaeration co-efficient (K_2) (at 20°C) can be computed as a function of the river's hydraulics by using the following formulas.

O'Cornnor-Dobbins (1958)

$$K_2(20) = 3.93\frac{U^{0.5}}{H^{1.5}} \qquad \text{........................(4.7a)}$$

Where,

U = mean water velocity (m/s)

Churchill (Churchill et al. 1964)

$$K_2(20) = 5.026\frac{U}{H^{1.67}} \qquad \text{...............(4.7b)}$$

Owens – Gibbs (Owen's et al. 1964)

$$K_2(20) = 5.32\frac{U^{0.67}}{H^{1.85}} \qquad \text{...............(4.7c)}$$

According to Covar (1976), the general rule to use the formula for determination of reaeration co-efficient is

- If H< 0.61 m, use the Owens – Gibbs formula
- If H> o.61 m and H> 3.45U $^{2.5}$, use the O' Connor – Dobbin's formula
- Otherwise, use the Churchill formula

In this present study, O'Connor – Dobbin's formula is used for determining reaeration coefficient in each reach of the river.

4.4.8.3 *Deoxygenation rate (K_1)*

The deoxygenation rate (at 20°C) can be computed as a function of river hydraulics by using the following formulas

$$K_1 = 0.17914\left[\frac{H}{8}\right]^{-0.434} \qquad for\ 0 \le H \le 2.44\ m$$

$$= 0.3 \qquad for\ H > 2.44\ m \qquad \text{.............(4.8)}$$

$$And\ K_1\ is\ deoxygenation\ coefficient\ in\ day^{-1}$$

The deoxygenation rate K_1 is a function of the water temperature, since the oxidation of the CBOD is a bacterially mediated process. The effect of temperature K_1 may be approximated by

$$(K_1)_T = (K_1)_{20} \times 1.047^{(T-20)} \qquad \text{.....................(4.9)}$$

Where, $(K_1)_T$ and $(K_1)_{20}$ are the decay co-efficient at water temperature T (°C) and 20°C respectively. The base 1.047 is reported to range from 1.02 to 1.09 (Zison et al. 1978).

4.4.8.4 *River decay rate (K_r)*

The river decay rate can be computed by the following formula

$$K_r = K_s + K_1$$

Where,

K_s = is the effective loss rate due to settling

K_r = is overall loss rate $[T^{-1}]$

In case, when a suspended solid is less than 30 mg/l, K_s may not be important due to absence of any significant particulate BOD. In the present study, K_s is taken as zero. Hence K_r equals to K_1.

4.4.8.5 *Mass balance of contaminant*

The mass balance at the outfall of the point (discharge point) sources can be written as:

Mass rate of substance upstream + mass rate added by outfall = mass rate of substance immediately downstream from outfall

Assuming complete mixing.

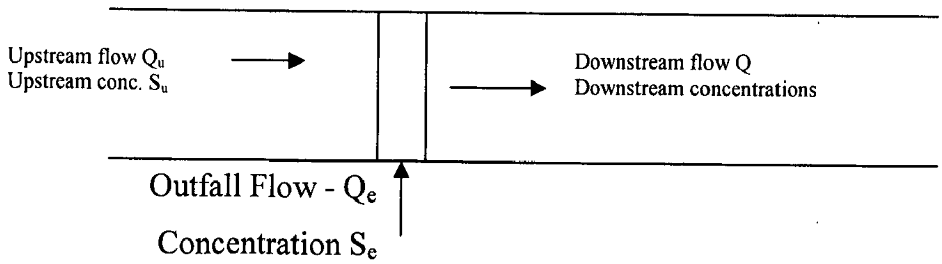

Fig. 4.4 Mass balance of contaminant

$$QS = Q_u S_u + Q_e S_e$$

or $$S = \frac{Q_u S_u + Q_e S_e}{Q} \qquad \text{.......................(4.10)}$$

Where,

Q_u = upstream flow

S_u = upstream concentration

Q_e = flow addition from drain

S_e = concentration of drain water

4.4.8.5 *BOD equation (Aerobic condition)*

For non-conservative substances, the decay of organic matter can be computed by the following equation

$$L = L_0 \exp(-kt) \qquad \text{.....................(4.11)}$$

4.4.8.6 *BOD equation (Anaerobic condition)*

Some rivers and streams may be so heavily loaded with CBOD, that the DO would approach complete depletion and anaerobic conditions would result. Gundelach and Castillo (1976) have analyzed this situation in detail. Assuming no other sources and sinks of BOD or DO, a single point source and $K_r = K_1$, then the rate of change of the CBOD downstream will be satisfied by the rate at which oxygen can be transferred across the surfaces of the stream and mixed into the river. The variation of CBOD and DO for complete oxygen depletion is shown in Fig. 4.5.

The beginning of the anaerobic reach can be obtained when C = 0. At that location and downstream, the CBOD profile can be computed by the equation given below.

$$L = L_i - K_2 C_s \left[\frac{X - X_i}{U} \right] \qquad \text{......................(4.12)}$$

Where,

L_i = is the BOD at the anaerobic conditions

X_i = is the location where DO reaches zero

C_s = saturation concentration of DO in liquid

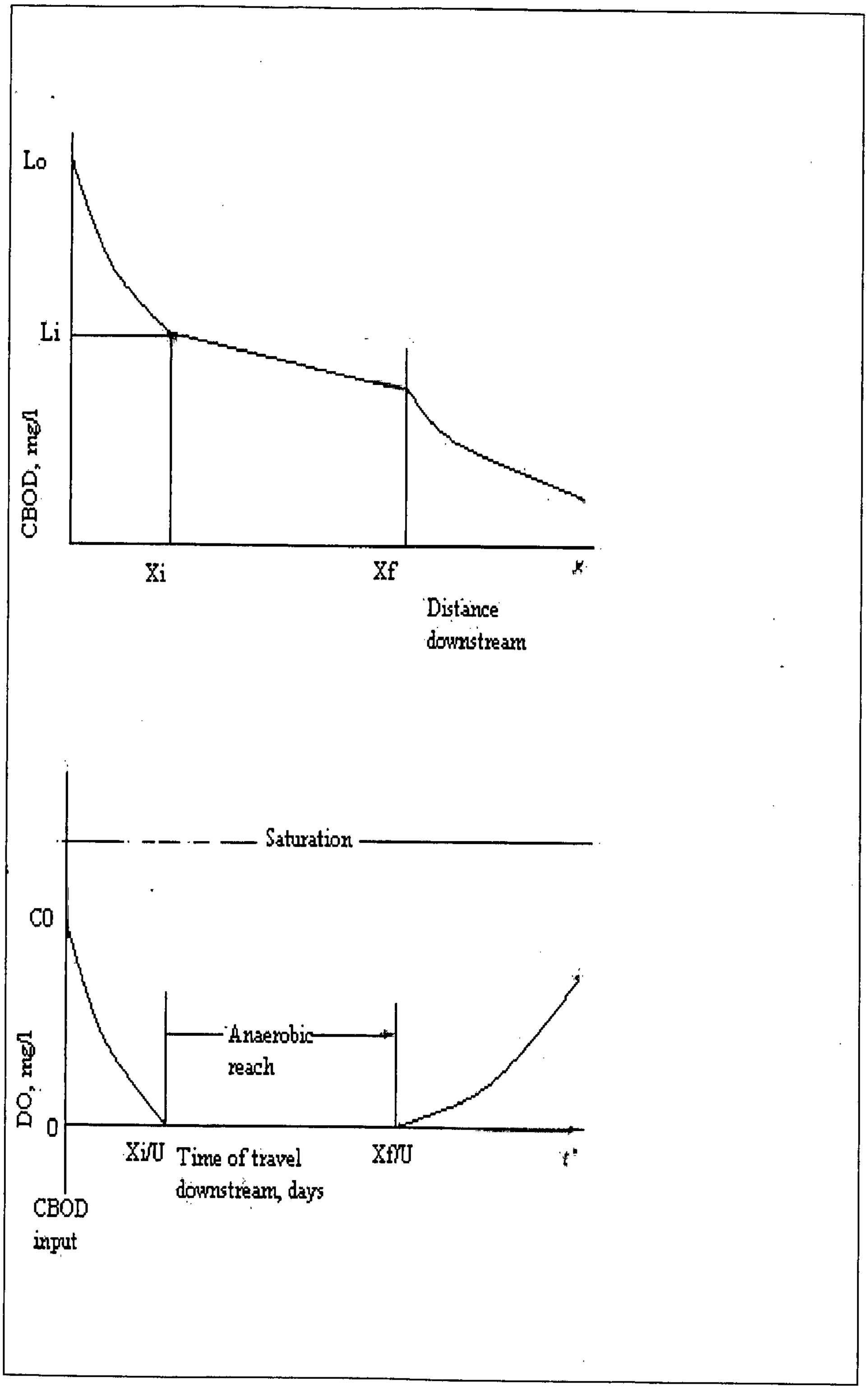

Fig. 4.5 Variation of CBOD and DO for anaerobic condition in river

4.4.8.7 *Dissolved oxygen analysis*

There are many variables that govern the spatial distribution of dissolved oxygen in a river. The concentration of DO decreases due to consumption of oxygen by microorganism for degradation of the organic matter, when organic matter is discharged into the river. However, the deficiency of oxygen is supplemented from the atmosphere by the process of reaeration. But the natural reaeration has its own limitation to maintain the oxygen level depending on the organic load. Therefore the DO in a river depends on reaeration co-efficient, river decay rate, deoxygenation rate, temperature (for O_2 saturation), initial DO deficit, photosynthesis by algae, algal respiration, benthic oxygen demand, sediment oxygen demand, point source and non point source load etc. The most famous simplified DO sag equation was developed by Streeter and Phelps, which may be given as below.

$$C = C_s - \left\{ \frac{K_1}{K_2 - K_r} \left[\exp\left(-K_r \frac{X}{U}\right) - \exp\left(-K_2 \frac{X}{U}\right) \right] \right\} L_0 - (C_s - C_0) \exp\left(-K_2 \frac{X}{U}\right) \quad \text{.......(4.13)}$$

Where,

C = concentration of DO at any distance x from the point source

C_0= concentration of DO at X = 0

C_0 and L_0 can be calculated by

$$C_0 = \frac{C_u Q_u + C_e Q_e}{Q_u + Q_e}. \quad \text{.......... .... 4.13 (a)}$$

$$L_0 = \frac{L_u Q_u + L_e Q_e}{Q_u + Q_e}. \quad \text{.......... .... 4.13 (b)}$$

5.4.8.8 *Effect of multiple point sources along the length of stream*

When there is more than one point source along the length of the stream, the effect on DO is cumulative. That is, each source contributes to the DO deficit depending on its BOD loading and individual contribution are additive. Mathematically this results from the fact that the basic BOD – DO equations are linear, so that the principle of superposition can be applied. Fig. 4.6 illustrates two individual DO sag curves and their sum. Computationally, the most direct way to compute the resulting total DO sag is to calculate the BOD and DO at the downstream location just before the next input. A mass balance then can be made to calculate the new concentration at the outfall after mixing with the next downstream point source. The preceding equations can be applied to the next reach. Let $L_1(x_1)$ and $c_1(x_1)$ be the BOD and DO at the end of the first reach given by x_1 but just before the next input W_2 is discharged.

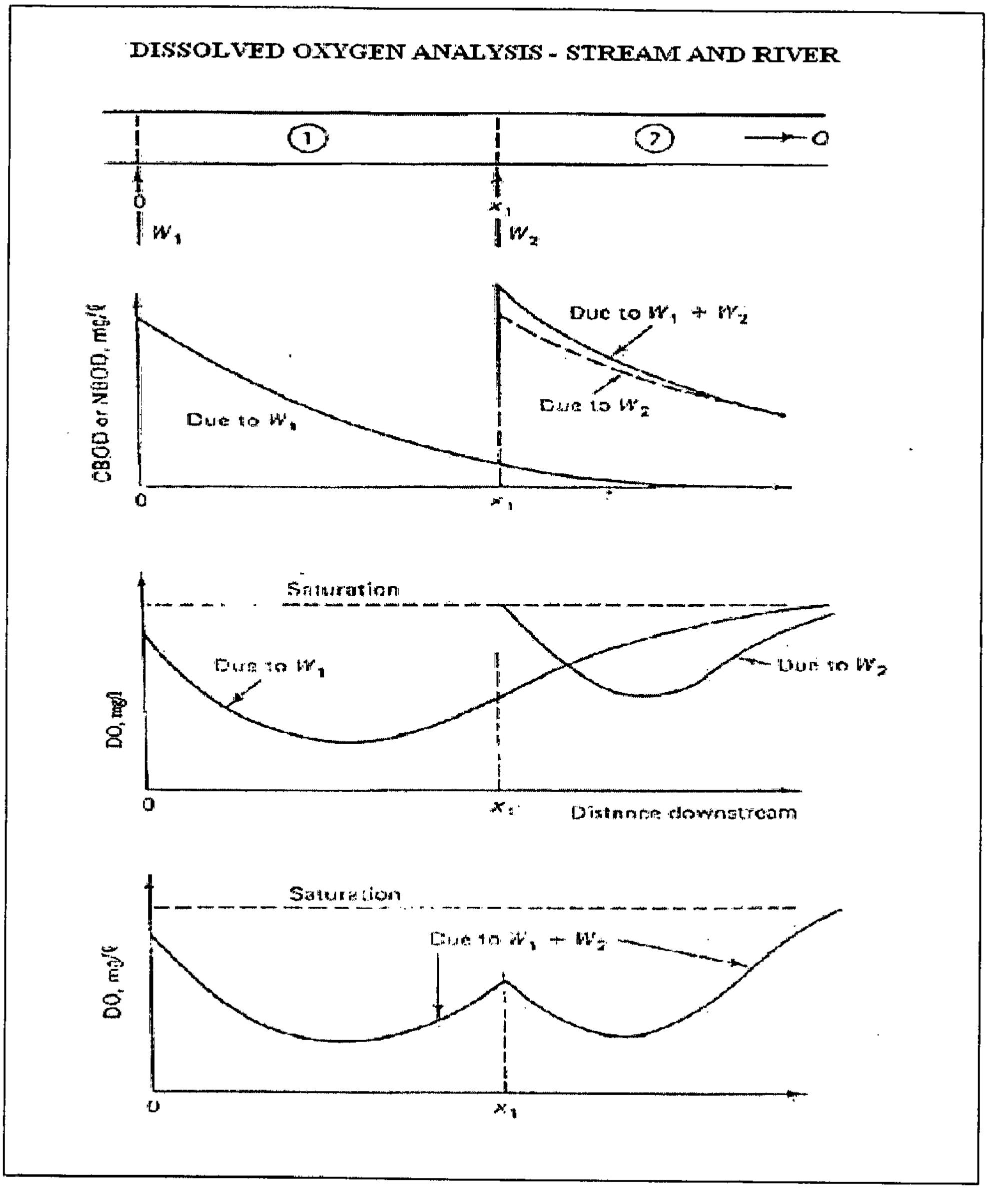

Fig. 4.6 Superposition of BOD and DO, two waste inputs in stream

Then the new BOD concentration at the second outfall after mixing is

$$L_{02} = \frac{L_1(x_1)Q_1 + L_{e2}Q_{e2}}{Q_1 + Q_{e2}} \qquad \text{..........................(4.14a)}$$

Where L_{02} is the new initial concentration for the second reach and L_{e2} and Q_{e2} are the effluent BOD concentration and flow, respectively, for the second input. Similarly, the new DO concentration at the beginning of the second reach c_{02}, is

$$c_{02} = \frac{c_1(x_1)Q_1 + c_{e2}Q_{e2}}{Q_1 + Q_{e2}} \qquad \text{......................(4.14b)}$$

4.4.9 Derivation of BOD Equation for n^{th} Point Load

The equation for spatial Variation of BOD for nth point sources in a river (aerobic condition) is derived as follows

Let,

Q_0 = Initial flow of the river (m^3/sec) at chainage 0.0m

S_0 = Initial BOD of river (mg/l) at chainage 0.0m

U_i = Velocity of flow at *i*th reach (m/sec)

K_{1i} = Decay rate at *i*th reach

Q_{ei} = flow from *i*th drain (m^3/sec)

S_i = BOD of *i*th drain (mg/l)

L_i = Length of the river from ch.0.0 m to the point where the *i*th drain joins the river

$S_{i\,(mix)}$ = BOD of the river after *i*th drain joins the river (mg/l)

S_{xi} = BOD profile of the river at *i*th reach (mg/l)

X_i= Length of the *i*th reach

Where, i = 1,2,3,.......n

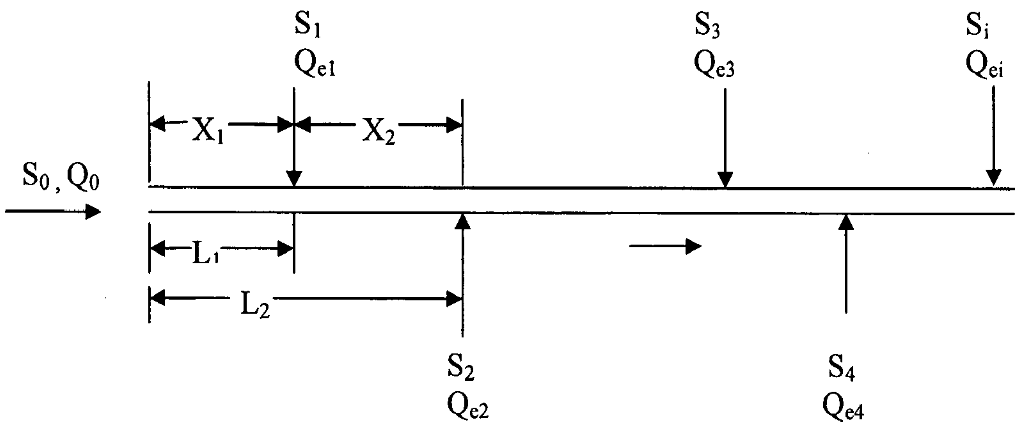

Fig. 4.7 Conceptual linearize diagram of multiple point load

For reach no.1:

$$S_{x1} = S_0 \times \exp(-K_{11} \times X_1 / U) \qquad \text{..............(4.15a)}$$

Equation for BOD mixing:

$$S_{1(mix)} = \frac{(Q_0 \times S_{x1} + Q_{e1} \times S_1)}{Q_0 + Q_{e1}}$$

$$= \frac{(Q_0 \times S_0 \exp(-\frac{K_{11} \times X_1}{U_1}) \times S_{x1} + Q_{e1} \times S_1)}{(Q_0 + Q_{e1})} \qquad \text{.............................(4.15}b\text{)}$$

For reach no.2:

$S_{x2} = S_{1(mix)} \times \exp[-K_{12} \times X_2/ U_2]$

$= [\{(Q_0 \times S_0 \times \exp(-K_{11} \times X_1/ U_1) \times S_{x1} + Q_{e1} \times S_1)\}/(Q_0 + Q_{e1})] \times \exp(-K_{12} \times X_2/ U_2)$

$= [Q_0 \times S_0 \times \exp\{(-K_{11}/ U_1) \times (X_1+X_2)\} + Q_{e1} \times S_1 \times \exp(-K_{12} \times X_2/ U_2)]/(Q_0 + Q_{e1})$

............................(4.15c)

$S_{2(mix)} = [S_{x2} \times (Q_0 + Q_{e1}) + Q_{e2} \times S_2]/ (Q_0 + Q_{e1} + Q_{e2})$

$= [Q_0 \times S_0 \times \exp\{(-K_{11}/ U_1) \times (X_1+X_2)\} + Q_{e1} \times S_1 \times \exp(-K_{12} \times X_2/ U_2) + Q_{e2} \times S_2]/$
$(Q_0 + Q_{e1} + Q_{e2})$ ....(4.15d)

For reach no.3:

$S_{x3} = S_{2(mix)} \times \exp[-K_{13} \times X_3/ U_3]$

$=[[Q_0 \times S_0 \times \exp\{(-K_{11}/ U_1) \times (X_1+X_2)\} + Q_{e1} \times S_1 \times \exp(-K_{12} \times X_2/ U_2) + Q_{e2} \times S_2]/$
$(Q_0 + Q_{e1} + Q_{e2})] \times \exp(-K_{13} \times X_3/ U_3)$

$=[Q_0 \times S_0 \times \exp\{(-K_{11}/ U_1) \times (X_1+X_2+X_3)\} + Q_{e1} \times S_1 \times \exp\{(-K_{12}/ U_2) \times$
$(X_2+X_3)\} + Q_{e2} \times S_2 \times \exp(-K_{13} \times X_3/ U_3)] / (Q_0 + Q_{e1} + Q_{e2})$ ....(4.15e)

$S_{3(mix)} = [S_{x3} \times (Q_0 + Q_{e1} + Q_{e2}) + Q_{e3} \times S_3]/ (Q_0 + Q_{e1} + Q_{e2} + Q_{e3})$

$= [Q_0 \times S_0 \times \exp\{(-K_{11}/ U_1) \times (X_1+X_2+X_3)\} + Q_{e1} \times S_1 \times \exp\{(-K_{12}/ U_2) \times$
$(X_2+X_3)\} + Q_{e2} \times S_2 \times \exp(-K_{13} \times X_3/ U_3)] + Q_{e3} \times S_3]/(Q_0+Q_{e1} + Q_{e2} + Q_{e3})$

...................(4.15f)

Table 5.1 Observed values of water quality parameters at different Sampling Stations

Sampling Station									
Parameter	**Month of collection**	**S_1**	**S_2**	**S_3**	**S_4**	**S_5**	**S_6**	**S_7**	**S_8**
Temperature (^0C)	Oct'05	26.3	26.7	27.1	27.7	26.7	26.8	26.9	27.1
	Jan'06	24.3	24.4	24.8	25.2	25.3	25.2	25.3	25.3
	Apr'06	25.6	25.8	26.1	26.3	26.4	26.1	26.5	26.5
Turbidity (NTU)	Oct'05	23	24	25	27	35	32	32	36
	Jan'06	25	27	27	29	38	35	31	35
	Apr'06	24	26	27	28	36	33	32	35
TS (mg/l)	Oct'05	320	310	380	378	450	440	400	430
	Jan'06	325	315	390	385	480	430	430	435
	Apr'06	320	315	384	382	465	435	425	430
SS (mg/l)	Oct'05	90	125	240	242	190	160	210	210
	Jan'06	105	130	220	236	165	155	210	205
	Apr'06	95	125	224	234	180	160	200	225
SPC (µmho/cm)	Oct'05	138	108	132	140	170	160	155	172
	Jan'06	132	114	135	140	165	155	161	168
	Apr'06	135	114	132	138	165	155	152	171
pH (Units)	Oct'05	7.2	7.3	7.8	7.4	7.3	7.2	7.5	7.4
	Jan'06	7.3	7.3	7.6	7.2	7.2	7.3	7.6	7.5
	Apr'06	7.4	7.4	7.8	7.5	7.2	7.1	7.4	7.3

$$S_{1(mix)} = \frac{(Q_0 \times S_{x1} + Q_{e1} \times S_1)}{Q_0 + Q_{e1}}$$

$$= \frac{(Q_0 \times S_0 \exp(-\frac{K_{11} \times X_1}{U_1}) \times S_{x1} + Q_{e1} \times S_1)}{(Q_0 + Q_{e1})} \quad \text{.............................(4.15}b\text{)}$$

