DEVELOPMENT OF REFINED DO MODEL FOR HIGHLY POLLUTED GOMTI RIVER AT LUCKNOW STRETCH

A PROJECT REPORT SUBMITTED IN PARTIAL FULFILMENT OF THE

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CERTIFICATE

It is to certify that the work presented in this report entitled "**DEVELOPMENT OF REFINED DO MODEL FOR HIGHLY POLLUTED GOMTI RIVER AT LUCKNOW STRETCH**'' by **Nuzhat Parveen, Roll no.2K14/ENE/13** in partial fulfilment of the requirement for the award of the degree of Master of Technology in Environmental Engineering, Delhi Technological University (Formerly Delhi College of Engineering),Delhi, is an authentic record. The work is being carried out by her under my guidance in the academic year 2016. This is to my knowledge has reached requisite standards.

The work embodied in this major project has not been submitted for the award of any other degree to the best of my knowledge.

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I am grateful to my parents for their moral support, they have been always around to cheer me up, in the odd times of this work.

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DECLARATION

I, hereby declare that the work being presented in the Project Report entitled "DEVELOPMENT OF REFINED DO MODEL FOR HIGHLY POLLUTED GOMTI RIVER AT LUCKNOW STRETCH'' is an original piece of work and an authentic report of my own work carried out during of 4th semester as a part of major project.

The data presented in this report was generated and collected from various sources and is being utilized by me for the submission of my Major Project Report to complete the requirements of Master's Degree of Examination Environmental Engineering, as per Delhi Technological University curriculum.

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ABSTRACT

This analysis was aimed to determine the current status of river Gomti along the Lucknow stretch. Physico-chemical characteristics, level of organic matter, various heavy metals and sewage pollution and their variation has been studied from upstream to downstream of Lucknow. Gaughat is upstream region and Pipraghat is downstream of Lucknow. Analysis has been done from upstream to downstream regions of the river. Water samples are subjected to analysis like BOD and DO. Study concluded that large number of drains are responsible for pollution in river Gomti that enter directly into the river carrying untreated industrial and domestic waste. Some other causes are like removal of solid wastes at pumping stations is still manual, sometimes pumping station does not work , so the sewage waste is by passed directly to the river Gomti or when most of the branch and trunk sewers do not function properly. Study indicates that the water quality has been deteriorated from Gaughat to Pipraghat due to discharge of untreated waste water from about 26 major drains in its entire course. Water of the river Gomti at upstream of Lucknow i.e.Gaughat showed minimum BOD and maximum dissolved oxygen. But due to the presence of 26 drains dissolved oxygen level decreases along its stretch and showed minimum DO at Pipraghat.

Keywords: Pollutants, B