For reach no.2:

$S_{x2} = S_{1(mix)} \times \exp[-K_{12} \times X_2 / U_2]$

$= [\{(Q_0 \times S_0 \times \exp(-K_{11} \times X_1 / U_1) \times S_{x1} + Q_{e1} \times S_1)\} / (Q_0 + Q_{e1})] \times \exp(-K_{12} \times X_2 / U_2)$

$= [Q_0 \times S_0 \times \exp\{(-K_{11} / U_1) \times (X_1 + X_2)\} + Q_{e1} \times S_1 \times \exp(-K_{12} \times X_2 / U_2)] / (Q_0 + Q_{e1})$

.............................(4.15c)

$S_{2(mix)} = [S_{x2} \times (Q_0 + Q_{e1}) + Q_{e2} \times S_2] / (Q_0 + Q_{e1} + Q_{e2})$

$= [Q_0 \times S_0 \times \exp\{(-K_{11} / U_1) \times (X_1 + X_2)\} + Q_{e1} \times S_1 \times \exp(-K_{12} \times X_2 / U_2) + Q_{e2} \times S_2] / (Q_0 + Q_{e1} + Q_{e2})$ ....(4.15d)

For reach no.3:

$S_{x3} = S_{2(mix)} \times \exp[-K_{13} \times X_3 / U_3]$

$= [[Q_0 \times S_0 \times \exp\{(-K_{11} / U_1) \times (X_1 + X_2)\} + Q_{e1} \times S_1 \times \exp(-K_{12} \times X_2 / U_2) + Q_{e2} \times S_2] / (Q_0 + Q_{e1} + Q_{e2})] \times \exp(-K_{13} \times X_3 / U_3)$

$= [Q_0 \times S_0 \times \exp\{(-K_{11} / U_1) \times (X_1 + X_2 + X_3)\} + Q_{e1} \times S_1 \times \exp\{(-K_{12} / U_2) \times (X_2 + X_3)\} + Q_{e2} \times S_2 \times \exp(-K_{13} \times X_3 / U_3)] / (Q_0 + Q_{e1} + Q_{e2})$ ....(4.15e)

$S_{3(mix)} = [S_{x3} \times (Q_0 + Q_{e1} + Q_{e2}) + Q_{e3} \times S_3] / (Q_0 + Q_{e1} + Q_{e2} + Q_{e3})$

$= [Q_0 \times S_0 \times \exp\{(-K_{11} / U_1) \times (X_1 + X_2 + X_3)\} + Q_{e1} \times S_1 \times \exp\{(-K_{12} / U_2) \times (X_2 + X_3)\} + Q_{e2} \times S_2 \times \exp(-K_{13} \times X_3 / U_3)] + Q_{e3} \times S_3] / (Q_0 + Q_{e1} + Q_{e2} + Q_{e3})$

...................(4.15f)

Similarly, for nth reach:

$$S_{xn} = [Q_0\times S_0\times\exp\{(-K_{11}/U_1)\times(X_1+X_2+X_3+......+X_n)\}+Q_{e1}\times S_1\times\exp\{(-K_{12}/U_2)\times(X_2+X_3+......+X_n)\}+Q_{e2}\times S_2\times\exp\{(-K_{13}/U_3)\times(X_3+X_4+......+X_n)\}+ ....+Q_{e(n-1)}\times S_{(n-1)}\times\exp\{(-K_{1n}/U_n)\times(X_{(n-1)}+X_n)\} + Q_{en}\times Sn\times\exp\{(-K_{1n}\times X_n/U_n) \qquad ......(15g)$$

$$Sn_{(mix)} = [Q_0\times S_0\times\exp\{(-K_{11}/U_1)\times(X_1+X_2+X_3+......X_n)\}+Q_{e1}\times S_1\times \exp\{(-K_{12}/U_2)\times(X_2+X_3+X_4+......+X_n)\}+Q_{e2}\times S_2\times\exp\{(-K_{13}/U_3) \times(X_3+X_4+X_5+......+X_n)\}+Q_{e3}\times S_3\times\exp\{(-K_{13}/U)\times (X_4+X_5+X_6+......+X_n)\}+Q_{e(n-1)}\times S_{(n-1)}\times\exp\{(-K_{1n}/U_n)\times (X_{(n-1)}+X_n)\}+Q_{en}\times Sn]/(Q_0+Q_{e1}+Q_{e2}+Q_{e3}+............+Q_{en}) \qquad ......(15h)$$

The above equations will be used to determine the concentration of BOD along the stretch of the river for aerobic condition. For anaerobic condition, the BOD equation given in Para 4.4.2.6 will be followed.

CHAPTER-5

RESULTS AND DISCUSSIONS

5.1 GENERAL

The River Bharalu has been monitored for certain physico-chemical and bacteriological parameters (viz. temperature, pH, turbidity, specific conductivity, total solids, suspended solids, dissolved oxygen, biochemical oxygen demand, chemical oxygen demand, nitrate, phosphate, total coliform and faecal coliform) from October 2005 to Apr 2006. The flow mainly consists of the base flow, infiltration and flow from spring. However, in monsoon it receives surface runoff generated from huge rainfall. The river received domestic sewage and industrial effluent when it enters the Guwahati city. The river water quality therefore changes while passing through the city.

The analysis and discussion of result is mainly divided into two parts. (I) The water quality variations of river Bharalu at Guwahati (II) Development of BOD and DO model. Moreover NSF WQIs have been evaluated at different sampling stations and used to designate the pollution level of river Bharalu in Guwahati city.

5.2 WATER QUALITY PARAMETERS

Observed values of various water quality parameters are given in Table 5.1 and discussed below.

5.2.1 Temperature

The temperature values were recorded at site during the time of sample collection. The recorded water temperature of the Bharalu River varies from station to station as shown in Table 5.1. Moreover, the seasonal variation of temperature is also observed. The temperature is one of the important factors for the survival of the aquatic life. Even 1^0C temperature rise in water may affect the aquatic organisms.

Table 5.1 Observed values of water quality parameters at different Sampling Stations

Sampling Station									
Parameter	**Month of collection**	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8
Temperature (^0C)	Oct'05	26.3	26.7	27.1	27.7	26.7	26.8	26.9	27.1
	Jan'06	24.3	24.4	24.8	25.2	25.3	25.2	25.3	25.3
	Apr'06	25.6	25.8	26.1	26.3	26.4	26.1	26.5	26.5
Turbidity (NTU)	Oct'05	23	24	25	27	35	32	32	36
	Jan'06	25	27	27	29	38	35	31	35
	Apr'06	24	26	27	28	36	33	32	35
TS (mg/l)	Oct'05	320	310	380	378	450	440	400	430
	Jan'06	325	315	390	385	480	430	430	435
	Apr'06	320	315	384	382	465	435	425	430
SS (mg/l)	Oct'05	90	125	240	242	190	160	210	210
	Jan'06	105	130	220	236	165	155	210	205
	Apr'06	95	125	224	234	180	160	200	225
SPC (µmho/cm)	Oct'05	138	108	132	140	170	160	155	172
	Jan'06	132	114	135	140	165	155	161	168
	Apr'06	135	114	132	138	165	155	152	171
pH (Units)	Oct'05	7.2	7.3	7.8	7.4	7.3	7.2	7.5	7.4
	Jan'06	7.3	7.3	7.6	7.2	7.2	7.3	7.6	7.5
	Apr'06	7.4	7.4	7.8	7.5	7.2	7.1	7.4	7.3

...Contd. Table 5.1

Sampling Station									
Parameter	**Month of collection**	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8
DO (mg/l)	Oct'05	3.1	0.9	0.5	0	0	0	0	0
	Jan'06	2.8	0.5	0	0	0	0	0	0
	Apr'06	3.0	0.6	0	0	0	0	0	0
BOD (mg/l)	Oct'05	2.4	30	30	42	53	54	60	64
	Jan'06	4.0	35	31	45	60	58	66	65
	Apr'06	2.9	32	30	44	58	56	64	63
COD (mg/l)	Oct'05	6	68	66	82	112	122	128	132
	Jan'06	12	78	69	90	126	128	136	134
	Apr'06	8	80	68	86	130	126	132	132
NO_3 (mg/l)	Oct'05	0.26	0.25	0.26	0.31	0.34	0.34	0.38	0.42
	Jan'06	0.27	0.26	0.27	0.32	0.32	0.35	0.37	0.43
	Apr'06	0.28	0.25	0.28	0.32	0.31	0.35	0.35	0.42
TP (mg/l)	Oct'05	3.1	3.2	3.4	3.4	2.8	3.2	3.9	4.2
	Jan'06	3.2	3.3	3.2	3.8	3.2	3.0	3.8	4.6
	Apr'06	3.1	3.4	3.3	3.6	3.1	3.1	4.2	4.5
TC (MPN 100ml/100ml)	Oct'05	214000	218000	219000	218000	235000	243000	242000	244000
	Jan'06	215000	220000	219500	218600	240000	245000	242500	245000
	Apr'06	214000	218500	219300	218400	238500	243000	240500	244500
FC (MPN/100ml)	Oct'05	126000	133200	134000	134500	132000	133000	132000	134500
	Jan'06	126500	132600	134800	134900	132600	133500	132500	134800
	Apr'06	126300	132400	134200	134700	132100	133600	132600	134200

The temperature varied from 26.3^{0}C to 27.1^{0}C in Oct, 24.3^{0}C to 25.3^{0}C in January, and 25.6^{0}C to 26.5^{0}C in April during the period of sample collection. Mostly the temperature at the middle river sampling station (S_4, S_5) was found higher by about 1^{0}C than those recorded at u/s sampling stations.

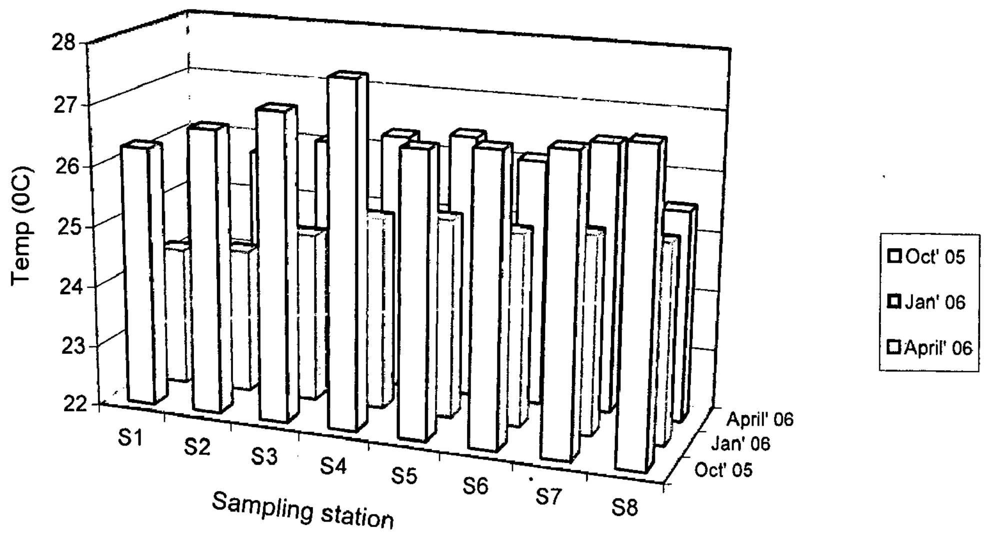

Fig. 5.1 Temporal and spatial variation of temperature

Weather conditions, load of organic and inorganic compounds, discharge of hot wastes from refinery and other drains are probably the main causes of the variation of temperature. At most urban centers where significant waste volume is discharged into the river, the temperature is generally found to rise due to warmer temperature of the wastewater and the same phenomenon has been noted at Guwahati. The temporal and spatial variation of temperature is shown in Fig. 5.1. The increase of temperature at station S_3, S_4 and S_5 indicate discharge of more untapped industrial and domestic waste into the river. Thus, such upswings in temperature of the river water may help to locate significant wastewater discharge point from municipal and industrial sources. Fish and other aquatic organism can survive within certain ranges of temperature and this varies from one species to another. Rapid temperature changes produce thermal shock (Chiras, 1985) and sudden death of fish and other aquatic organisms. In an unpolluted stream diatom grow best at 18^{0}C to 20^{0}C, green algae at 30^{0}C to 35^{0}C and blue green algae at 35^{0}C to 40^{0}C. Thermal discharges to water body may thus favour the growth of blue green algae over green algae. Blue green algae are a poorer food source and are believed in some cases toxic to fish. Higher temperature also affects the physical and chemical properties of water. Generally, the rate of growth of microorganism increases with increase in temperature.

5.2.2 pH

The present analysis shows that the water of Bharalu River is slightly alkaline. The pH value ranges from 7.1 to 7.8 throughout the stretch. Fig 5.2 shows the temporal and spatial variation of pH. It has been observed that pH increases in station 3 due to the discharge of wastewater with higher pH value. Moreover, seasonal variation of pH with high values in Apr and lower value in January has been observed. IS 2296-1974 and EEC standards have specified pH value between 6.0 to 9.0 for primary contact sports like swimming, outdoor bathing etc. Thus river is safe for swimming etc. from pH point of view. CPCB has also specified similar pH range (6.5 to 8.5) for bathing purposes. It is found that, pH less than 4.5 and more than 9.0 is hazardous to fish life.

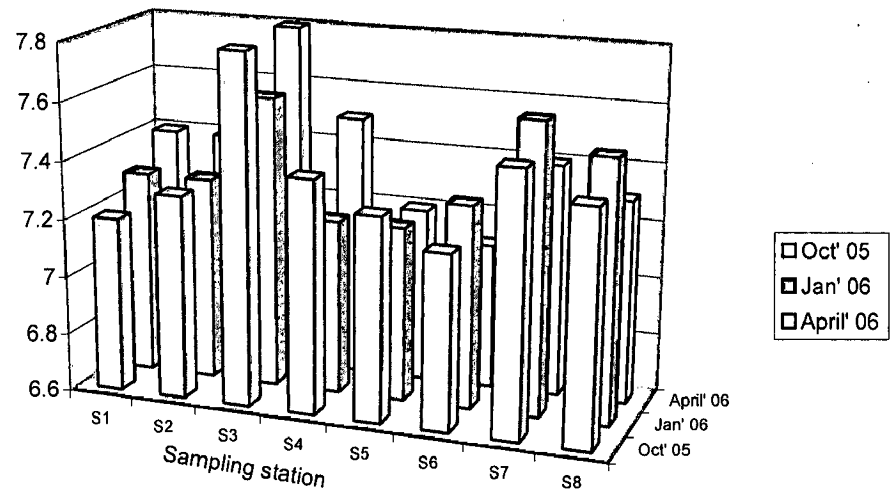

Fig. 5.2 Temporal and spatial variation of pH

Thus the pH values are within the acceptable range and so far as pH values are concerned no serious problem is likely to be encountered by using the water from Bharalu River for different purposes.

5.2.3 Dissolved Oxygen (DO)

The concentration of DO is one of the most important indices of purity of river water. The concentration of DO in water represents the nature of organic matter present, the temperature (Kamath, 1980), bacterial activities (Somashekal et al., 1984), photosynthesis and reaeration from the atmosphere. The concentration of oxygen will also reflect whether the processes undergoing in water aerobic or anaerobic. Low oxygen concentration is generally associated with heavy contamination of water by organic matters. If DO is less than 4mg/l, the fish life does not survive except certain tolerant species. The present analysis shows that the DO concentrations are within the range of 3.1mg/l to 0. From station 4 (R.C.C. bridge, G.S.Road, Rukminigaon), the water body gets anaerobic and anaerobic bacteria predominate and start oxidizing organic matter evolving H_2S, CH_4 and CO_2. This gives rise to smell problem.

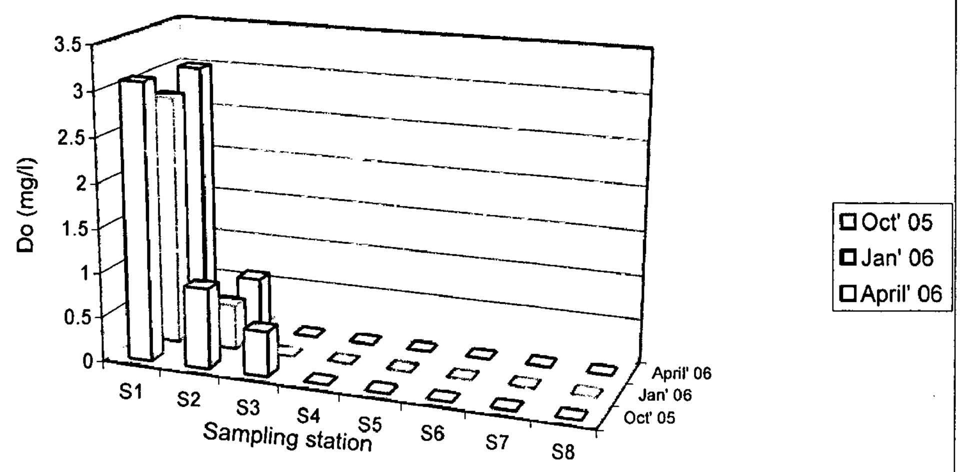

Fig. 5.3 Temporal and spatial variation of DO

The maximum DO has been observed on the u/s side (before the river enters the city), decreases gradually after it enters the city and reduces to zero at a distance of about 3.7 km d/s from reference point till it discharges its pollution load to river Brahmaputra. The phenomenon can be explained with the fact that combined wastewaters having zero DO are discharged by many drains into the river in this area. The temporal and spatial variation of DO is shown in Fig. 5.3. Generally, the DO value increases with the decrease in temperature. But due to the decrease in head flow of the river in the month of January, the DO observed in January is lower than DO observed in Apr and October.

5.2.4 Biochemical Oxygen Demand (BOD)

BOD approximates the amount of oxdisable organic matter in water. The BOD value is important in the wastewater treatment system for its stabilization process, design, loading calculation, useful in stream pollution control management and evaluating the self-purification capacities of the rivers. In the present study, the BOD values are found to be increasing gradually towards downstream part of the river. The BOD values were found within the range of 2.4 mg/l to 65.0 mg/. The temporal and spatial variation of BOD is shown in Fig. 5.4. Due to the shortening of monsoon in the year 2005, the sample collected in the month of Oct'05 were not representative of the post

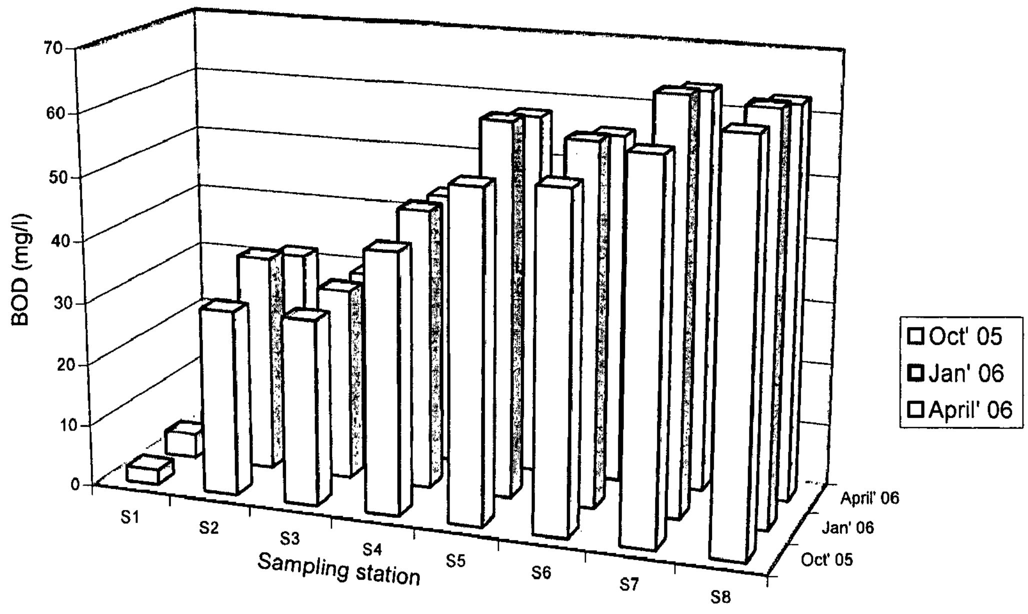

Fig.5.4 Temporal and spatial variation of BOD

monsoon scenario. Hence the difference of BOD of the sample collected in the month of October'05 and January'06 is negligible. Generally, the concentrations become highest in the month of January and February when the flow is lowest. The increase of BOD toward the d/s stretch can be explained by the fact that city wastewater having high BOD (range 30mg/l to 75mg/l) are discharged into the river. Average BOD values at all the sampling stations are higher than 3mg/l.

5.2.5 Chemical Oxygen Demand (COD)

Chemical oxygen demand is the oxygen required by the organic substances in water for chemical oxidation. For all practical purposes, its values are very close to the amount of chemically oxidisable carbonaceous matter, which may be quite useful in the control of treatment processes. COD values cannot correspond with BOD values (Trivedy and Goel, 1984). But Ogunrombi and Onuoha (1982) have shown that a strong correlation exists between BOD and COD of raw wastewater. COD value measures the total oxygen required for chemical oxidation of the organic matter in wastewater to carbon dioxide and water. Hence COD values are usually greater than BOD values especially when the wastewater contains a significant amount of biologically resistant organic matter. In this study, it is found that the COD values are higher than the BOD values at each sampling station. The COD values are within the range 6 mg/l to 132 mg/l. The temporal and spatial variation of COD is shown in Fig. 5.5. The COD values obtained in the month of January'06 are higher than the COD values obtained in the month of Oct'05 and Apr'06. During the period from June to Sept, COD values are expected to decrease rapidly due to the heavy rainfall in monsoon. It is observed that COD values increase gradually from upstream to the downstream of the river. The BOD to COD ratio for Oct'05 & Jan'06 ranges between 0.44 to 0.49. IS 2296-1974 does not specify any value for COD for primary contact, outdoor bathing, washing clothes etc. If an ideal BOD to COD ratio of 0.46 is assumed, the COD value should not exceed 3/(0.46) i.e. 6.5 mg/l. It is observed that COD values are more than 6.5 mg/l at all other sampling station except station 1 (Oct'05).

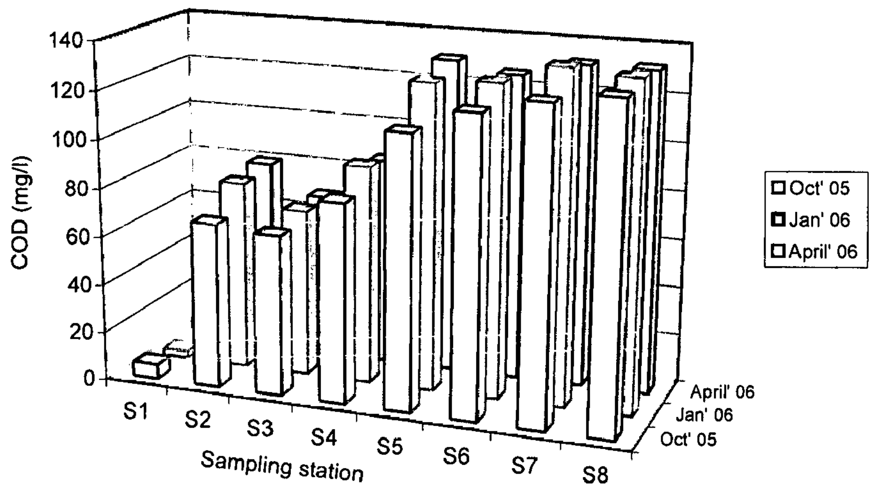

Fig.5.5 Temporal and spatial variation of COD

5.2.6 Turbidity

Turbid water interferes with recreational use and aesthetic enjoyment of water. Less turbid waters are more desirable for bathing, washing clothes, swimming and other uses. EEC has specified transparency value not less than 2m for primary contact sports. The temporal and spatial variation of turbidity is shown in Fig 5.6. The difference of turbidity at various sampling station is not very much. The values of turbidity during monsoon (June to September) are higher than the values in winter due to the fact that during rains, the flow is turbulent and having much suspended matter than the winter.

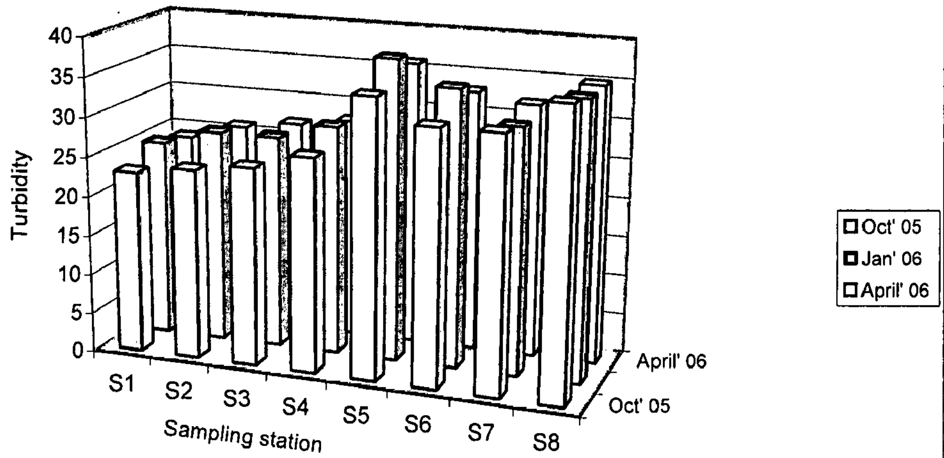

Fig. 5.6 Temporal and spatial variation of Tubidity

The maximum values of turbidity in Oct'05, Jan'06 and Apr'06 are 36 NTU, 38 NTU and 36 NTU respectively. The guide value set for drinking water by WHO is 5 NTU. CPCB has not specified any limit for primary contact sports as far as turbidity is concerned. Low turbidity means greater penetration of light resulting in better photosynthetic activity in river and leading to better water quality. Thus, river water is suitable for recreational purpose, bathing and washing clothes etc. as far as turbidity is concerned.

5.2.7 Solids

Fig. 5.7 and Fig. 5.8 show spatial and temporal variation of Total Solids (TS) and Total Suspended Solids (TSS). Range of total solids was found from 310 mg/l to 480 mg/l, which is well below the Indian drinking water standards, which permit 500 to 1000 mg/l of TS in public supplies. More suspended solids possess more turbidity. The floating and heavy solids try to deposit on banks & bottom. They enmesh themselves with certain essential biolife and made them to settle near it. Due to less photosynthesis and low DO, water in d/s stretches may have high BOD values. The odour problem and aesthetically bad conditions make the river water unsuitable for bathing, washing clothes and other uses.

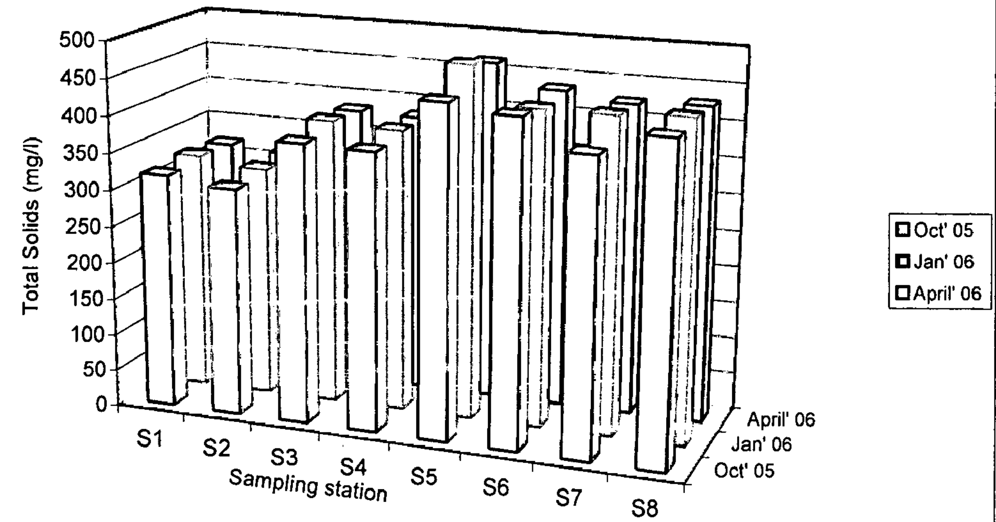

Fig. 5.7 Temporal and spatial variation of Total Solids

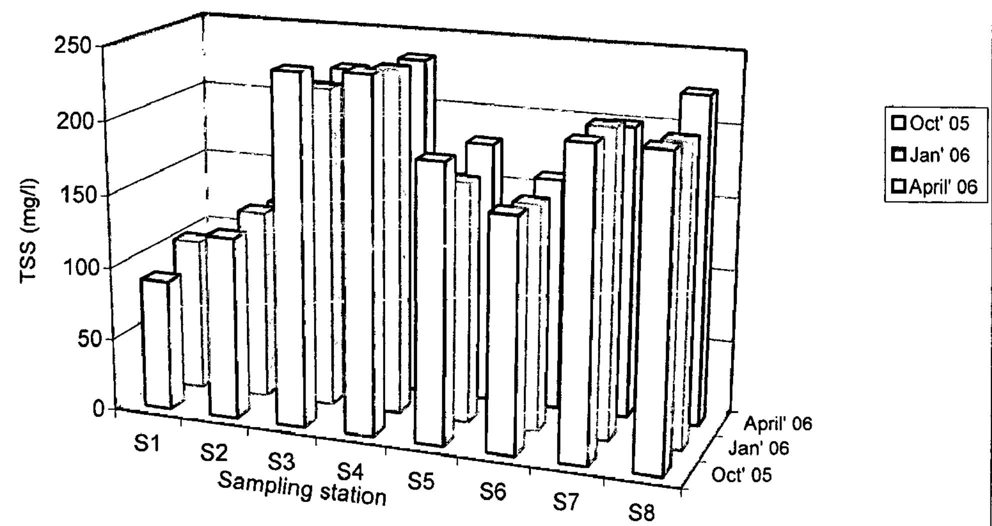

Fig. 5.8 Temporal and spatial variation of TSS

5.2.8 Nitrates (NO_3)

Nitrates are formed by the aerobic oxidation of NH4-N and other nitrogenous organic compounds. Temporal and spatial variation of nitrates is shown in Fig. 5.9. IS 2296 1974 has specified maximum nitrate value of 50 mg/l for bathing ghats. So the stretch under study is safe (less than 0.45 mg/l) as far as nitrate concentrations are concerned.

5.2.9 Specific Conductivity

Specific conductivity is an indirect measure of the total dissolved salts in water. The temporal and spatial variation of specific conductivity is shown in Fig.5.10. Conductivity is the reciprocal of the resistivity and is expressed in unit of ohm^{-1} or mhos. The conductivity of a water sample depends on their ions that are present and their concentrations.

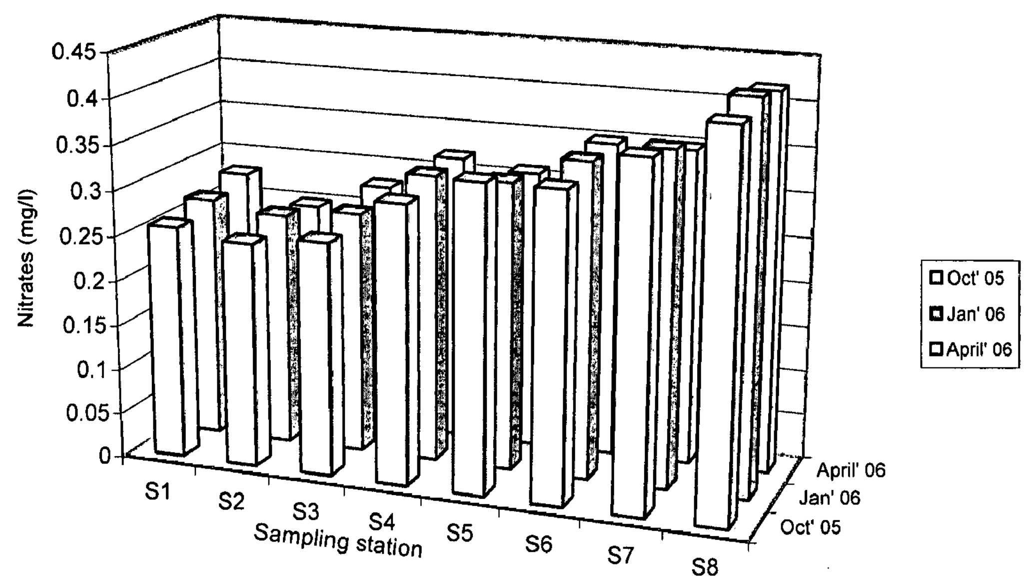

Fig. 5.9 Temporal and spatial variation of Nitrates

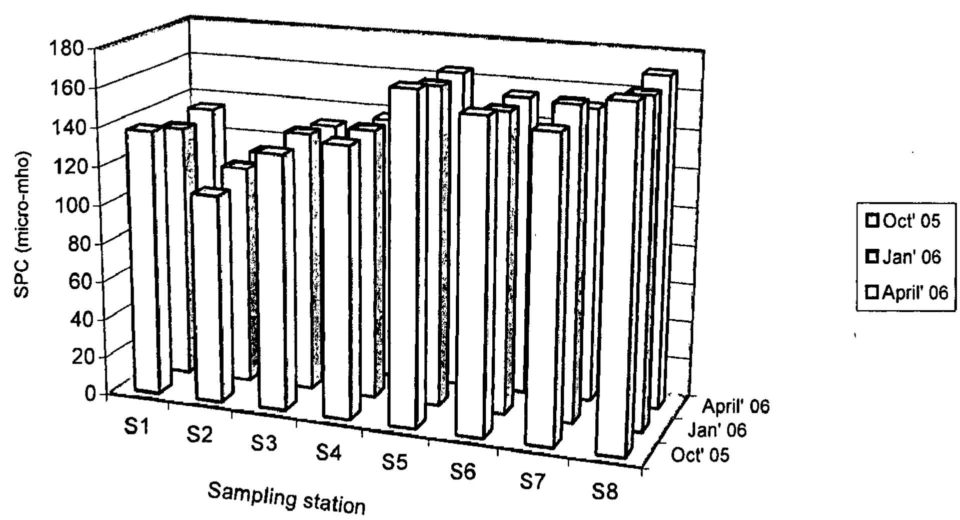

Fig. 5.10 Temporal and spatial variation of Specific Conductivity

5.2.10 Total Phosphate (PO_4)

Phosphates induce the growth of microscopic plant life in surface waters. Algae are basically second forms of pollution. They add DO to streams but contribute organic loading after they die. However, in the absence of phosphorous, practically algal life is not possible. The temporal and spatial variation of phosphate is shown in Fig. 5.11. The phosphate concentration ranges between 2.8 mg/l to 4.6 mg/l. Higher values of phosphate is found near the outfall of the river.

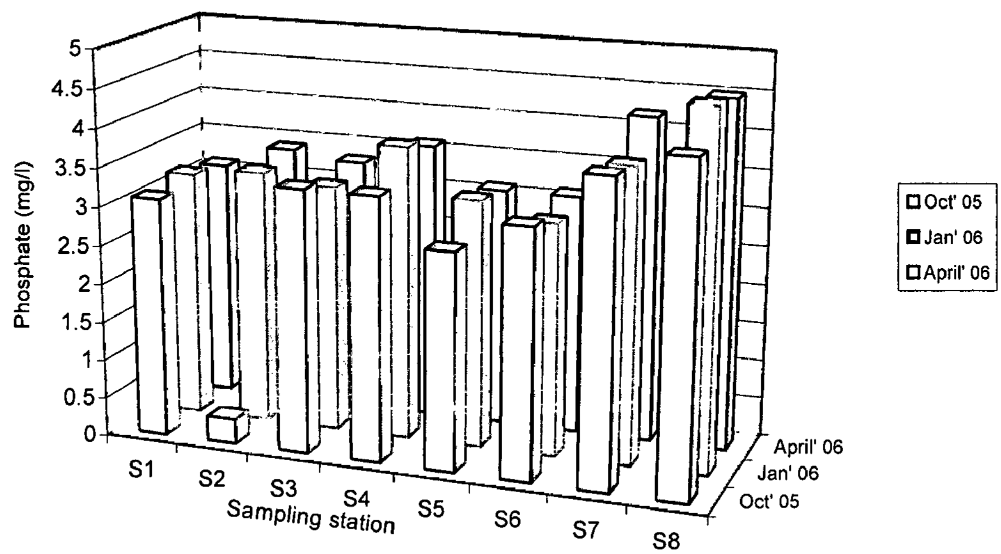

Fig. 5.11 Temporal and spatial variation of Phosphate

5.2.11 Total Coliform

The presence of coliform is an important indication of the degree of health risk associated with use of river water for different purposes. CPCB has prescribed maximum value for MPN of 500/100ml while IS 2296 – 1974 has specified a much higher value of 5000/100ml. The observed values of total coliform in all the eight sampling stations exceed 214000/100 ml, which indicate river water is grossly polluted and water is not suitable for bathing and other uses.

5.2.12 Faecal Coliform

The coliform group has a limitation that it has been known to multiply in water if environmental factors tend to promote and may give exaggerated index of pollution. Faecal coliform can be used for pollution assessment as these organisms occurr primarily in the faecal matter and are normally present in the intestinal tract of man and other warm blooded animals. In the present study, it has been observed that density of FC is more than 126000^+ per 100ml sample at all the eight sampling stations. The river is grossly polluted and is unsafe for bathing and primary contact recreational activities.

5.2.13 Heavy Metal

The water samples from various sampling stations were tested for heavy metals. The observed values are shown in Table 5.2. The permissible limit for various water quality parameters is given in Table 5.3. It is observed that, all the heavy metals are within the permissible limit.

Table 5.2 Observed values of heavy metal

Sampling Station	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8
Hg (ppb)	0.36	0.47	0.76	0.76	3.42	1.83	0.57	0.46
As (ppb)	0.03	0.03	0.03	0.02	0.02	0.01	0.02	0.02
Pb (ppb)	21.11	24.00	24.00	11.01	6.06	10.73	19.02	21.52
Ni (ppb)	8.77	9.63	9.63	5.54	10.05	5.98	14.23	6.19

Table 5.3 Permissible values of various water quality parameters for drinking water

Sl. No.	Parameter	CPHEEO*	BIS* 1983	BIS* 1991	WHO*
1.	Colour Pt/Co Scale	25	50	25	15
2.	Turbidity NTU	10	25	10	5
3.	Total Dissolved solids mg/L	2000	3000	2000	1000
4.	pH	6.5 – 9.2	6.5 – 9.2	6.5 – 8.5	6.5 – 8.5
5.	Alkalinity (as $CaCO_3$) mg/L	600	-	600	-
6.	Total Hardness (as $CaCO_3$) mg/L	600	600	600	500
7.	Calcium (as Ca) mg/L	200	200	200	-
8.	Magnesium (as Mg) mg/L	150	100	100	-
9.	Sodium (as Na) mg/L	-	-	-	200
10.	Iron (as Fe) mg/L	1.0	1.0	1.0	0.3
11.	Manganese (as Mn) mg/L	0.5	0.5	0.3	0.1
12.	Chloride (as Cl) mg/L	1000	1000	1000	250
13.	Fluoride (as F) mg/L	1.5	1.5	1.5	1.5
14.	Sulphate (as SO4) mg/L	400	400	400	400
15.	Nitrate (as NO3) mg/L	45	45	100	45
16.	Copper (as Cu) mg/L	1.5	1.5	1.5	1.0
17.	Cadmium (as Cd) mg/L	0.01	0.01	0.01	0.01
18.	Selenium (as Se) mg/L	0.01	0.01	0.01	0.01
19.	Mercurry (as Hg) mg/L	0.001	0.001	0.001	0.001
20.	Arsenic (as As) mg/L	0.05	0.1	0.05	0.05
21.	Lead (as Pb) mg/L	0.05	0.1	0.05	0.05
22.	Zinc (as Zn) mg/L	15	15	15	5
23.	Chromium (as Cr) mg/L	0.05	0.05	0.05	0.01
24.	Cyanide (as CN) mg/L	0.05	0.05	0.05	0.01
25.	Anionic Detergents (as MBAS) Cyanide (as CN) mg/L	1.0	1.0	1.0	-
26.	Phenolic compounds mg/L	0.002	0.002	0.002	-
27.	Mineral oil mg/L	0.03	0.03	0.03	-
28.	Pesticides mg/L	-	-	0.001	-
29.	Residual Free Chlorine mg/L	-	0.2	0.2	-
30.	Aluminium mg/L	0.2	-	0.2	0.2
31.	Boron mg/L	-	-	5	-
32.	Alpha emitters Bq/L	0.1	0.1	0.1	0.1
33.	Beta emitters Bq/L	1.0	1.0	1.0	1.0
34.	Faecal cliform Counts/mL	0	0	0	0
35.	Protozoa	-	Nil	Nil	Nil
36.	Helminths	-	Nil	Nil	Nil
37.	Free living organisms	-	Nil	Nil	Nil
38.	Nickel (mg/l)	3.0			

*CPHEEO – Central Public Health & Environmental Engineering Organization.

*BIS – Bureau of Indian Standards

*WHO – World Health Organization

5.3 POLLUTION LOAD CONTRIBUTED BY CITY

As there are no separate drains for industrial effluent and domestic sewage, it is very difficult to distinguish the amount of wastewater generated by industrial and domestic uses. Moreover some of the drains carry the fresh spring water coming from the hillside. At the same time, the data regarding population in the Bharalu basin particularly in Guwahati city is not available. Therefore, the combined wastewater of the city, being discharged into river Bharalu is taken as the discharge of the river near the confluence of Bharalu and Brahmaputra (during lean period), which is about 311.04 MLD. On the basis of this, pollution load is calculated. The pollution load of the city is shown in Table 5.4.

Table 5.4 Pollutional load in combined wastewater

Sl. No.	Month	Oct'05		Jan'06		Apr'06	
	Parameter	Value (mg/l)	Pollutional Load (Kg/day)	Value (mg/l)	Pollutional Load (Kg/day)	Value (mg/l)	Pollutional Load (Kg/day)
1.	TS	430	133,747.2	435	1,35,302.4	430	133,747.2
2.	TSS	210	65,318.4	205	63,763.2	225	69,984.0
3.	BOD	75	23,328.0	80	24,883.2	78	24261.1
4.	COD	160	49,766.4	168	52,254.72	166	51,632.6
5.	TP	4.2	1306.4	4.6	1,430.78	4.5	1,399.6
6.	NO_3	0.42	130.6	0.43	133.75	0.42	130.6

5.4 WATER QUALITY INDICES FOR RIVER BHARALU

There are various water quality indices available in the literature as already discussed in Chapter-2. In this study, NSF WQI has been used for assessment of the river water quality.

5.4.1 NSF WQI

NSF WQI is the most commonly employed and easy to use index. NSF WQIs have been calculated for Oct'05, Jan'06 and Apr'06 and are shown in Table 5.5, Table 5.6

and Table 5.7 respectively. Higher value of the index indicates better water quality. Under following limitations, index has been applied for the data obtained in the present study. Turbidity was measured in NTU, while Brown et al. has measured it in JTU. The variation of sub index function for turbidity has been adopted without any change for turbidity in NTU. Since for a sample same colloidal and suspended particles are reflected by JTU and NTU values, this assumption is not expected to alter NSF WQI appreciably. Secondly, feacal coliforms for all the samples were observed 126000^+. The sub index has been calculated assuming numerous counts. However, this will not alter NSF WQI much since the river is grossly polluted.

The spatial and temporal variation of NSF WQI has been shown in Fig. 5.12. It clearly indicates that river water quality degrades while its passage through the city. The index value decreases from station 1 towards d/s and attains lowest value at station 5. The values of WQI indicates, the river water quality as "Bad" in the descriptive words as discussed in Para 2.4.6.2 (Table 2.4). This WQI gives an idea of relative water quality levels existing at different monitoring stations.

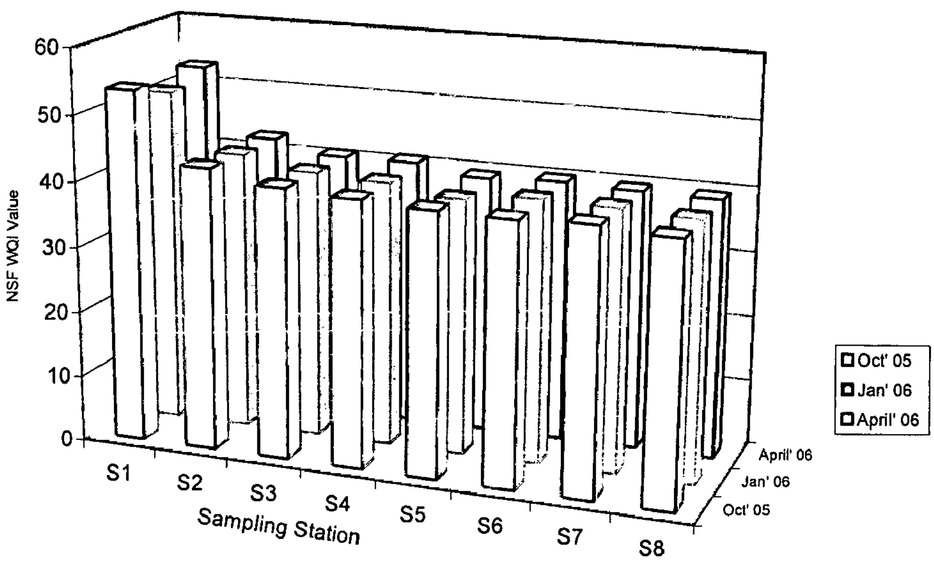

Fig.5.12 Temporal and spatial variation of NSF WQI for river Bharalu

Table 5.5 Calculation of NSF WQI for Oct'05 (River Bharalu)

Sampl. Stn.		S_1			S_2			S_3			S_4			S_5			S_6			S_7			S_8		
Parameter (Q)	Weight (W)	Value of (Q)	Sub Index (I_1)	I_1W	Value of (Q)	Sub Index (I_1)	I_1W	Value of (Q)	Sub Index (I_1)	I_1W	Value of (Q)	Sub Index (I_1)	I_1W	Value of (Q)	Sub Index (I_1)	I_1W	Value of (Q)	Sub Index (I_1)	I_1W	Value of (Q)	Sub Index (I_1)	I_1W	Value of (Q)	Sub Index (I_1)	I_1W
DO	0.17	38.31	28	4.76	11.2	8	1.36	6.27	5	0.85	0	2	0.34	0	2	0.34	0	2	0.34	0	2	0.34	0	2	0.34
FC	0.15	214000	2	0.3	133200	2	0.3	134000	2	0.3	134500	2	0.3	132000	2	0.3	133000	2	0.3	133000	2	0.3	134500	2	0.3
pH	0.12	7.2	92	11	7.3	93	11.2	7.8	90	10.8	7.4	93	11.2	7.3	93	11.2	7.2	93	11.2	7.5	93	11.2	7.4	93	11.2
BOD5	0.10	2.4	72	7.2	30	2	0.2	30	2	0.2	42	2	0.2	53	2	0.2	54	2	0.2	60	2	0.2	64	2	0.2
TN	0.10	0.26	97	9.7	0.25	97	9.7	0.26	97	9.7	0.31	97	9.7	0.34	97	9.7	0.34	97	9.7	0.38	97	9.7	0.42	97	9.7
TP	0.10	3.1	21	2.1	3.2	20	2	3.4	19	1.9	3.4	19	1.9	2.8	22	2.2	3.2	17	1.7	3.9	17	1.7	4.2	16	1.6
TEMP	0.10	0	93	9.3	0.4	91	9.1	0.8	90	9	1.4	87	8.7	0.4	91	9.1	0.5	91	9.1	0.6	91	9.1	0.8	90	9
TUR	0.08	23	59	4.72	24	58	4.64	25	57	4.56	27	55	4.4	35	49	3.92	32	51	4.08	32	51	4.08	36	48	3.84
TS	0.08	320	57	4.56	310	58	4.64	380	49	3.92	378	49	3.92	450	40	3.2	400	41	3.28	400	47	3.76	430	43	3.44
TOTAL	1.00			53.7			43.1			41.2			40.6			40.1			39.9			40.3			39.6

Table 5.6 Calculation of NSF WQI for Jan'06 (River Bharalu)

Sampling Stn.		S_1			S_2			S_3			S_4			S_5			S_6			S_7			S_8		
Parameter (Q)	Weight (W)	Value of (Q)	Sub Index (I_1)	I_1W	Value of (Q)	Sub Index (I_1)	I_1W	Value of (Q)	Sub Index (I_1)	I_1W	Value of (Q)	Sub Index (I_1)	I_1W	Value of (Q)	Sub Index (I_1)	I_1W	Value of (Q)	Sub Index (I_1)	I_1W	Value of (Q)	Sub Index (I_1)	I_1W	Value of (Q)	Sub Index (I_1)	I_1W
DO	0.17	33.35	21	3.57	5.97	5	0.85	0	2	0.34	0	2	0.34	0	2	0.34	0	2	0.34	0	2	0.34	0	2	0.34
FC	0.15	126500	2	0.3	132600	2	0.3	134800	2	0.3	134900	2	0.3	132600	2	0.3	133500	2	0.3	132500	2	0.3	134800	2	0.3
pH	0.12	7.3	93	11.2	7.3	93	11.2	7.6	92	11	7.2	92	11	7.2	92	11	7.3	93	11.2	7.6	92	11	7.5	93	11.2
BOD5	0.10	4	61	6.1	35	2	0.2	31	2	0.2	45	2	0.2	60	2	0.2	58	2	0.2	66	2	0.2	65	2	0.2
TN	0.10	0.27	97	9.7	0.26	97	9.7	0.27	97	9.7	0.32	97	9.7	0.32	97	9.7	0.35	97	9.7	0.37	97	9.7	0.43	97	9.7
TP	0.10	3.2	20	2	3.3	20	2	3.2	20	2	3.8	18	1.8	3.2	20	2	3	21	2.1	3.8	18	1.8	4.6	15	1.5
TEMP	0.10	0	93	9.3	0.1	93	9.3	0.5	91	9.1	0.9	89	8.9	1	89	8.9	0.9	89	8.9	1	89	8.9	1	89	8.9
TUR	0.08	25	57	4.56	27	55	4.4	27	55	4.4	29	54	4.32	38	47	3.76	35	49	3.92	31	52	4.16	35	49	3.92
TS	0.08	325	56	4.48	315	58	4.64	390	48	3.84	385	48	3.84	480	35	2.8	430	43	3.44	430	43	3.44	435	42	3.36
TOTAL	1.00			51.2			42.6			40.9			40.4			39			40.1			39.9			39.4

Table 5.7 Calculation of NSF WQI for Apr'06 (River Bharalu)

Sampling Stn.		S_5			S_5			S_5			S_5			S_5			S_6			S_7			S_8		
Parameter (Q)	Weight (W)	Value of (Q)	Sub Index (I_1)	I_1W	Value of (Q)	Sub Index (I_1)	I_1W	Value of (Q)	Sub Index (I_1)	I_1W	Value of (Q)	Sub Index (I_1)	I_1W	Value of (Q)	Sub Index (I_1)	I_1W	Value of (Q)	Sub Index (I_1)	I_1W	Value of (Q)	Sub Index (I_1)	I_1W	Value of (Q)	Sub Index (I_1)	I_1W
DO	0.17	36.61	26	4.42	7.35	6	1.02	0	2	0.34	0	2	0.34	0	2	0.34	0	2	0.34	0	2	0.34	0	2	0.34
FC	0.15	126300	2	0.3	132400	2	0.3	134200	2	0.3	134700	2	0.3	132100	2	0.3	133600	2	0.3	132600	2	0.3	134200	2	0.3
pH	0.12	7.4	93	11.2	7.4	93	11.2	7.8	90	10.8	7.5	93	11.2	7.2	92	11	7.1	90	10.8	7.4	93	11.2	7.3	93	11.2
BOD5	0.10	2.9	68	6.8	32	2	0.2	30	2	0.2	44	2	0.2	58	2	0.2	56	2	0.2	64	2	0.2	63	2	0.2
TN	0.10	0.28	97	9.7	0.25	97	9.7	0.28	97	9.7	0.32	97	9.7	0.31	97	9.7	0.35	97	9.7	0.35	97	9.7	0.42	97	9.7
TP	0.10	3.1	21	2.1	3.4	19	1.9	3.3	20	2	3.6	19	1.9	3.1	21	2.1	3.1	21	2.1	4.2	16	1.6	4.5	15	1.5
TEMP	0.10	0	93	9.3	0.2	92	9.2	0.5	91	9.1	0.7	90	9	0.8	90	9	0.5	91	9.1	0.9	89	8.9	0.9	89	8.9
TUR	0.08	24	58	4.64	26	56	4.48	27	55	4.4	28	55	4.4	36	48	3.84	33	51	4.08	32	51	4.08	35	49	3.92
TS	0.08	320	57	4.56	315	58	4.64	384	49	3.92	382	49	3.92	465	37	2.96	435	42	3.36	425	43	3.44	430	43	3.44
TOTAL	1.00			53			42.6			40.8			40.9			39.5			40			39.7			39.5

5.5 DEVELOPMENT OF BOD AND DO MODEL FOR RIVER BHARALU

The observed values of water quality parameters at various locations of drain and river are given in Table 5.8. By using various hydrodynamic parameters of the river, the values of k_a, k_d, k_r and C_s have been calculated for respective reach of the river. These values along with the values of DO and BOD of drains have been used for calculating BOD and DO profile of the respective reach by using Streeter and Phelps model.

5.5.1 Model Validation

The hydrological data of the river, i.e. flow, depth, velocity, temperature etc. and water quality data of drain water (i.e. DO and BOD) were fed into the model. The predicted BOD and DO values along with the observed values have been compared along the stretch at eight sampling stations, which are shown in Table 5.9. At station 4, the observed value of BOD is about 8.8% higher than the predicted value after about 5.85 km d/s from reference point, while at station 2 and 3, the observed values of BOD are about 8% higher than the predicted values after about 2.03 km and 3.7 km d/s from the reference point. On the other hand, the observed values of BOD and DO match well with the predicted value throughout the reach.

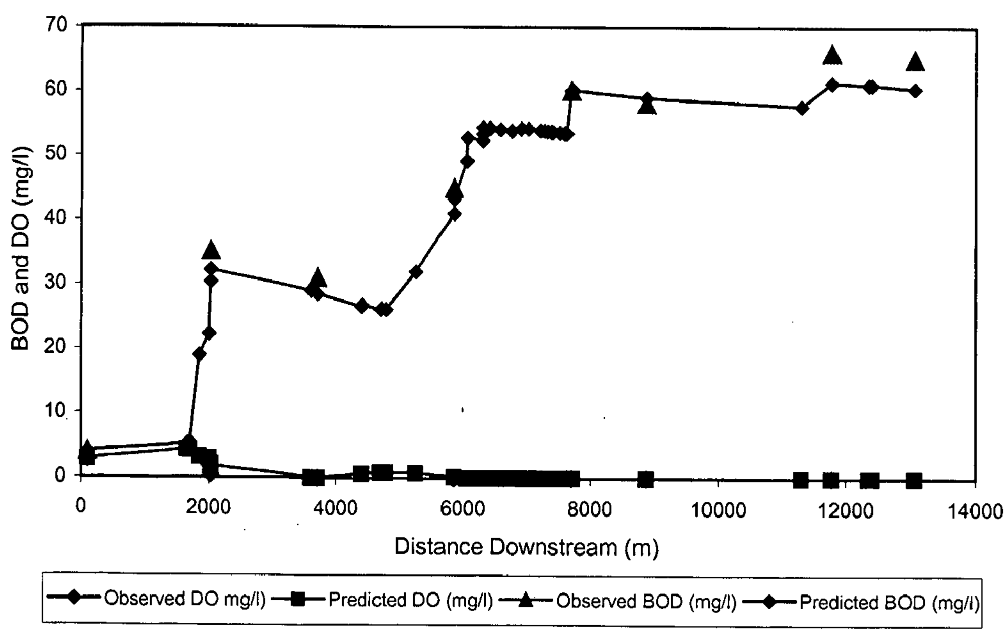

Fig.5.13 Validation curve for DO and BOD

Table 5.8 Observed values of quality parameters for drains and River

Drain data					River data			
Drain No.	Dist. of drains from POR (M)	DO (mg/l)	BOD (mg/l)	Flow of drain (M^3/sec)	Flow depth (m)	Width at top (m)	Velocity (m/s)	Temp (^{0}C)
1	100	2.80	4	0.1080	0.70	3.08	0.05	24.30
2	1650	0.00	48	0.0050	0.80	3.53	0.04	24.30
3	1700	0.00	50	0.0008	0.49	2.90	0.08	24.30
4	1850	0.00	53	0.0450	0.61	3.25	0.08	24.30
5	2000	0.00	54	0.0180	0.75	2.95	0.08	24.40
6	2030	0.00	50	0.0730	0.83	3.76	0.08	24.40
7	2030	0.00	55	0.0200	1.20	3.76	0.06	24.40
8	3600	0.00	57	0.0010	0.77	7.00	0.05	24.80
9	3700	0.00	50	0.0015	0.47	7.20	0.08	24.90
10	4400	0.00	57	0.0025	0.46	7.50	0.08	25.10
11	4410	0.00	60	0.0025	0.46	7.50	0.08	25.10
12	4700	0.00	40	0.0030	0.50	8.00	0.07	25.20
13	4710	0.00	50	0.0020	0.50	8.00	0.07	25.20
14	4780	0.00	51	0.0010	0.51	8.00	0.07	25.20
15	5250	0.00	60	0.0750	0.60	9.00	0.07	25.20
16	5850	0.00	69	0.1440	0.59	9.00	0.09	25.20
17	5850	0.00	56	0.0900	0.66	9.00	0.10	25.20
18	6050	0.00	65	0.2400	0.71	9.00	0.13	25.20
19	6060	0.00	65	0.2400	0.85	9.00	0.14	25.20
20	6060	0.00	69	0.0015	0.85	9.00	0.14	25.20
21	6300	0.00	54	0.0030	0.80	9.00	0.15	25.20
22	6300	0.00	67	0.0750	0.85	9.00	0.15	25.20
23	6308	0.00	61	0.0030	0.86	9.00	0.15	25.20
24	6308	0.00	70	0.0750	0.91	9.00	0.15	25.20
25	6410	0.00	60	0.0075	0.81	9.00	0.17	25.20
26	6416	0.00	61	0.0075	0.81	9.00	0.17	25.20

Contd...

Contd. **Table 5.8**

27	6580	0.00	59	0.0005	0.81	9.00	0.17	25.20
28	6750	0.00	57	0.0013	0.77	9.00	0.18	25.20
29	6756	0.00	60	0.0025	0.73	9.00	0.19	25.20
30	6902	0.00	64	0.0600	0.73	9.00	0.20	25.20
31	6908	0.00	57	0.0600	0.77	9.00	0.20	25.20
32	7018	0.00	53	0.0010	0.77	9.00	0.20	25.20
33	7208	0.00	58	0.0050	0.77	9.00	0.20	25.20
34	7274	0.00	52	0.0030	0.77	9.00	0.20	25.20
35	7322	0.00	62	0.0001	0.77	9.00	0.20	25.20
36	7382	0.00	60	0.0024	0.77	9.00	0.20	25.20
37	7388	0.00	58	0.0024	0.77	9.00	0.20	25.20
38	7412	0.00	49	0.0018	0.77	9.00	0.20	25.30
39	7510	0.00	51	0.0001	0.77	9.00	0.20	25.30
40	7516	0.00	59	0.0002	0.77	9.00	0.20	25.30
41	7590	0.00	55	0.0015	0.77	9.00	0.20	25.30
42	7596	0.00	54	0.0012	0.77	9.00	0.20	25.30
43	7620	0.00	64	0.0013	0.77	9.00	0.20	25.30
44	7626	0.00	63	0.0015	0.63	11.00	0.20	25.30
45	7700	0.00	72	0.7920	0.81	11.61	0.23	25.30
46	7720	0.00	65	0.0150	0.79	12.00	0.23	25.30
47	7720	0.00	75	0.0039	0.80	12.00	0.23	25.30
48	8870	0.00	60	0.2700	0.81	12.77	0.24	25.10
49	11300	0.00	70	0.2268	0.81	15.72	0.21	25.20
50	11775	0.00	75	0.8100	0.91	16.00	0.24	25.30
51	12350	0.00	70	0.0800	0.93	16.00	0.24	25.30
52	12400	0.00	68	0.0036	0.94	16.00	0.24	25.30
53	13050	0.00	60	0.0072	0.94	16.00	0.24	25.30

Table 5.9 Predicted versus observed values of DO and BOD at eight sampling stations.

Sl. No.	Dist. d/s from ref. point(m)	Sampling station	Observed Values of DO	Predicted value of DO	Observed values of BOD	Predicted value of BOD
1	100	S1	2.8	2.80	4	4.00
2	1650			4.28		5.18
3	1700			4.27		5.45
4	1850			3.20		18.86
5	2000			2.86		22.20
6	2030			2.01		30.28
7	2030	S2	0.5	1.86	35	32.11
8	3600			0.00		28.96
9	3700	S3	0	0.00	31	28.43
10	4400			0.60		26.59
11	4410			0.60		26.86
12	4700			0.83		26.14
13	4710			0.83		26.28
14	4780			0.84		26.14
15	5250			0.77		32.05
16	5850	S4	0	0.16	45	41.04
17	5850			0.14		43.31
18	6050			0.00		49.24
19	6060			0.00		52.76
20	6060			0.00		52.78
21	6300			0.00		52.44
22	6300			0.00		53.38
23	6308			0.00		53.39
24	6308			0.00		54.41
25	6410			0.00		54.30
26	6416			0.00		54.33
27	6580			0.00		54.13

Contd...

...Contd. Table 5.9

Sl. No.	Dist. d/s from ref. point(m)	Sampling station	Observed Values of DO	Predicted value of DO	Observed values of BOD	Predicted value of BOD
28	6750			0.00		53.90
29	6756			0.00		53.90
30	6902			0.00		54.17
31	6908			0.00		54.28
32	7018			0.00		54.15
33	7208			0.00		53.92
34	7274			0.00		53.84
35	7322			0.00		53.78
36	7382			0.00		53.71
37	7388			0.00		53.71
38	7412			0.00		53.68
39	7510			0.00		53.56
40	7516			0.00		53.55
41	7590			0.00		53.46
42	7596			0.00		53.45
43	7620			0.00		53.43
44	7626			0.00		53.43
45	7700	S5	0	0.00	60	60.11
46	7720			0.00		60.12
47	7720			0.00		60.15
48	8870	S6	0	0.00	58	59.00
40	11300			0.00		57.70
50	11775	S7	0	0.00	66	61.34
51	12350			0.00		61.05
52	12400			0.00		61.02
53	13050	S8		0.00	65	60.47

Table 5.10 Observed values of parameters used in modeling for zero head flow

Drain No.	Dist. d/s from ref. point (m)	BOD (mg/l) of the drain water	Flow of the drain, Q_i (m^3/sec)	Flow of river after mixing (m^3/sec)	BOD of river water after mixing (mg/l)	BOD just before the point of discharge	Velocity of flow of river (m/s)	Average water depth (m)	Width of flow (m)	Temperature (^{0}C)	k_2	k_1	$(k_1)_T$	k_r	Cs (mg/l)	DO of drain water	DO of river water after mixing	DO just before the point of discharge
1	100	4	0.1080	0.11	4.00		0.05	0.70	3.08	24.30	1.50	0.51	0.63	0.63	8.39	2.80	2.80	
2	1650	48	0.0050	0.11	5.18	3.19	0.04	0.80	3.53	24.30	1.10	0.49	0.59	0.59	8.39	0.00	4.28	4.48
3	1700	50	0.0008	0.11	5.45	5.13	0.08	0.49	2.90	24.30	3.24	0.60	0.73	0.73	8.39	0.00	4.27	4.30
4	1850	53	0.0450	0.16	18.86	5.36	0.08	0.61	3.25	24.30	2.33	0.55	0.67	0.67	8.39	0.00	3.20	4.46
5	2000	54	0.0180	0.18	22.20	18.59	0.08	0.75	2.95	24.40	1.71	0.50	0.61	0.61	8.38	0.00	2.86	3.18
6	2030	50	0.0730	0.25	30.28	22.14	0.08	0.83	3.76	24.40	1.47	0.48	0.59	0.59	8.38	0.00	2.01	2.84
7	2030	55	0.0200	0.27	32.11	30.28	0.06	1.20	3.76	24.40	0.74	0.41	0.50	0.50	8.38	0.00	1.86	2.01
8	3600	57	0.0010	0.27	28.96	28.86	0.05	0.77	7.00	24.80	1.29	0.49	0.62	0.62	8.32	0.00	0.00	0.00
9	3700	50	0.0015	0.27	28.43	28.31	0.08	0.47	7.20	24.90	3.42	0.61	0.77	0.77	8.30	0.00	0.00	0.00
10	4400	57	0.0025	0.27	26.59	26.31	0.08	0.46	7.50	25.10	3.59	0.62	0.78	0.78	8.27	0.00	0.60	0.60
11	4410	60	0.0025	0.28	26.86	26.55	0.08	0.46	7.50	25.10	3.54	0.62	0.78	0.78	8.27	0.00	0.60	0.61
12	4700	40	0.0030	0.28	26.14	25.99	0.07	0.50	8.00	25.20	2.94	0.60	0.76	0.76	8.26	0.00	0.83	0.84
13	4710	50	0.0020	0.28	26.28	26.11	0.07	0.50	8.00	25.20	2.91	0.59	0.75	0.75	8.26	0.00	0.83	0.83
14	4780	51	0.0010	0.28	26.14	26.05	0.07	0.51	8.00	25.20	2.89	0.59	0.75	0.75	8.26	0.00	0.84	0.84
15	5250	60	0.0750	0.36	32.05	24.65	0.07	0.60	9.00	25.20	2.21	0.55	0.70	0.70	8.26	0.00	0.77	0.97
16	5850	69	0.1440	0.50	41.04	29.80	0.09	0.59	9.00	25.20	2.63	0.55	0.70	0.70	8.26	0.00	0.16	0.23
17	5850	56	0.0900	0.59	43.31	41.04	0.10	0.66	9.00	25.20	2.33	0.53	0.67	0.67	8.26	0.00	0.14	0.16
18	6050	65	0.2400	0.83	49.24	42.86	0.13	0.71	9.00	25.20	2.36	0.51	0.65	0.65	8.26	0.00	0.00	0.00
19	6060	65	0.2400	1.07	52.76	49.23	0.14	0.85	9.00	25.20	1.87	0.47	0.60	0.60	8.26	0.00	0.00	0.00
20	6060	69	0.0015	1.07	52.78	52.76	0.14	0.85	9.00	25.20	1.87	0.47	0.60	0.60	8.26	0.00	0.00	0.00
21	6300	54	0.0030	1.08	52.44	52.43	0.15	0.80	9.00	25.20	2.14	0.49	0.62	0.62	8.26	0.00	0.00	0.00
22	6300	67	0.0750	1.15	53.38	52.44	0.15	0.85	9.00	25.20	1.93	0.47	0.60	0.60	8.26	0.00	0.00	0.00
23	6308	61	0.0030	1.15	53.39	53.37	0.15	0.86	9.00	25.20	1.92	0.47	0.60	0.60	8.26	0.00	0.00	0.00

Contd...

…Contd. **Table 5.10**

24	6308	70	0.0750	1.23	54.41	53.39	0.15	0.91	9.00	25.20	1.75	0.46	0.58	0.58	8.26	0.00	0.00	0.00
25	6410	60	0.0075	1.24	54.30	54.26	0.17	0.81	9.00	25.20	2.23	0.48	0.61	0.61	8.26	0.00	0.00	0.00
26	6416	61	0.0075	1.24	54.33	54.29	0.17	0.81	9.00	25.20	2.21	0.48	0.61	0.61	8.26	0.00	0.00	0.00
27	6580	59	0.0005	1.25	54.13	54.13	0.17	0.81	9.00	25.20	2.21	0.48	0.61	0.61	8.26	0.00	0.00	0.00
28	6750	57	0.0013	1.25	53.90	53.89	0.18	0.77	9.00	25.20	2.47	0.49	0.63	0.63	8.26	0.00	0.00	0.00
29	6756	60	0.0025	1.25	53.90	53.89	0.19	0.73	9.00	25.20	2.74	0.51	0.64	0.64	8.26	0.00	0.00	0.00
30	6902	64	0.0600	1.31	54.17	53.70	0.20	0.73	9.00	25.20	2.78	0.50	0.64	0.64	8.26	0.00	0.00	0.00
31	6908	57	0.0600	1.37	54.28	54.16	0.20	0.77	9.00	25.20	2.60	0.49	0.63	0.63	8.26	0.00	0.00	0.00
32	7018	53	0.0010	1.37	54.15	54.15	0.20	0.77	9.00	25.20	2.59	0.49	0.63	0.63	8.26	0.00	0.00	0.00
33	7208	58	0.0050	1.38	53.92	53.91	0.20	0.77	9.00	25.20	2.58	0.49	0.63	0.63	8.26	0.00	0.00	0.00
34	7274	52	0.0030	1.38	53.84	53.84	0.20	0.77	9.00	25.20	2.57	0.49	0.63	0.63	8.26	0.00	0.00	0.00
35	7322	62	0.0001	1.38	53.78	53.78	0.20	0.77	9.00	25.20	2.57	0.49	0.63	0.63	8.26	0.00	0.00	0.00
36	7382	60	0.0024	1.38	53.71	53.70	0.20	0.77	9.00	25.20	2.62	0.50	0.63	0.63	8.26	0.00	0.00	0.00
37	7388	58	0.0024	1.38	53.71	53.71	0.20	0.77	9.00	25.20	2.61	0.49	0.63	0.63	8.26	0.00	0.00	0.00
38	7412	49	0.0018	1.38	53.68	53.68	0.20	0.77	9.00	25.30	2.60	0.49	0.63	0.63	8.24	0.00	0.00	0.00
39	7510	51	0.0001	1.38	53.56	53.56	0.20	0.77	9.00	25.30	2.60	0.49	0.63	0.63	8.24	0.00	0.00	0.00
40	7516	59	0.0002	1.39	53.55	53.55	0.20	0.77	9.00	25.30	2.60	0.49	0.63	0.63	8.24	0.00	0.00	0.00
41	7590	55	0.0015	1.39	53.46	53.46	0.20	0.77	9.00	25.30	2.60	0.49	0.63	0.63	8.24	0.00	0.00	0.00
42	7596	54	0.0012	1.39	53.45	53.45	0.20	0.77	9.00	25.30	2.60	0.49	0.63	0.63	8.24	0.00	0.00	0.00
43	7620	64	0.0013	1.39	53.43	53.42	0.20	0.77	9.00	25.30	2.59	0.49	0.63	0.63	8.24	0.00	0.00	0.00
44	7626	63	0.0015	1.39	53.43	53.42	0.20	0.63	11.00	25.30	3.50	0.54	0.69	0.69	8.24	0.00	0.00	0.00
45	7700	72	0.7920	2.18	60.11	53.34	0.23	0.81	11.61	25.30	2.62	0.48	0.62	0.62	8.24	0.00	0.00	0.00
46	7720	65	0.0150	2.20	60.12	60.09	0.23	0.79	12.00	25.30	2.72	0.49	0.63	0.63	8.24	0.00	0.00	0.00
47	7720	75	0.0039	2.20	60.15	60.12	0.23	0.80	12.00	25.30	2.65	0.49	0.62	0.62	8.24	0.00	0.00	0.00
48	8870	60	0.2700	2.47	59.00	58.88	0.24	0.81	12.77	25.10	2.66	0.48	0.61	0.61	8.27	0.00	0.00	0.00
49	11300	70	0.2268	2.70	57.70	56.57	0.21	0.81	15.72	25.20	2.51	0.48	0.62	0.62	8.26	0.00	0.00	0.00
50	11775	75	0.8100	3.51	61.34	57.23	0.24	0.91	16.00	25.30	2.20	0.46	0.59	0.59	8.24	0.00	0.00	0.00
51	12350	70	0.0800	3.59	61.05	60.85	0.24	0.93	16.00	25.30	2.13	0.45	0.58	0.58	8.24	0.00	0.00	0.00
52	12400	68	0.0036	3.59	61.02	61.01	0.24	0.94	16.00	25.30	2.13	0.45	0.58	0.58	8.24	0.00	0.00	0.00
53	13050	60	0.0072	3.60	60.47	60.47	0.24	0.94	16.00	25.30	2.12	0.45	0.58	0.58	8.24	0.00	0.00	0.00

The model has been validated for the river water quality for premonsoon (Nov-Apr) season. Typical results validating the model are shown in Fig.5.13. The observed values of parameter related with BOD and DO modeling for zero head flow condition (i.e. the present condition) are given in Table 5.10.

5.5.2 Simulations

The model was simulated with different upstream conditions to assess the changes of DO and BOD of the downstream water of the river. The following alternative solutions were considered to improve the water quality of the water body for class "B or C" as per DBU.

5.5.2.1 *Zero discharge from Industries*

In this case it is assumed that no effluent is discharged from industries. There are three major industries in the eastern part of Guwahati (Noonmati area). The quantity and quality of wastewater generated by these industries are given in Table 5.11. The wastewater generated from these industries is carried by drain no.45 and joins river Bharalu at 7700m downstream from reference point. Other medium and small-scale industries are scattered in the city.

Table 5.11 Showing the values of discharge, DO and BOD of effluent

Sr. No.	Name of Industry	Discharge (m^3/s)	DO (mg/l)	BOD (mg/l)
1.	IOC Refinery, Noonmati	0.01940	0	20
2.	India Carbon Ltd, Noonmati	0.00278	1.0	15
3.	Railway workshop, Bamunimaidam	0.00231	0.9	16
Total discharge = 0.02449 m^3/s				
Average DO = 0.198 mg/l				
Average BOD = 19.055 mg/l				

If the effluent discharge from the industries are reduced to 0, then applying mass balance of DO and BOD

Table 5.12 Observed values of DO and BOD before and after simulation for zero discharge

Sl. No.	Dist. d/s from ref. point(m)	DO before zero discharge	DO after zero discharge	BOD before zero discharge	BOD after zero discharge
1	100	2.80	2.80	4.00	4.00
2	1650	4.28	4.28	5.18	5.18
3	1700	4.27	4.27	5.45	5.45
4	1850	3.20	3.20	18.86	18.86
5	2000	2.86	2.86	22.20	22.20
6	2030	2.01	2.01	30.28	30.28
7	2030	1.86	1.86	32.11	32.11
8	3600	0.00	0.00	28.96	28.96
9	3700	0.00	0.00	28.43	28.43
10	4400	0.60	0.60	26.59	26.59
11	4410	0.60	0.60	26.86	26.86
12	4700	0.83	0.83	26.14	26.14
13	4710	0.83	0.83	26.28	26.28
14	4780	0.84	0.84	26.14	26.14
15	5250	0.77	0.77	32.05	32.05
16	5850	0.16	0.16	41.04	41.04
17	5850	0.14	0.14	43.31	43.31
18	6050	0.00	0.00	49.24	49.24
19	6060	0.00	0.00	52.76	52.76
20	6060	0.00	0.00	52.78	52.78
21	6300	0.00	0.00	52.44	52.44
22	6300	0.00	0.00	53.38	53.38
23	6308	0.00	0.00	53.39	53.39
24	6308	0.00	0.00	54.41	54.41
25	6410	0.00	0.00	54.30	54.30
26	6416	0.00	0.00	54.33	54.33
27	6580	0.00	0.00	54.13	54.13

Contd…

….Contd. Table 5.12

Sl. No.	Dist. d/s from ref. point(m)	DO before zero discharge	DO after zero discharge	BOD before zero discharge	BOD after zero discharge
28	6750	0.00	0.00	53.90	53.90
29	6756	0.00	0.00	53.90	53.90
30	6902	0.00	0.00	54.17	54.17
31	6908	0.00	0.00	54.28	54.28
32	7018	0.00	0.00	54.15	54.15
33	7208	0.00	0.00	53.92	53.92
34	7274	0.00	0.00	53.84	53.84
35	7322	0.00	0.00	53.78	53.78
36	7382	0.00	0.00	53.71	53.71
37	7388	0.00	0.00	53.71	53.71
38	7412	0.00	0.00	53.68	53.68
39	7510	0.00	0.00	53.56	53.56
40	7516	0.00	0.00	53.55	53.55
41	7590	0.00	0.00	53.46	53.46
42	7596	0.00	0.00	53.45	53.45
43	7620	0.00	0.00	53.43	53.43
44	7626	0.00	0.00	53.43	53.43
45	7700	0.00	0.00	60.11	60.58
46	7720	0.00	0.00	60.12	60.59
47	7720	0.00	0.00	60.15	60.61
48	8870	0.00	0.00	59.00	59.39
40	11300	0.00	0.00	57.70	58.04
50	11775	0.00	0.00	61.34	61.62
51	12350	0.00	0.00	61.05	61.33
52	12400	0.00	0.00	61.02	61.29
53	13050	0.00	0.00	60.47	60.74

Table 5.13 Observed values of parameters of the model after simulation of zero discharge from industries with 0 m^3 head flow

Drain No.	Dist. D/s from ref. point(m)	BOD (mg/l) of the drain water	Fflow of the drain, Q_i (m^3/sec)	Flow of river after mixing(m^3/sec)	BOD of river water after mixing (mg/l)	BOD just before the point of discharge	Velocity of flow of river (m/s)	Average water depth (m)	Width of flow (m)	Temperature (^{0}C)	k_2	k_1	$(k_1)_T$	k_r	Cs(mg/l)	DO of drain water	DO of river water after mixing	DO just before the point of discharge
1	100	4	0.1080	0.11	4.00		0.05	0.70	3.08	24.30	1.50	0.51	0.63	0.63	8.39	2.80	2.80	
2	1650	48	0.0050	0.11	5.18	3.19	0.04	0.80	3.53	24.30	1.10	0.49	0.59	0.59	8.39	0.00	4.28	4.48
3	1700	50	0.0008	0.11	5.45	5.13	0.08	0.49	2.90	24.30	3.24	0.60	0.73	0.73	8.39	0.00	4.27	4.30
4	1850	53	0.0450	0.16	18.86	5.36	0.08	0.61	3.25	24.30	2.33	0.55	0.67	0.67	8.39	0.00	3.20	4.46
5	2000	54	0.0180	0.18	22.20	18.59	0.08	0.75	2.95	24.40	1.71	0.50	0.61	0.61	8.38	0.00	2.86	3.18
6	2030	50	0.0730	0.25	30.28	22.14	0.08	0.83	3.76	24.40	1.47	0.48	0.59	0.59	8.38	0.00	2.01	2.84
7	2030	55	0.0200	0.27	32.11	30.28	0.06	1.20	3.76	24.40	0.74	0.41	0.50	0.50	8.38	0.00	1.86	2.01
8	3600	57	0.0010	0.27	28.96	28.86	0.05	0.77	7.00	24.80	1.29	0.49	0.62	0.62	8.32	0.00	0.00	0.00
9	3700	50	0.0015	0.27	28.43	28.31	0.08	0.47	7.20	24.90	3.42	0.61	0.77	0.77	8.30	0.00	0.00	0.00
10	4400	57	0.0025	0.27	26.59	26.31	0.08	0.46	7.50	25.10	3.59	0.62	0.78	0.78	8.27	0.00	0.60	0.60
11	4410	60	0.0025	0.28	26.86	26.55	0.08	0.46	7.50	25.10	3.54	0.62	0.78	0.78	8.27	0.00	0.60	0.61
12	4700	40	0.0030	0.28	26.14	25.99	0.07	0.50	8.00	25.20	2.94	0.60	0.76	0.76	8.26	0.00	0.83	0.84
13	4710	50	0.0020	0.28	26.28	26.11	0.07	0.50	8.00	25.20	2.91	0.59	0.75	0.75	8.26	0.00	0.83	0.83
14	4780	51	0.0010	0.28	26.14	26.05	0.07	0.51	8.00	25.20	2.89	0.59	0.75	0.75	8.26	0.00	0.84	0.84
15	5250	60	0.0750	0.36	32.05	24.65	0.07	0.60	9.00	25.20	2.21	0.55	0.70	0.70	8.26	0.00	0.77	0.97
16	5850	69	0.1440	0.50	41.04	29.80	0.09	0.59	9.00	25.20	2.63	0.55	0.70	0.70	8.26	0.00	0.16	0.23
17	5850	56	0.0900	0.59	43.31	41.04	0.10	0.66	9.00	25.20	2.33	0.53	0.67	0.67	8.26	0.00	0.14	0.16
18	6050	65	0.2400	0.83	49.24	42.86	0.13	0.71	9.00	25.20	2.36	0.51	0.65	0.65	8.26	0.00	0.00	0.00
19	6060	65	0.2400	1.07	52.76	49.23	0.14	0.85	9.00	25.20	1.87	0.47	0.60	0.60	8.26	0.00	0.00	0.00
20	6060	69	0.0015	1.07	52.78	52.76	0.14	0.85	9.00	25.20	1.87	0.47	0.60	0.60	8.26	0.00	0.00	0.00
21	6300	54	0.0030	1.08	52.44	52.43	0.15	0.80	9.00	25.20	2.14	0.49	0.62	0.62	8.26	0.00	0.00	0.00
22	6300	67	0.0750	1.15	53.38	52.44	0.15	0.85	9.00	25.20	1.93	0.47	0.60	0.60	8.26	0.00	0.00	0.00
23	6308	61	0.0030	1.15	53.39	53.37	0.15	0.86	9.00	25.20	1.92	0.47	0.60	0.60	8.26	0.00	0.00	0.00

Contd...

...Contd. **Table 5.13**

24	6308	70	0.0750	1.23	54.41	53.39	0.15	0.91	9.00	25.20	1.75	0.46	0.58	0.58	8.26	0.00	0.00	0.00
25	6410	60	0.0075	1.24	54.30	54.26	0.17	0.81	9.00	25.20	2.23	0.48	0.61	0.61	8.26	0.00	0.00	0.00
26	6416	61	0.0075	1.24	54.33	54.29	0.17	0.81	9.00	25.20	2.21	0.48	0.61	0.61	8.26	0.00	0.00	0.00
27	6580	59	0.0005	1.25	54.13	54.13	0.17	0.81	9.00	25.20	2.21	0.48	0.61	0.61	8.26	0.00	0.00	0.00
28	6750	57	0.0013	1.25	53.90	53.89	0.18	0.77	9.00	25.20	2.47	0.49	0.63	0.63	8.26	0.00	0.00	0.00
29	6756	60	0.0025	1.25	53.90	53.89	0.19	0.73	9.00	25.20	2.74	0.51	0.64	0.64	8.26	0.00	0.00	0.00
30	6902	64	0.0600	1.31	54.17	53.70	0.20	0.73	9.00	25.20	2.78	0.50	0.64	0.64	8.26	0.00	0.00	0.00
31	6908	57	0.0600	1.37	54.28	54.16	0.20	0.77	9.00	25.20	2.60	0.49	0.63	0.63	8.26	0.00	0.00	0.00
32	7018	53	0.0010	1.37	54.15	54.15	0.20	0.77	9.00	25.20	2.59	0.49	0.63	0.63	8.26	0.00	0.00	0.00
33	7208	58	0.0050	1.38	53.92	53.91	0.20	0.77	9.00	25.20	2.58	0.49	0.63	0.63	8.26	0.00	0.00	0.00
34	7274	52	0.0030	1.38	53.84	53.84	0.20	0.77	9.00	25.20	2.57	0.49	0.63	0.63	8.26	0.00	0.00	0.00
35	7322	62	0.0001	1.38	53.78	53.78	0.20	0.77	9.00	25.20	2.57	0.49	0.63	0.63	8.26	0.00	0.00	0.00
36	7382	60	0.0024	1.38	53.71	53.70	0.20	0.77	9.00	25.20	2.62	0.50	0.63	0.63	8.26	0.00	0.00	0.00
37	7388	58	0.0024	1.38	53.71	53.71	0.20	0.77	9.00	25.20	2.61	0.49	0.63	0.63	8.26	0.00	0.00	0.00
38	7412	49	0.0018	1.38	53.68	53.68	0.20	0.77	9.00	25.30	2.60	0.49	0.63	0.63	8.24	0.00	0.00	0.00
39	7510	51	0.0001	1.38	53.56	53.56	0.20	0.77	9.00	25.30	2.60	0.49	0.63	0.63	8.24	0.00	0.00	0.00
40	7516	59	0.0002	1.39	53.55	53.55	0.20	0.77	9.00	25.30	2.60	0.49	0.63	0.63	8.24	0.00	0.00	0.00
41	7590	55	0.0015	1.39	53.46	53.46	0.20	0.77	9.00	25.30	2.60	0.49	0.63	0.63	8.24	0.00	0.00	0.00
42	7596	54	0.0012	1.39	53.45	53.45	0.20	0.77	9.00	25.30	2.60	0.49	0.63	0.63	8.24	0.00	0.00	0.00
43	7620	64	0.0013	1.39	53.43	53.42	0.20	0.77	9.00	25.30	2.59	0.49	0.63	0.63	8.24	0.00	0.00	0.00
44	7626	63	0.0015	1.39	53.43	53.42	0.20	0.63	11.00	25.30	3.50	0.54	0.69	0.69	8.24	0.00	0.00	0.00
45	7700	73.7	0.7675	2.16	60.58	53.34	0.23	0.80	11.61	25.30	2.66	0.49	0.62	0.62	8.24	0.00	0.00	0.00
46	7720	65	0.0150	2.17	60.59	60.55	0.23	0.78	12.00	25.30	2.77	0.49	0.63	0.63	8.24	0.00	0.00	0.00
47	7720	75	0.0039	2.18	60.61	60.59	0.23	0.79	12.00	25.30	2.69	0.49	0.62	0.62	8.24	0.00	0.00	0.00
48	8870	60	0.2700	2.45	59.39	59.32	0.24	0.80	12.77	25.10	2.70	0.49	0.62	0.62	8.27	0.00	0.00	0.00
49	11300	70	0.2268	2.67	58.04	56.94	0.21	0.80	15.72	25.20	2.54	0.49	0.62	0.62	8.26	0.00	0.00	0.00
50	11775	75	0.8100	3.48	61.62	57.57	0.24	0.91	16.00	25.30	2.23	0.46	0.59	0.59	8.24	0.00	0.00	0.00
51	12350	70	0.0800	3.56	61.33	61.13	0.24	0.93	16.00	25.30	2.15	0.46	0.58	0.58	8.24	0.00	0.00	0.00
52	12400	68	0.0036	3.57	61.29	61.29	0.24	0.93	16.00	25.30	2.15	0.46	0.58	0.58	8.24	0.00	0.00	0.00
53	13050	60	0.0072	3.57	60.74	60.74	0.24	0.93	16.00	25.30	2.14	0.46	0.58	0.58	8.24	0.00	0.00	0.00

$DO\ of\ waste\ water\ of\ drain\ no.45 = 0.0$ mg/l

$BOD\ of\ wastewater\ of\ drain\ no.45 = 73.69$ mg/l

Flow of drain no. 45 will be = 0.76751 m^3/s

The above values of DO, BOD and flow of drain no.45 are substituted into the model. The impact of zero discharge from above three industries on DO and BOD profile is shown in Fig.5.14. The BOD has increased marginally (0.47 mg/l) from outfall of drain no.45 to the confluence of river Bharalu and Brahmaputra. DO remains same as 0 mg/l. The zero discharge has little impact on DO and BOD of the downstream water.

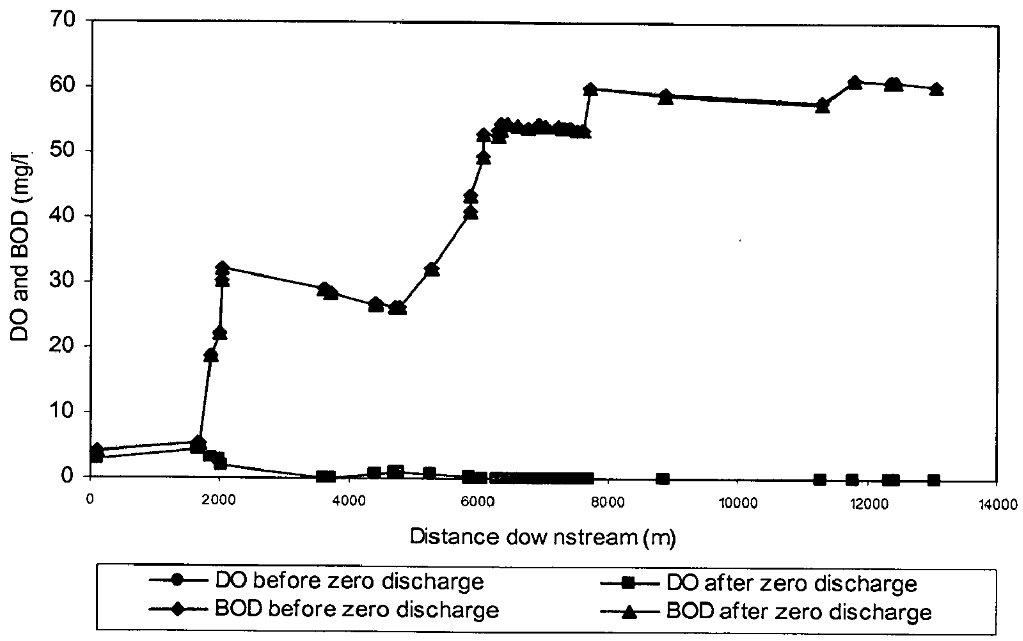

Fig.5.14 Coparison of DO and BOD before and after zero discharge

The comparisons of BOD, DO throughout the stretch of the river before and after zero discharge from industries are given in Table 5.12. The other parameters of the model after simulation for zero discharge are given in Table 5.13.

5.5.2.2 *Flow augmentation:*

To study the impact of diverting water in river Bharalu, survey was carried out for the availability of water sources in the area. The water carried by river Bharalu is diverted at Natun Bazar Sluice Gate (reference point) and connected to river Basistha. So, the sluice gate can be regulated to augment the flow. Moreover, flow can be diverted to river Bharalu from Basistha River to increase the flow. The water quality of river Bharalu, upstream of sluice gate is good in terms of DO and BOD, which are the basic parameters considered for the dilution of d/s stretch. It was observed that, the pollutant concentration is found to be highest during winter (Nov- Mar). Three options were assessed for the winter season to bring down the pollutant levels to acceptable limits for organized outdoor bathing (Class 'B' as per DBU).

Option I- Addition of flow (3.0m^3/s) with DO 6mg/l and BOD 1.0 mg/l
Option II- Addition of flow (6.0 m^3/s) with DO 8mg/l and BOD 1.0mg/l
Option III- Addition of flow (9.0 m^3/s) with DO 8mg/l and BOD 1.0mg/l

Option I: Simulation of the first option indicates that there would be significant changes in DO and BOD of the river. The modified values of DO and BOD are given in Table 5.14 and the comparison of DO and BOD value before and after dilution is shown in Fig.5.15. The observed values of other parameter after simulation by flow augmentation of 3m^3 headwater are given in Table 5.15.

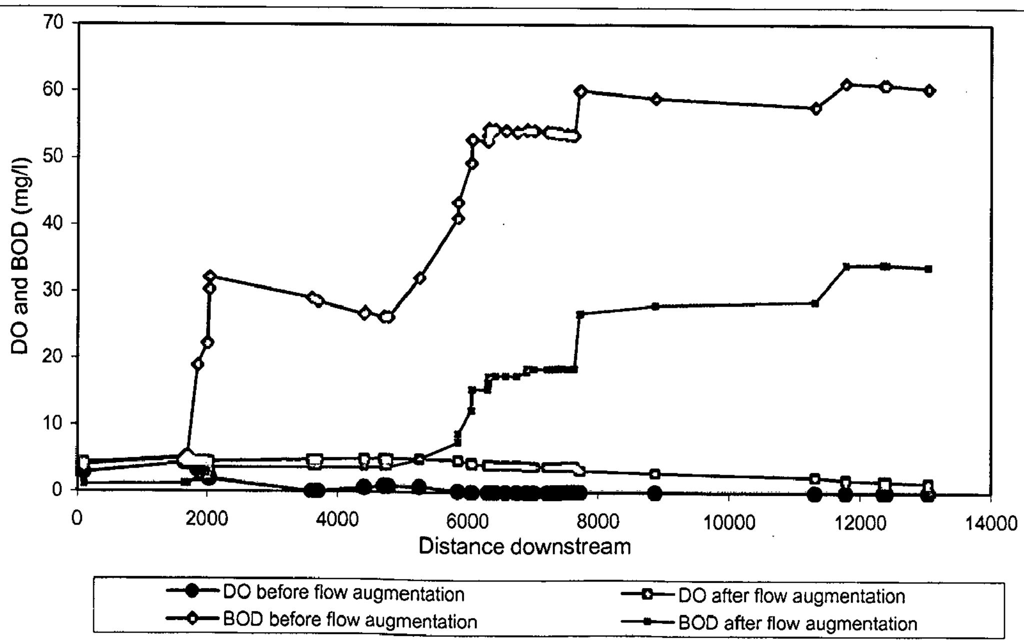

Fig. 5.15 Comparison of DO and BOD after flow augmentation by 3 m3 head water

The BOD of the river remains low (BOD<3 mg/l) upto 2.0 km from reference point. Further downstream upto 6.902km BOD remains less than 18 mg/l, which increases abruptly to 26.64mg/l at 7.7km d/s from reference point. This is due to the huge amount of organic load discharges by the drain no.45 at this point. The BOD increases to 33.75mg/l till outfall of the river. In case of dissolved oxygen, it remains above 4.0mg/l

Table 5.14 Observed values of DO and BOD before and after flow augmentation by 3m³ head water

Sl. No.	Dist. d/s from ref. point(m)	DO before flow augment-ation	DO after flow augment-ation	BOD before flow augment-ation	BOD after flow augment-ation
1	100	2.80	4.37	4.00	1.10
2	1650	4.28	4.64	5.18	1.17
3	1700	4.27	4.65	5.45	1.18
4	1850	3.20	4.61	18.86	1.92
5	2000	2.86	4.61	22.20	2.21
6	2030	2.01	4.51	30.28	3.29
7	2030	1.86	4.48	32.11	3.60
8	3600	0.00	4.73	28.96	3.58
9	3700	0.00	4.75	28.43	3.59
10	4400	0.60	4.88	26.59	3.60
11	4410	0.60	4.88	26.86	3.64
12	4700	0.83	4.92	26.14	3.66
13	4710	0.83	4.92	26.28	3.69
14	4780	0.84	4.93	26.14	3.70
15	5250	0.77	4.91	32.05	4.93
16	5850	0.16	4.80	41.04	7.52
17	5850	0.14	4.68	43.31	8.73
18	6050	0.00	4.40	49.24	12.23
19	6060	0.00	4.14	52.76	15.34
20	6060	0.00	4.14	52.78	15.36
21	6300	0.00	4.14	52.44	15.33
22	6300	0.00	4.07	53.38	16.26
23	6308	0.00	4.07	53.39	16.29
24	6308	0.00	3.99	54.41	17.25
25	6410	0.00	3.99	54.30	17.30
26	6416	0.00	3.98	54.33	17.37
27	6580	0.00	3.98	54.13	17.34

Contd...

.:.Contd. Table 5.14

Sl. No.	Dist. d/s from ref. point(m)	DO before flow augment-ation	DO after flow augment-ation	BOD before flow augment-ation	BOD after flow augment-ation
28	6750	0.00	3.97	53.90	17.30
29	6756	0.00	3.97	53.90	17.33
30	6902	0.00	3.91	54.17	17.94
31	6908	0.00	3.86	54.28	18.48
32	7018	0.00	3.86	54.15	18.46
33	7208	0.00	3.85	53.92	18.45
34	7274	0.00	3.85	53.84	18.46
35	7322	0.00	3.84	53.78	18.45
36	7382	0.00	3.84	53.71	18.45
37	7388	0.00	3.84	53.71	18.47
38	7412	0.00	3.84	53.68	18.48
39	7510	0.00	3.83	53.56	18.45
40	7516	0.00	3.83	53.55	18.45
41	7590	0.00	3.83	53.46	18.45
42	7596	0.00	3.83	53.45	18.46
43	7620	0.00	3.83	53.43	18.46
44	7626	0.00	3.83	53.43	18.48
45	7700	0.00	3.24	60.11	26.64
46	7720	0.00	3.23	60.12	26.74
47	7720	0.00	3.22	60.15	26.77
48	8870	0.00	2.87	59.00	27.93
40	11300	0.00	2.33	57.70	28.53
50	11775	0.00	1.93	61.34	34.07
51	12350	0.00	1.71	61.05	34.15
52	12400	0.00	1.69	61.02	34.13
53	13050	0.00	1.47	60.47	33.75

Table 5.15 Observed values of parameters of the model after flow augmentation by 3m^3 head water

Drain No.	Dist. D/s from ref. point (m)	BOD (mg/l) of the drain water	Flow of the drain, Q_i (m^3/sec)	Flow of river after mixing (m^3/sec)	BOD of river water after mixing (mg/l)	BOD just before the point of discharge	Velocity of flow of river (m/s)	Average water depth (m)	Width of flow (m)	Temperature (^{0}C)	k_2	k_1	$(k_1)_T$	k_r	Cs (mg/l)	DO of drain water	DO of river water after mixing	DO just before the point of discharge
1	100	4	0.1080	3.11	1.10		1.06	0.95	3.08	24.30	4.38	0.45	0.55	0.55	8.39	2.80	4.37	
2	1650	48	0.0050	3.11	1.17	1.09	0.93	0.95	3.53	24.30	4.09	0.45	0.55	0.55	8.39	0.00	4.64	4.65
3	1700	50	0.0008	3.11	1.18	1.17	1.13	0.95	2.90	24.30	4.51	0.45	0.55	0.55	8.39	0.00	4.65	4.65
4	1850	53	0.0450	3.16	1.92	1.18	1.02	0.96	3.25	24.30	4.24	0.45	0.55	0.55	8.39	0.00	4.61	4.67
5	2000	54	0.0180	3.18	2.21	1.92	1.12	0.96	2.95	24.40	4.44	0.45	0.55	0.55	8.38	0.00	4.61	4.63
6	2030	50	0.0730	3.25	3.29	2.21	0.89	0.97	3.76	24.40	3.89	0.45	0.55	0.55	8.38	0.00	4.51	4.61
7	2030	55	0.0200	3.27	3.60	3.29	0.90	0.97	3.76	24.40	3.88	0.45	0.55	0.55	8.38	0.00	4.48	4.51
8	3600	57	0.0010	3.27	3.58	3.56	0.48	0.97	7.00	24.80	2.85	0.45	0.56	0.56	8.32	0.00	4.73	4.73
9	3700	50	0.0015	3.27	3.59	3.57	0.47	0.97	7.20	24.90	2.81	0.45	0.56	0.56	8.30	0.00	4.75	4.75
10	4400	57	0.0025	3.27	3.60	3.56	0.45	0.97	7.50	25.10	2.75	0.45	0.56	0.56	8.27	0.00	4.88	4.88
11	4410	60	0.0025	3.28	3.64	3.60	0.45	0.97	7.50	25.10	2.75	0.45	0.56	0.56	8.27	0.00	4.88	4.88
12	4700	40	0.0030	3.28	3.66	3.63	0.42	0.97	8.00	25.20	2.66	0.45	0.57	0.57	8.26	0.00	4.92	4.93
13	4710	50	0.0020	3.28	3.69	3.66	0.42	0.97	8.00	25.20	2.66	0.45	0.57	0.57	8.26	0.00	4.92	4.93
14	4780	51	0.0010	3.28	3.70	3.68	0.42	0.97	8.00	25.20	2.66	0.45	0.57	0.57	8.26	0.00	4.93	4.94
15	5250	60	0.0750	3.36	4.93	3.67	0.38	0.98	9.00	25.20	2.48	0.44	0.56	0.56	8.26	0.00	4.91	5.02
16	5850	69	0.1440	3.50	7.52	4.88	0.39	1.00	9.00	25.20	2.44	0.44	0.56	0.56	8.26	0.00	4.80	5.00
17	5850	56	0.0900	3.59	8.73	7.52	0.39	1.01	9.00	25.20	2.42	0.44	0.56	0.56	8.26	0.00	4.68	4.80
18	6050	65	0.2400	3.83	12.23	8.70	0.41	1.04	9.00	25.20	2.36	0.43	0.55	0.55	8.26	0.00	4.40	4.70
19	6060	65	0.2400	4.07	15.34	12.23	0.42	1.07	9.00	25.20	2.30	0.43	0.54	0.54	8.26	0.00	4.14	4.40
20	6060	69	0.0015	4.07	15.36	15.34	0.42	1.07	9.00	25.20	2.30	0.43	0.54	0.54	8.26	0.00	4.14	4.14
21	6300	54	0.0030	4.08	15.33	15.30	0.42	1.07	9.00	25.20	2.30	0.43	0.54	0.54	8.26	0.00	4.14	4.15
22	6300	67	0.0750	4.15	16.26	15.33	0.43	1.08	9.00	25.20	2.28	0.43	0.54	0.54	8.26	0.00	4.07	4.14
23	6308	61	0.0030	4.15	16.29	16.26	0.43	1.08	9.00	25.20	2.28	0.43	0.54	0.54	8.26	0.00	4.07	4.07

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...Contd. **Table 5.15**

24	6308	70	0.0750	4.23	17.25	16.29	0.43	1.09	9.00	25.20	2.26	0.43	0.54	0.54	8.26	0.00	3.99	4.07
25	6410	60	0.0075	4.24	17.30	17.22	0.43	1.09	9.00	25.20	2.26	0.42	0.54	0.54	8.26	0.00	3.99	3.99
26	6416	61	0.0075	4.24	17.37	17.29	0.43	1.09	9.00	25.20	2.26	0.42	0.54	0.54	8.26	0.00	3.98	3.99
27	6580	59	0.0005	4.25	17.34	17.33	0.43	1.09	9.00	25.20	2.26	0.42	0.54	0.54	8.26	0.00	3.98	3.98
28	6750	57	0.0013	4.25	17.30	17.29	0.43	1.09	9.00	25.20	2.26	0.42	0.54	0.54	8.26	0.00	3.97	3.97
29	6756	60	0.0025	4.25	17.33	17.30	0.43	1.09	9.00	25.20	2.26	0.42	0.54	0.54	8.26	0.00	3.97	3.97
30	6902	64	0.0600	4.31	17.94	17.29	0.44	1.10	9.00	25.20	2.25	0.42	0.54	0.54	8.26	0.00	3.91	3.97
31	6908	57	0.0600	4.37	18.48	17.94	0.44	1.11	9.00	25.20	2.24	0.42	0.54	0.54	8.26	0.00	3.86	3.91
32	7018	53	0.0010	4.37	18.46	18.45	0.44	1.11	9.00	25.20	2.24	0.42	0.54	0.54	8.26	0.00	3.86	3.86
33	7208	58	0.0050	4.38	18.45	18.41	0.44	1.11	9.00	25.20	2.23	0.42	0.54	0.54	8.26	0.00	3.85	3.85
34	7274	52	0.0030	4.38	18.46	18.43	0.44	1.11	9.00	25.20	2.23	0.42	0.54	0.54	8.26	0.00	3.85	3.85
35	7322	62	0.0001	4.38	18.45	18.45	0.44	1.11	9.00	25.20	2.23	0.42	0.54	0.54	8.26	0.00	3.84	3.84
36	7382	60	0.0024	4.38	18.45	18.43	0.44	1.11	9.00	25.20	2.23	0.42	0.54	0.54	8.26	0.00	3.84	3.84
37	7388	58	0.0024	4.38	18.47	18.45	0.44	1.11	9.00	25.20	2.23	0.42	0.54	0.54	8.26	0.00	3.84	3.84
38	7412	49	0.0018	4.38	18.48	18.47	0.44	1.11	9.00	25.30	2.23	0.42	0.54	0.54	8.24	0.00	3.84	3.84
39	7510	51	0.0001	4.38	18.45	18.45	0.44	1.11	9.00	25.30	2.23	0.42	0.54	0.54	8.24	0.00	3.83	3.83
40	7516	59	0.0002	4.39	18.45	18.45	0.44	1.11	9.00	25.30	2.23	0.42	0.54	0.54	8.24	0.00	3.83	3.83
41	7590	55	0.0015	4.39	18.45	18.44	0.44	1.11	9.00	25.30	2.23	0.42	0.54	0.54	8.24	0.00	3.83	3.83
42	7596	54	0.0012	4.39	18.46	18.45	0.44	1.11	9.00	25.30	2.23	0.42	0.54	0.54	8.24	0.00	3.83	3.83
43	7620	64	0.0013	4.39	18.46	18.45	0.44	1.11	9.00	25.30	2.23	0.42	0.54	0.54	8.24	0.00	3.83	3.83
44	7626	63	0.0015	4.39	18.48	18.46	0.36	1.11	11.00	25.30	2.02	0.42	0.54	0.54	8.24	0.00	3.83	3.83
45	7700	72	0.7920	5.18	26.64	18.45	0.37	1.20	11.61	25.30	1.84	0.41	0.52	0.52	8.24	0.00	3.24	3.82
46	7720	65	0.0150	5.20	26.74	26.63	0.36	1.20	12.00	25.30	1.81	0.41	0.52	0.52	8.24	0.00	3.23	3.23
47	7720	75	0.0039	5.20	26.77	26.74	0.36	1.20	12.00	25.30	1.81	0.41	0.52	0.52	8.24	0.00	3.22	3.23
48	8870	60	0.2700	5.47	27.93	26.27	0.35	1.22	12.77	25.10	1.72	0.40	0.51	0.51	8.27	0.00	2.87	3.01
49	11300	70	0.2268	5.70	28.53	26.81	0.29	1.25	15.72	25.20	1.52	0.40	0.51	0.51	8.26	0.00	2.33	2.42
50	11775	75	0.8100	6.51	34.07	28.25	0.31	1.32	16.00	25.30	1.43	0.39	0.50	0.50	8.24	0.00	1.93	2.20
51	12350	70	0.0800	6.59	34.15	33.71	0.31	1.33	16.00	25.30	1.42	0.39	0.50	0.50	8.24	0.00	1.71	1.73
52	12400	68	0.0036	6.59	34.13	34.11	0.31	1.33	16.00	25.30	1.42	0.39	0.50	0.50	8.24	0.00	1.69	1.69
53	13050	60	0.0072	6.60	33.75	33.72	0.31	1.33	16.00	25.30	1.42	0.39	0.50	0.50	8.24	0.00	1.47	1.47

upto 6.3 km downstream from reference point. Its values decrease towards downstream and remain above 2.0mg/l upto 11.3 km downstream from point of reference. It becomes .47mg/l at the outfall. Therefore, adoption of this option would not change the water quality to the desired level (class 'B').

Option II: With Option II, the modified value of DO and BOD is given in Table 5.16. And the comparison of DO and BOD value before dilution and after dilution is shown in Fig.5.16. The observed values of other parameter after simulation by flow augmentation of 6m^3 headwater are given in Table 5.17.

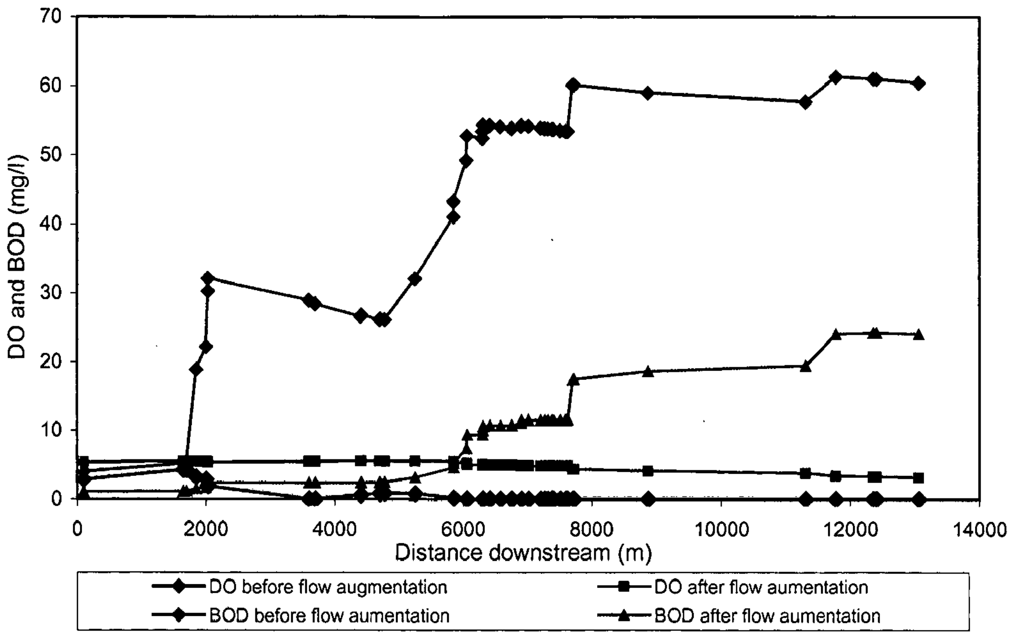

Fig 5.16 Comparison of DO and BOD after flow augmentation by 6m3 headwater

The BOD of the river remains low (BOD<3 mg/l) upto 4.78km from reference point. Further downstream upto 7.62km BOD will remain less than 11.46 mg/l, which increases 17.32 mg/l at 7.7km d/s from reference point. The BOD increases to maximum of 24.18 mg/l at 12.4 km d/s from reference point and becomes 23.99 mg/l near the confluence of the river Bharalu and Brahmaputra. In case of dissolved oxygen, it remains above 5.0mg/l upto 6.06 km d/s from reference point. Its values decrease towards downstream and remain more than 4.0mg/l upto 8.87km downstream from point of reference. Thereafter it decreases to 3.15 mg/l near the confluence of river Bharalu and Brahmaputra.

Table 5.16 Observed values of DO and BOD before and after flow augmentation by 6m^3 head water

Sl. No.	Dist. d/s from ref. point(m)	DO before flow augment-ation	DO after flow augment-ation by 6m3 hw	BOD before flow augment-ation	BOD after flow augment-ation by 6m3 hw
1	100	2.80	5.38	4.00	1.05
2	1650	4.28	5.48	5.18	1.09
3	1700	4.27	5.48	5.45	1.09
4	1850	3.20	5.45	18.86	1.47
5	2000	2.86	5.45	22.20	1.62
6	2030	2.01	5.39	30.28	2.19
7	2030	1.86	5.37	32.11	2.36
8	3600	0.00	5.48	28.96	2.35
9	3700	0.00	5.48	28.43	2.36
10	4400	0.60	5.54	26.59	2.37
11	4410	0.60	5.54	26.86	2.39
12	4700	0.83	5.56	26.14	2.40
13	4710	0.83	5.56	26.28	2.42
14	4780	0.84	5.56	26.14	2.42
15	5250	0.77	5.53	32.05	3.09
16	5850	0.16	5.46	41.04	4.53
17	5850	0.14	5.38	43.31	5.23
18	6050	0.00	5.20	49.24	7.32
19	6060	0.00	5.03	52.76	9.28
20	6060	0.00	5.03	52.78	9.29
21	6300	0.00	5.03	52.44	9.29
22	6300	0.00	4.98	53.38	9.89
23	6308	0.00	4.97	53.39	9.91
24	6308	0.00	4.92	54.41	10.54
25	6410	0.00	4.92	54.30	10.58
26	6416	0.00	4.91	54.33	10.63
27	6580	0.00	4.91	54.13	10.62

Contd...

...Contd. Table 5.16

Sl. No.	Dist. d/s from ref. point(m)	DO before flow augment-ation	DO after flow augment-ation by 6m3 hw	BOD before flow augment-ation	BOD after flow augment-ation by 6m3 hw
28	6750	0.00	4.91	53.90	10.61
29	6756	0.00	4.91	53.90	10.62
30	6902	0.00	4.87	54.17	11.05
31	6908	0.00	4.83	54.28	11.42
32	7018	0.00	4.83	54.15	11.41
33	7208	0.00	4.83	53.92	11.42
34	7274	0.00	4.83	53.84	11.43
35	7322	0.00	4.83	53.78	11.43
36	7382	0.00	4.83	53.71	11.44
37	7388	0.00	4.83	53.71	11.45
38	7412	0.00	4.83	53.68	11.46
39	7510	0.00	4.83	53.56	11.45
40	7516	0.00	4.83	53.55	11.45
41	7590	0.00	4.82	53.46	11.45
42	7596	0.00	4.82	53.45	11.46
43	7620	0.00	4.82	53.43	11.46
44	7626	0.00	4.82	53.43	11.47
45	7700	0.00	4.35	60.11	17.32
46	7720	0.00	4.34	60.12	17.41
47	7720	0.00	4.34	60.15	17.43
48	8870	0.00	4.12	59.00	18.56
40	11300	0.00	3.80	57.70	19.37
50	11775	0.00	3.42	61.34	23.99
51	12350	0.00	3.28	61.05	24.18
52	12400	0.00	3.27	61.02	24.18
53	13050	0.00	3.15	60.47	23.99

Table 5.17 Observed values of parameters of the model after flow augmentation by $6m^3$ head water

Drain No.	Dist. D/s from ref. point (m)	BOD (mg/l) of the drain water	Flow of the drain, Q_i (m^3/sec)	Flow of river after mixing (m^3/sec)	BOD of river water after mixing (mg/l)	BOD just before the point of discharge	Velocity of flow of river (m/s)	Average water depth (m)	Width of flow (m)	Temperature (^0C)	k_2	k_1	$(k_1)_T$	k_r	Cs (mg/l)	DO of drain water	DO of river water after mixing	DO just before the point of discharge
1	100	4	0.1080	6.11	1.05		1.54	1.29	3.08	24.30	3.34	0.40	0.48	0.48	8.39	2.80	5.38	
2	1650	48	0.0050	6.11	1.09	1.05	1.35	1.29	3.53	24.30	3.12	0.40	0.48	0.48	8.39	0.00	5.48	5.49
3	1700	50	0.0008	6.11	1.09	1.09	1.64	1.29	2.90	24.30	3.44	0.40	0.48	0.48	8.39	0.00	5.48	5.48
4	1850	53	0.0450	6.16	1.47	1.09	1.47	1.29	3.25	24.30	3.24	0.40	0.48	0.48	8.39	0.00	5.45	5.49
5	2000	54	0.0180	6.18	1.62	1.47	1.62	1.29	2.95	24.40	3.40	0.39	0.48	0.48	8.38	0.00	5.45	5.46
6	2030	50	0.0730	6.25	2.19	1.62	1.28	1.30	3.76	24.40	3.00	0.39	0.48	0.48	8.38	0.00	5.39	5.45
7	2030	55	0.0200	6.27	2.36	2.19	1.28	1.30	3.76	24.40	2.99	0.39	0.48	0.48	8.38	0.00	5.37	5.39
8	3600	57	0.0010	6.27	2.35	2.34	0.69	1.30	7.00	24.80	2.19	0.39	0.49	0.49	8.32	0.00	5.48	5.48
9	3700	50	0.0015	6.27	2.36	2.35	0.67	1.30	7.20	24.90	2.16	0.39	0.49	0.49	8.30	0.00	5.48	5.48
10	4400	57	0.0025	6.27	2.37	2.34	0.64	1.30	7.50	25.10	2.12	0.39	0.50	0.50	8.27	0.00	5.54	5.54
11	4410	60	0.0025	6.28	2.39	2.37	0.64	1.30	7.50	25.10	2.12	0.39	0.50	0.50	8.27	0.00	5.54	5.54
12	4700	40	0.0030	6.28	2.40	2.38	0.60	1.30	8.00	25.20	2.05	0.39	0.50	0.50	8.26	0.00	5.56	5.56
13	4710	50	0.0020	6.28	2.42	2.40	0.60	1.30	8.00	25.20	2.05	0.39	0.50	0.50	8.26	0.00	5.56	5.56
14	4780	51	0.0010	6.28	2.42	2.41	0.60	1.30	8.00	25.20	2.05	0.39	0.50	0.50	8.26	0.00	5.56	5.56
15	5250	60	0.0750	6.36	3.09	2.41	0.54	1.31	9.00	25.20	1.92	0.39	0.50	0.50	8.26	0.00	5.53	5.60
16	5850	69	0.1440	6.50	4.53	3.07	0.55	1.32	9.00	25.20	1.91	0.39	0.50	0.50	8.26	0.00	5.46	5.58
17	5850	56	0.0900	6.59	5.23	4.53	0.55	1.33	9.00	25.20	1.90	0.39	0.49	0.49	8.26	0.00	5.38	5.46
18	6050	65	0.2400	6.83	7.32	5.22	0.56	1.35	9.00	25.20	1.87	0.39	0.49	0.49	8.26	0.00	5.20	5.39
19	6060	65	0.2400	7.07	9.28	7.32	0.57	1.37	9.00	25.20	1.84	0.38	0.49	0.49	8.26	0.00	5.03	5.20
20	6060	69	0.0015	7.07	9.29	9.28	0.57	1.37	9.00	25.20	1.84	0.38	0.49	0.49	8.26	0.00	5.03	5.03
21	6300	54	0.0030	7.08	9.29	9.27	0.57	1.37	9.00	25.20	1.84	0.38	0.49	0.49	8.26	0.00	5.03	5.03
22	6300	67	0.0750	7.15	9.89	9.29	0.58	1.38	9.00	25.20	1.84	0.38	0.49	0.49	8.26	0.00	4.98	5.03
23	6308	61	0.0030	7.15	9.91	9.89	0.58	1.38	9.00	25.20	1.84	0.38	0.49	0.49	8.26	0.00	4.97	4.98

Contd…

...Contd. **Table 5.17**

24	6308	70	0.0750	7.23	10.54	9.91	0.58	1.39	9.00	25.20	1.83	0.38	0.49	0.49	8.26	0.00	4.92	4.97
25	6410	60	0.0075	7.24	10.58	10.53	0.58	1.39	9.00	25.20	1.83	0.38	0.49	0.49	8.26	0.00	4.92	4.92
26	6416	61	0.0075	7.24	10.63	10.58	0.58	1.39	9.00	25.20	1.83	0.38	0.49	0.49	8.26	0.00	4.91	4.92
27	6580	59	0.0005	7.25	10.62	10.61	0.58	1.39	9.00	25.20	1.83	0.38	0.49	0.49	8.26	0.00	4.91	4.91
28	6750	57	0.0013	7.25	10.61	10.60	0.58	1.39	9.00	25.20	1.83	0.38	0.49	0.49	8.26	0.00	4.91	4.92
29	6756	60	0.0025	7.25	10.62	10.61	0.58	1.39	9.00	25.20	1.83	0.38	0.49	0.49	8.26	0.00	4.91	4.91
30	6902	64	0.0600	7.31	11.05	10.61	0.58	1.40	9.00	25.20	1.82	0.38	0.49	0.49	8.26	0.00	4.87	4.91
31	6908	57	0.0600	7.37	11.42	11.05	0.58	1.40	9.00	25.20	1.81	0.38	0.48	0.48	8.26	0.00	4.83	4.87
32	7018	53	0.0010	7.37	11.41	11.41	0.58	1.40	9.00	25.20	1.81	0.38	0.48	0.48	8.26	0.00	4.83	4.83
33	7208	58	0.0050	7.38	11.42	11.39	0.58	1.40	9.00	25.20	1.81	0.38	0.48	0.48	8.26	0.00	4.83	4.83
34	7274	52	0.0030	7.38	11.43	11.42	0.59	1.40	9.00	25.20	1.81	0.38	0.48	0.48	8.26	0.00	4.83	4.83
35	7322	62	0.0001	7.38	11.43	11.43	0.59	1.40	9.00	25.20	1.81	0.38	0.48	0.48	8.26	0.00	4.83	4.83
36	7382	60	0.0024	7.38	11.44	11.42	0.59	1.40	9.00	25.20	1.81	0.38	0.48	0.48	8.26	0.00	4.83	4.83
37	7388	58	0.0024	7.38	11.45	11.44	0.59	1.40	9.00	25.20	1.81	0.38	0.48	0.48	8.26	0.00	4.83	4.83
38	7412	49	0.0018	7.38	11.46	11.45	0.59	1.40	9.00	25.30	1.81	0.38	0.49	0.49	8.24	0.00	4.83	4.83
39	7510	51	0.0001	7.38	11.45	11.45	0.59	1.40	9.00	25.30	1.81	0.38	0.49	0.49	8.24	0.00	4.83	4.83
40	7516	59	0.0002	7.39	11.45	11.45	0.59	1.40	9.00	25.30	1.81	0.38	0.49	0.49	8.24	0.00	4.83	4.83
41	7590	55	0.0015	7.39	11.45	11.44	0.59	1.40	9.00	25.30	1.81	0.38	0.49	0.49	8.24	0.00	4.82	4.83
42	7596	54	0.0012	7.39	11.46	11.45	0.59	1.40	9.00	25.30	1.81	0.38	0.49	0.49	8.24	0.00	4.82	4.82
43	7620	64	0.0013	7.39	11.46	11.45	0.59	1.40	9.00	25.30	1.81	0.38	0.49	0.49	8.24	0.00	4.82	4.82
44	7626	63	0.0015	7.39	11.47	11.46	0.48	1.40	11.00	25.30	1.64	0.38	0.49	0.49	8.24	0.00	4.82	4.82
45	7700	72	0.7920	8.18	17.32	11.46	0.48	1.47	11.61	25.30	1.53	0.37	0.48	0.48	8.24	0.00	4.35	4.82
46	7720	65	0.0150	8.20	17.41	17.32	0.47	1.47	12.00	25.30	1.51	0.37	0.48	0.48	8.24	0.00	4.34	4.35
47	7720	75	0.0039	8.20	17.43	17.41	0.47	1.47	12.00	25.30	1.50	0.37	0.48	0.48	8.24	0.00	4.34	4.34
48	8870	60	0.2700	8.47	18.56	17.20	0.44	1.49	12.77	25.10	1.44	0.37	0.47	0.47	8.27	0.00	4.12	4.25
49	11300	70	0.2268	8.70	19.37	18.02	0.37	1.51	15.72	25.20	1.28	0.37	0.47	0.47	8.26	0.00	3.80	3.91
50	11775	75	0.8100	9.51	23.99	19.24	0.38	1.57	16.00	25.30	1.23	0.36	0.46	0.46	8.24	0.00	3.42	3.74
51	12350	70	0.0800	9.59	24.18	23.79	0.38	1.58	16.00	25.30	1.22	0.36	0.46	0.46	8.24	0.00	3.28	3.31
52	12400	68	0.0036	9.59	24.18	24.16	0.38	1.58	16.00	25.30	1.22	0.36	0.46	0.46	8.24	0.00	3.27	3.27
53	13050	60	0.0072	9.60	23.99	23.96	0.38	1.58	16.00	25.30	1.22	0.36	0.46	0.46	8.24	0.00	3.15	3.15

Adoption of this option would change the water quality to the desired level (class 'B') upto 4.78km downstream from reference point. Moreover, downstream stretch will remain aerobic upto the confluence of river Bharalu and Brahmaputra. Hence, no foul smell will be felt after this stretch.

Option III: If the Option III is exercised, then there will be significant impact on DO and BOD of the downstream water. The change value of DO and BOD is given in Table 5.18. And the comparisons of DO and BOD value before dilution and after dilution are shown in Fig.5.17. The observed values of other parameter after simulation by $9m^3$ headwater are given in Table 5.19.

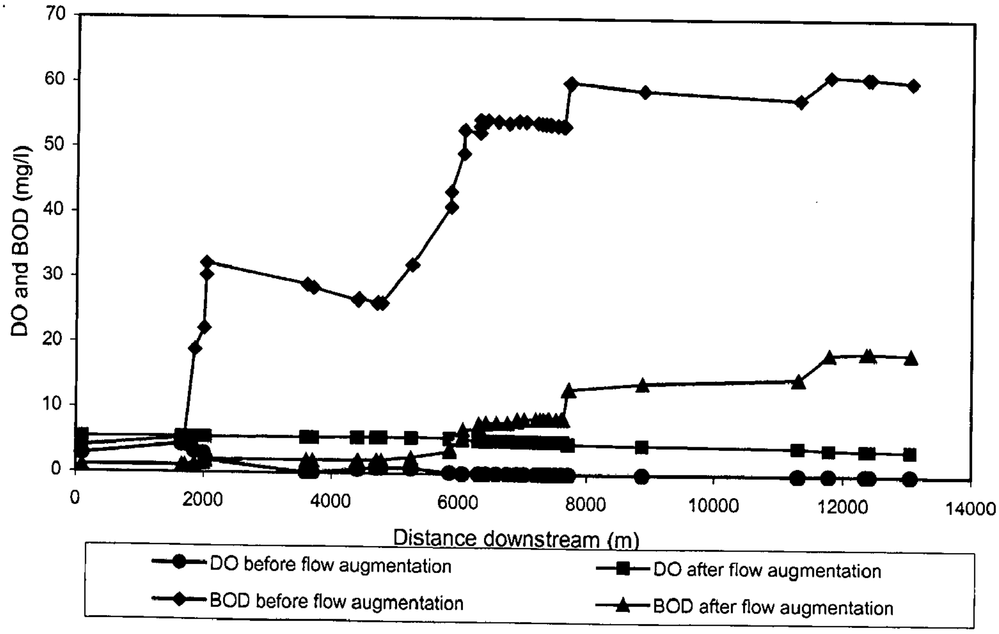

Fig. 5.17 Comparison of DO and BOD after flow augmentation by 9m3 headwater

The BOD of the river remains low (BOD<3 mg/l) upto 5.25km from reference point. Further downstream upto 7.62km BOD will remain less than 8.47 mg/l, which increases to 12.97 mg/l at 7.7km d/s from reference point. The BOD increases to maximum of 18.82mg/l at 12.35 km d/s from reference point and becomes 18.70 mg/l near the confluence of the river Bharalu and Brahmaputra. In case of dissolved oxygen, it remains above 5.0mg/l upto 7.626km d/s from reference point. Its values decrease towards downstream and remain more than 4.0mg/l upto 11.775 km downstream from point of reference. Thereafter it decreases to 3.82 mg/l near the

Table 5.18 Observed values of DO and BOD before and after flow augmentation by 9m^3 head water

Sl. No.	Dist. d/s from ref. point(m)	DO before flow augment-ation	DO after flow augment-ation	BOD before flow augment-ation	BOD after flow augment-ation
1	100	2.80	5.38	4.00	1.04
2	1650	4.28	5.46	5.18	1.06
3	1700	4.27	5.46	5.45	1.06
4	1850	3.20	5.44	18.86	1.32
5	2000	2.86	5.43	22.20	1.42
6	2030	2.01	5.39	30.28	1.80
7	2030	1.86	5.38	32.11	1.92
8	3600	0.00	5.46	28.96	1.91
9	3700	0.00	5.46	28.43	1.92
10	4400	0.60	5.50	26.59	1.93
11	4410	0.60	5.50	26.86	1.94
12	4700	0.83	5.52	26.14	1.95
13	4710	0.83	5.51	26.28	1.96
14	4780	0.84	5.52	26.14	1.96
15	5250	0.77	5.50	32.05	2.42
16	5850	0.16	5.45	41.04	3.42
17	5850	0.14	5.40	43.31	3.91
18	6050	0.00	5.28	49.24	5.40
19	6060	0.00	5.15	52.76	6.82
20	6060	0.00	5.15	52.78	6.83
21	6300	0.00	5.16	52.44	6.83
22	6300	0.00	5.12	53.38	7.27
23	6308	0.00	5.12	53.39	7.29
24	6308	0.00	5.08	54.41	7.75
25	6410	0.00	5.08	54.30	7.78
26	6416	0.00	5.07	54.33	7.82
27	6580	0.00	5.08	54.13	7.81

Contd...

...Contd. Table 5.18

Sl. No	Dist. d/s from ref. point(m)	DO before flow augment-ation	DO after flow augment-ation	BOD before flow augment-ation	BOD after flow augment-ation
28	6750	0.00	5.08	53.90	7.81
29	6756	0.00	5.08	53.90	7.82
30	6902	0.00	5.05	54.17	8.14
31	6908	0.00	5.02	54.28	8.42
32	7018	0.00	5.02	54.15	8.42
33	7208	0.00	5.02	53.92	8.43
34	7274	0.00	5.02	53.84	8.44
35	7322	0.00	5.02	53.78	8.44
36	7382	0.00	5.02	53.71	8.45
37	7388	0.00	5.02	53.71	8.46
38	7412	0.00	5.02	53.68	8.46
39	7510	0.00	5.02	53.56	8.46
40	7516	0.00	5.02	53.55	8.46
41	7590	0.00	5.02	53.46	8.46
42	7596	0.00	5.02	53.45	8.46
43	7620	0.00	5.02	53.43	8.47
44	7626	0.00	5.02	53.43	8.48
45	7700	0.00	4.67	60.11	12.97
46	7720	0.00	4.66	60.12	13.04
47	7720	0.00	4.66	60.15	13.06
48	8870	0.00	4.51	59.00	14.03
40	11300	0.00	4.31	57.70	14.79
50	11775	0.00	4.00	61.34	18.61
51	12350	0.00	3.91	61.05	18.82
52	12400	0.00	3.90	61.02	18.82
53	13050	0.00	3.82	60.47	18.70

Table 5.19 Observed values of parameters of the model after flow augmentation by $9m^3$ head water

Drain No.	Dist. D/s from ref. point (m)	BOD (mg/l) of the drain water	Flow of the drain, Q_i (m^3/sec)	Flow of river after mixing (m^3/sec)	BOD of river water after mixing (mg/l)	BOD just before the point of discharge	Velocity of flow of river (m/s)	Average water depth (m)	Width of flow (m)	Temperature (^0C)	k_2	k_1	$(k_1)_T$	k_r	Cs (mg/l)	DO of drain water	DO of river water after mixing	DO just before the point of discharge
1	100	4	0.1080	9.11	1.04		1.92	1.54	3.08	24.30	2.85	0.37	0.45	0.45	8.39	2.80	5.38	
2	1650	48	0.0050	9.11	1.06	1.03	1.68	1.54	3.53	24.30	2.66	0.37	0.45	0.45	8.39	0.00	5.46	5.46
3	1700	50	0.0008	9.11	1.06	1.06	2.04	1.54	2.90	24.30	2.93	0.37	0.45	0.45	8.39	0.00	5.46	5.46
4	1850	53	0.0450	9.16	1.32	1.06	1.82	1.54	3.25	24.30	2.77	0.37	0.45	0.45	8.39	0.00	5.44	5.46
5	2000	54	0.0180	9.18	1.42	1.32	2.01	1.55	2.95	24.40	2.90	0.37	0.45	0.45	8.38	0.00	5.43	5.45
6	2030	50	0.0730	9.25	1.80	1.42	1.59	1.55	3.76	24.40	2.56	0.36	0.45	0.45	8.38	0.00	5.39	5.44
7	2030	55	0.0200	9.27	1.92	1.80	1.59	1.55	3.76	24.40	2.56	0.36	0.45	0.45	8.38	0.00	5.38	5.39
8	3600	57	0.0010	9.27	1.91	1.91	0.85	1.55	7.00	24.80	1.88	0.36	0.45	0.45	8.32	0.00	5.46	5.46
9	3700	50	0.0015	9.27	1.92	1.91	0.83	1.55	7.20	24.90	1.85	0.36	0.46	0.46	8.30	0.00	5.46	5.46
10	4400	57	0.0025	9.27	1.93	1.91	0.80	1.55	7.50	25.10	1.81	0.36	0.46	0.46	8.27	0.00	5.50	5.50
11	4410	60	0.0025	9.28	1.94	1.93	0.80	1.55	7.50	25.10	1.81	0.36	0.46	0.46	8.27	0.00	5.50	5.50
12	4700	40	0.0030	9.28	1.95	1.94	0.75	1.55	8.00	25.20	1.75	0.36	0.46	0.46	8.26	0.00	5.52	5.52
13	4710	50	0.0020	9.28	1.96	1.95	0.75	1.55	8.00	25.20	1.75	0.36	0.46	0.46	8.26	0.00	5.51	5.52
14	4780	51	0.0010	9.28	1.96	1.96	0.75	1.55	8.00	25.20	1.75	0.36	0.46	0.46	8.26	0.00	5.52	5.52
15	5250	60	0.0750	9.36	2.42	1.96	0.67	1.56	9.00	25.20	1.65	0.36	0.46	0.46	8.26	0.00	5.50	5.55
16	5850	69	0.1440	9.50	3.42	2.41	0.67	1.57	9.00	25.20	1.64	0.36	0.46	0.46	8.26	0.00	5.45	5.54
17	5850	56	0.0900	9.59	3.91	3.42	0.68	1.58	9.00	25.20	1.63	0.36	0.46	0.46	8.26	0.00	5.40	5.45
18	6050	65	0.2400	9.83	5.40	3.91	0.69	1.59	9.00	25.20	1.62	0.36	0.46	0.46	8.26	0.00	5.28	5.41
19	6060	65	0.2400	10.07	6.82	5.40	0.69	1.61	9.00	25.20	1.60	0.36	0.46	0.46	8.26	0.00	5.15	5.28
20	6060	69	0.0015	10.07	6.83	6.82	0.69	1.61	9.00	25.20	1.60	0.36	0.46	0.46	8.26	0.00	5.15	5.15
21	6300	54	0.0030	10.08	6.83	6.82	0.69	1.61	9.00	25.20	1.60	0.36	0.46	0.46	8.26	0.00	5.16	5.16
22	6300	67	0.0750	10.15	7.27	6.83	0.70	1.62	9.00	25.20	1.60	0.36	0.45	0.45	8.26	0.00	5.12	5.16
23	6308	61	0.0030	10.15	7.29	7.27	0.70	1.62	9.00	25.20	1.60	0.36	0.45	0.45	8.26	0.00	5.12	5.12

Contd...

...Contd. **Table 5.19**

24	6308	70	0.0750	10.23	7.75	7.29	0.70	1.62	9.00	25.20	1.59	0.36	0.45	0.45	8.26	0.00	5.08	5.12
25	6410	60	0.0075	10.24	7.78	7.74	0.70	1.62	9.00	25.20	1.59	0.36	0.45	0.45	8.26	0.00	5.08	5.08
26	6416	61	0.0075	10.24	7.82	7.78	0.70	1.62	9.00	25.20	1.59	0.36	0.45	0.45	8.26	0.00	5.07	5.08
27	6580	59	0.0005	10.25	7.81	7.81	0.70	1.62	9.00	25.20	1.59	0.36	0.45	0.45	8.26	0.00	5.08	5.08
28	6750	57	0.0013	10.25	7.81	7.80	0.70	1.62	9.00	25.20	1.59	0.36	0.45	0.45	8.26	0.00	5.08	5.08
29	6756	60	0.0025	10.25	7.82	7.81	0.70	1.62	9.00	25.20	1.59	0.36	0.45	0.45	8.26	0.00	5.08	5.08
30	6902	64	0.0600	10.31	8.14	7.81	0.70	1.63	9.00	25.20	1.59	0.36	0.45	0.45	8.26	0.00	5.05	5.08
31	6908	57	0.0600	10.37	8.42	8.14	0.71	1.63	9.00	25.20	1.58	0.36	0.45	0.45	8.26	0.00	5.02	5.05
32	7018	53	0.0010	10.37	8.42	8.42	0.71	1.63	9.00	25.20	1.58	0.36	0.45	0.45	8.26	0.00	5.02	5.02
33	7208	58	0.0050	10.38	8.43	8.41	0.71	1.63	9.00	25.20	1.58	0.36	0.45	0.45	8.26	0.00	5.02	5.03
34	7274	52	0.0030	10.38	8.44	8.43	0.71	1.63	9.00	25.20	1.58	0.36	0.45	0.45	8.26	0.00	5.02	5.02
35	7322	62	0.0001	10.38	8.44	8.44	0.71	1.63	9.00	25.20	1.58	0.36	0.45	0.45	8.26	0.00	5.02	5.02
36	7382	60	0.0024	10.38	8.45	8.43	0.71	1.63	9.00	25.20	1.58	0.36	0.45	0.45	8.26	0.00	5.02	5.02
37	7388	58	0.0024	10.38	8.46	8.45	0.71	1.63	9.00	25.20	1.58	0.36	0.45	0.45	8.26	0.00	5.02	5.02
38	7412	49	0.0018	10.38	8.46	8.46	0.71	1.63	9.00	25.30	1.58	0.36	0.46	0.46	8.24	0.00	5.02	5.02
39	7510	51	0.0001	10.38	8.46	8.46	0.71	1.63	9.00	25.30	1.58	0.36	0.45	0.45	8.24	0.00	5.02	5.02
40	7516	59	0.0002	10.39	8.46	8.46	0.71	1.63	9.00	25.30	1.58	0.36	0.45	0.45	8.24	0.00	5.02	5.02
41	7590	55	0.0015	10.39	8.46	8.45	0.71	1.63	9.00	25.30	1.58	0.36	0.45	0.45	8.24	0.00	5.02	5.02
42	7596	54	0.0012	10.39	8.46	8.46	0.71	1.63	9.00	25.30	1.58	0.36	0.45	0.45	8.24	0.00	5.02	5.02
43	7620	64	0.0013	10.39	8.47	8.46	0.71	1.63	9.00	25.30	1.58	0.36	0.45	0.45	8.24	0.00	5.02	5.02
44	7626	63	0.0015	10.39	8.48	8.47	0.58	1.63	11.00	25.30	1.43	0.36	0.45	0.45	8.24	0.00	5.02	5.02
45	7700	72	0.7920	11.18	12.97	8.47	0.57	1.69	11.61	25.30	1.35	0.35	0.45	0.45	8.24	0.00	4.67	5.02
46	7720	65	0.0150	11.20	13.04	12.97	0.55	1.69	12.00	25.30	1.33	0.35	0.45	0.45	8.24	0.00	4.66	4.67
47	7720	75	0.0039	11.20	13.06	13.04	0.55	1.69	12.00	25.30	1.33	0.35	0.45	0.45	8.24	0.00	4.66	4.66
48	8870	60	0.2700	11.47	14.03	12.92	0.53	1.71	12.77	25.10	1.28	0.35	0.44	0.44	8.27	0.00	4.51	4.62
49	11300	70	0.2268	11.70	14.79	13.70	0.43	1.72	15.72	25.20	1.14	0.35	0.44	0.44	8.26	0.00	4.31	4.40
50	11775	75	0.8100	12.51	18.61	14.71	0.44	1.78	16.00	25.30	1.10	0.34	0.44	0.44	8.24	0.00	4.00	4.28
51	12350	70	0.0800	12.59	18.82	18.49	0.44	1.78	16.00	25.30	1.10	0.34	0.44	0.44	8.24	0.00	3.91	3.93
52	12400	68	0.0036	12.59	18.82	18.81	0.44	1.78	16.00	25.30	1.10	0.34	0.44	0.44	8.24	0.00	3.90	3.90
53	13050	60	0.0072	12.60	18.70	18.68	0.44	1.78	16.00	25.30	1.10	0.34	0.44	0.44	8.24	0.00	3.82	3.83

confluence. Adoption of this option would change the water quality to Class 'B' upto 5.25km d/s from reference point. However, this is not feasible just now.

5.5.2.3 *Flow augmentation and waste water treatment*

Let us consider the case for combined impact by flow augmentation by $6m^3$ headwater (DO= 8mg/l and BOD= 1.0mg/l) and setting up two mini STP at 7700m d/s and 11775m d/s from reference point to treat the waste water discharged by the drain no.45 and 50 respectively. The quality and quantity of wastewater discharge by drain no. 45 is

Flow of waste water = 0.798 m^3/sec

BOD = 72 mg/l

DO = 0 mg/l

For drain no. 50,

Flow of waste water = 0.81 m^3/sec

BOD = 75 mg/l

DO = 0 mg/l

Let assume after treatment, STP effluent has BOD = 20 mg/l and DO = 6mg/l. If this option is exercised, then there will be significant impact on DO and BOD of the downstream water. The modified value of DO and BOD is given in Table 5.20. And the comparison of DO and BOD value before and after flow augmentation is shown in Fig.5.18. The observed values of other parameter after simulation by $6m^3$ headwater and setting up of two STP are given in Table 5.21.

The values of DO and BOD of the STP effluent are substituted into the model in place of DO and BOD values of drain no.45 and 50 respectively with $6m^3$ headwater. It is observed that, the BOD remains below 3 mg/l upto 4.78 km d/s of reference point and 15 mg/l upto 11.3 km d/s from reference point. The maximum BOD (15.53 mg/l) occurs at 12.4 km d/s from reference point. The BOD at outfall is 15.42 mg/l. In case of DO, it is observed that, it will remain above 5 mg/l upto 6.3 km d/s from reference point. The DO will remain more than 4.1 mg/l upto its outfall. Adoption of this option would change the water quality to class 'B' upto 4.78 km d/s from reference point. Further d/s from this point, the BOD will reduce significantly as compared to other options.

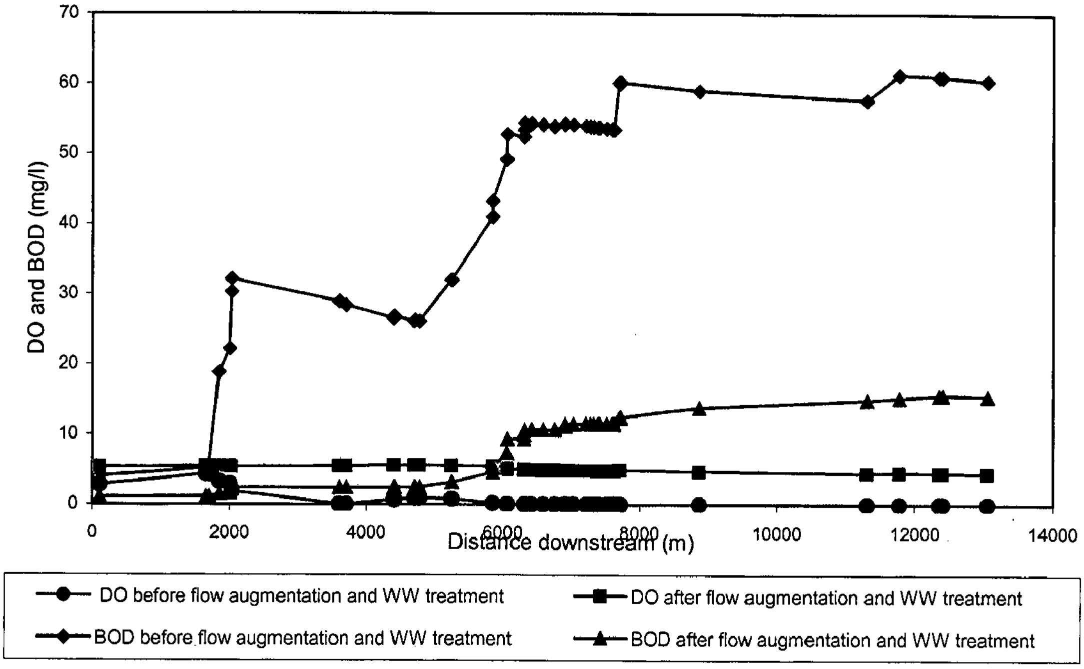

Fig.5.18 Comparison of DO and BOD after combined effect of flow augmentation and waste water treatment

Table 5.20 Observed values of DO and BOD before and after flow augmentation by 6m^3 head water and waste water treatment

Sl. No.	Dist. D/s from ref. point(m)	DO before flow augmentation and WW treatment	DO after flow augmentation and WW treatment	BOD before flow augmentation and WW treatment	BOD after flow augmentation and WW treatment
1	100	2.80	5.38	4.00	1.05
2	1650	4.28	5.48	5.18	1.09
3	1700	4.27	5.48	5.45	1.09
4	1850	3.20	5.45	18.86	1.47
5	2000	2.86	5.45	22.20	1.62
6	2030	2.01	5.39	30.28	2.19
7	2030	1.86	5.37	32.11	2.36
8	3600	0.00	5.48	28.96	2.35
9	3700	0.00	5.48	28.43	2.36
10	4400	0.60	5.54	26.59	2.37
11	4410	0.60	5.54	26.86	2.39
12	4700	0.83	5.56	26.14	2.40
13	4710	0.83	5.56	26.28	2.42
14	4780	0.84	5.56	26.14	2.42
15	5250	0.77	5.53	32.05	3.09
16	5850	0.16	5.46	41.04	4.53
17	5850	0.14	5.38	43.31	5.23
18	6050	0.00	5.20	49.24	7.32
19	6060	0.00	5.03	52.76	9.28
20	6060	0.00	5.03	52.78	9.29
21	6300	0.00	5.03	52.44	9.29
22	6300	0.00	4.98	53.38	9.89
23	6308	0.00	4.97	53.39	9.91
24	6308	0.00	4.92	54.41	10.54
25	6410	0.00	4.92	54.30	10.58
26	6416	0.00	4.91	54.33	10.63
27	6580	0.00	4.91	54.13	10.62

Contd...

...Contd. Table 5.20

Sl. No	Dist. D/s from ref. point(m)	DO before flow augmentation and WW treatment	DO after flow augmentation and WW treatment	BOD before flow augmentation and WW treatment	BOD after flow augmentation and WW treatment
28	6750	0.00	4.91	53.90	10.61
29	6756	0.00	4.91	53.90	10.62
30	6902	0.00	4.87	54.17	11.05
31	6908	0.00	4.83	54.28	11.42
32	7018	0.00	4.83	54.15	11.41
33	7208	0.00	4.83	53.92	11.42
34	7274	0.00	4.83	53.84	11.43
35	7322	0.00	4.83	53.78	11.43
36	7382	0.00	4.83	53.71	11.44
37	7388	0.00	4.83	53.71	11.45
38	7412	0.00	4.83	53.68	11.46
39	7510	0.00	4.83	53.56	11.45
40	7516	0.00	4.83	53.55	11.45
41	7590	0.00	4.82	53.46	11.45
42	7596	0.00	4.82	53.45	11.46
43	7620	0.00	4.82	53.43	11.46
44	7626	0.00	4.82	53.43	11.47
45	7700	0.00	4.93	60.11	12.29
46	7720	0.00	4.93	60.12	12.38
47	7720	0.00	4.92	60.15	12.41
48	8870	0.00	4.73	59.00	13.77
40	11300	0.00	4.49	57.70	14.84
50	11775	0.00	4.58	61.34	15.19
51	12350	0.00	4.48	61.05	15.52
52	12400	0.00	4.48	61.02	15.53
53	13050	0.00	4.41	60.47	15.42

Table 5.21 Observed values of parameters of the model after flow augmentation by 6m^3 head water and waste water treatment

Drain No.	Dist. D/s from ref. point (m)	BOD (mg/l) of the drain water	Flow of the drain, Q_i (m^3/sec)	Flow of river after mixing (m^3/sec)	BOD of river water after mixing (mg/l)	BOD just before the point of discharge	Velocity of flow of river (m/s)	Average water depth (m)	Width of flow (m)	Temperature (^{0}C)	k_2	k_1	$(k_1)_T$	k_r	Cs (mg/l)	DO of drain water	DO of river water after mixing	DO just before the point of discharge
1	100	4	0.1080	6.11	1.05		1.54	1.29	3.08	24.30	3.34	0.40	0.48	0.48	8.39	2.80	5.38	
2	1650	48	0.0050	6.11	1.09	1.05	1.35	1.29	3.53	24.30	3.12	0.40	0.48	0.48	8.39	0.00	5.48	5.49
3	1700	50	0.0008	6.11	1.09	1.09	1.64	1.29	2.90	24.30	3.44	0.40	0.48	0.48	8.39	0.00	5.48	5.48
4	1850	53	0.0450	6.16	1.47	1.09	1.47	1.29	3.25	24.30	3.24	0.40	0.48	0.48	8.39	0.00	5.45	5.49
5	2000	54	0.0180	6.18	1.62	1.47	1.62	1.29	2.95	24.40	3.40	0.39	0.48	0.48	8.38	0.00	5.45	5.46
6	2030	50	0.0730	6.25	2.19	1.62	1.28	1.30	3.76	24.40	3.00	0.39	0.48	0.48	8.38	0.00	5.39	5.45
7	2030	55	0.0200	6.27	2.36	2.19	1.28	1.30	3.76	24.40	2.99	0.39	0.48	0.48	8.38	0.00	5.37	5.39
8	3600	57	0.0010	6.27	2.35	2.34	0.69	1.30	7.00	24.80	2.19	0.39	0.49	0.49	8.32	0.00	5.48	5.48
9	3700	50	0.0015	6.27	2.36	2.35	0.67	1.30	7.20	24.90	2.16	0.39	0.49	0.49	8.30	0.00	5.48	5.48
10	4400	57	0.0025	6.27	2.37	2.34	0.64	1.30	7.50	25.10	2.12	0.39	0.50	0.50	8.27	0.00	5.54	5.54
11	4410	60	0.0025	6.28	2.39	2.37	0.64	1.30	7.50	25.10	2.12	0.39	0.50	0.50	8.27	0.00	5.54	5.54
12	4700	40	0.0030	6.28	2.40	2.38	0.60	1.30	8.00	25.20	2.05	0.39	0.50	0.50	8.26	0.00	5.56	5.56
13	4710	50	0.0020	6.28	2.42	2.40	0.60	1.30	8.00	25.20	2.05	0.39	0.50	0.50	8.26	0.00	5.56	5.56
14	4780	51	0.0010	6.28	2.42	2.41	0.60	1.30	8.00	25.20	2.05	0.39	0.50	0.50	8.26	0.00	5.56	5.56
15	5250	60	0.0750	6.36	3.09	2.41	0.54	1.31	9.00	25.20	1.92	0.39	0.50	0.50	8.26	0.00	5.53	5.60
16	5850	69	0.1440	6.50	4.53	3.07	0.55	1.32	9.00	25.20	1.91	0.39	0.50	0.50	8.26	0.00	5.46	5.58
17	5850	56	0.0900	6.59	5.23	4.53	0.55	1.33	9.00	25.20	1.90	0.39	0.49	0.49	8.26	0.00	5.38	5.46
18	6050	65	0.2400	6.83	7.32	5.22	0.56	1.35	9.00	25.20	1.87	0.39	0.49	0.49	8.26	0.00	5.20	5.39
19	6060	65	0.2400	7.07	9.28	7.32	0.57	1.37	9.00	25.20	1.84	0.38	0.49	0.49	8.26	0.00	5.03	5.20
20	6060	69	0.0015	7.07	9.29	9.28	0.57	1.37	9.00	25.20	1.84	0.38	0.49	0.49	8.26	0.00	5.03	5.03
21	6300	54	0.0030	7.08	9.29	9.27	0.57	1.37	9.00	25.20	1.84	0.38	0.49	0.49	8.26	0.00	5.03	5.03
22	6300	67	0.0750	7.15	9.89	9.29	0.58	1.38	9.00	25.20	1.84	0.38	0.49	0.49	8.26	0.00	4.98	5.03
23	6308	61	0.0030	7.15	9.91	9.89	0.58	1.38	9.00	25.20	1.84	0.38	0.49	0.49	8.26	0.00	4.97	4.98

Contd...

...Contd. **Table 5.21**

24	6308	70	0.0750	7.23	10.54	9.91	0.58	1.39	9.00	25.20	1.83	0.38	0.49	0.49	8.26	0.00	4.92	4.97
25	6410	60	0.0075	7.24	10.58	10.53	0.58	1.39	9.00	25.20	1.83	0.38	0.49	0.49	8.26	0.00	4.92	4.92
26	6416	61	0.0075	7.24	10.63	10.58	0.58	1.39	9.00	25.20	1.83	0.38	0.49	0.49	8.26	0.00	4.91	4.92
27	6580	59	0.0005	7.25	10.62	10.61	0.58	1.39	9.00	25.20	1.83	0.38	0.49	0.49	8.26	0.00	4.91	4.91
28	6750	57	0.0013	7.25	10.61	10.60	0.58	1.39	9.00	25.20	1.83	0.38	0.49	0.49	8.26	0.00	4.91	4.92
29	6756	60	0.0025	7.25	10.62	10.61	0.58	1.39	9.00	25.20	1.83	0.38	0.49	0.49	8.26	0.00	4.91	4.91
30	6902	64	0.0600	7.31	11.05	10.61	0.58	1.40	9.00	25.20	1.82	0.38	0.49	0.49	8.26	0.00	4.87	4.91
31	6908	57	0.0600	7.37	11.42	11.05	0.58	1.40	9.00	25.20	1.81	0.38	0.48	0.48	8.26	0.00	4.83	4.87
32	7018	53	0.0010	7.37	11.41	11.41	0.58	1.40	9.00	25.20	1.81	0.38	0.48	0.48	8.26	0.00	4.83	4.83
33	7208	58	0.0050	7.38	11.42	11.39	0.58	1.40	9.00	25.20	1.81	0.38	0.48	0.48	8.26	0.00	4.83	4.83
34	7274	52	0.0030	7.38	11.43	11.42	0.59	1.40	9.00	25.20	1.81	0.38	0.48	0.48	8.26	0.00	4.83	4.83
35	7322	62	0.0001	7.38	11.43	11.43	0.59	1.40	9.00	25.20	1.81	0.38	0.48	0.48	8.26	0.00	4.83	4.83
36	7382	60	0.0024	7.38	11.44	11.42	0.59	1.40	9.00	25.20	1.81	0.38	0.48	0.48	8.26	0.00	4.83	4.83
37	7388	58	0.0024	7.38	11.45	11.44	0.59	1.40	9.00	25.20	1.81	0.38	0.48	0.48	8.26	0.00	4.83	4.83
38	7412	49	0.0018	7.38	11.46	11.45	0.59	1.40	9.00	25.30	1.81	0.38	0.49	0.49	8.24	0.00	4.83	4.83
39	7510	51	0.0001	7.38	11.45	11.45	0.59	1.40	9.00	25.30	1.81	0.38	0.49	0.49	8.24	0.00	4.83	4.83
40	7516	59	0.0002	7.39	11.45	11.45	0.59	1.40	9.00	25.30	1.81	0.38	0.49	0.49	8.24	0.00	4.83	4.83
41	7590	55	0.0015	7.39	11.45	11.44	0.59	1.40	9.00	25.30	1.81	0.38	0.49	0.49	8.24	0.00	4.82	4.83
42	7596	54	0.0012	7.39	11.46	11.45	0.59	1.40	9.00	25.30	1.81	0.38	0.49	0.49	8.24	0.00	4.82	4.82
43	7620	64	0.0013	7.39	11.46	11.45	0.59	1.40	9.00	25.30	1.81	0.38	0.49	0.49	8.24	0.00	4.82	4.82
44	7626	63	0.0015	7.39	11.47	11.46	0.48	1.40	11.00	25.30	1.64	0.38	0.49	0.49	8.24	0.00	4.82	4.82
45	7700	20	0.7920	8.18	12.29	11.46	0.48	1.47	11.61	25.30	1.53	0.37	0.48	0.48	8.24	6.00	4.93	4.82
46	7720	65	0.0150	8.20	12.38	12.29	0.47	1.47	12.00	25.30	1.51	0.37	0.48	0.48	8.24	0.00	4.93	4.93
47	7720	75	0.0039	8.20	12.41	12.38	0.47	1.47	12.00	25.30	1.50	0.37	0.48	0.48	8.24	0.00	4.92	4.93
48	8870	60	0.2700	8.47	13.77	12.24	0.44	1.49	12.77	25.10	1.44	0.37	0.47	0.47	8.27	0.00	4.73	4.88
49	11300	70	0.2268	8.70	14.84	13.36	0.37	1.51	15.72	25.20	1.28	0.37	0.47	0.47	8.26	0.00	4.49	4.61
50	11775	20	0.8100	9.51	15.19	14.74	0.38	1.57	16.00	25.30	1.23	0.36	0.46	0.46	8.24	6.00	4.58	4.45
51	12350	70	0.0800	9.59	15.52	15.06	0.38	1.58	16.00	25.30	1.22	0.36	0.46	0.46	8.24	0.00	4.48	4.52
52	12400	68	0.0036	9.59	15.53	15.51	0.38	1.58	16.00	25.30	1.22	0.36	0.46	0.46	8.24	0.00	4.48	4.48
53	13050	60	0.0072	9.60	15.42	15.39	0.38	1.58	16.00	25.30	1.22	0.36	0.46	0.46	8.24	0.00	4.41	4.41

CHAPTER-6

CONCLUSIONS

6.1 CONCLUSIONS

From the study, the following conclusions are drawn.

1) The existing water quality of the river is varying throughout the stretch. The BOD is increasing, while DO is decreasing towards downstream stretch of the river. The water body is grossly polluted with high BOD and low DO.
2) The stretch of the river within the city is not conforming to the use based classification. According to the use of this water body, it should have been class B, while present water quality shows its status as class E.
3) Out of the various indices, NSF WQI is determined in this study. This shows that, water quality is bad throughout the stretch as its value is < 50.
4) To make the water quality conforming to DBU, various alternative solutions have been considered. Out of the solutions, the flow augmentation from river Basistha in combination with STP has been found to be most suitable.
5) The impact of industrial wastewater is insignificant. Municipal wastewater is the major contributor towards the degradation of water quality of river Bharalu.

6.2 LIMITATION OF THE STUDY

The major limitations of the study were:

a) Only the grab sample were collected
b) Sediment oxygen demand has not been studied
c) Nonpoint source pollution has not been considered
d) The flow measurement and water quality analysis undertaken during the month of October 2005 which is not representative of post monsoon season due to the shortening of monsoon in Assam during that year.
f) Diurnal variation of water quality of the drain is not studied.

6.3 FURTHER SCOPE OF WORK

The sediment oxygen demand, benthic oxygen demand, non point source pollution is to be studied further for the development of more accurate BOD and DO model. The hydrological parameters like flow variation throughout the year; stage discharge and velocity relationship of the river are to be studied more extensively.

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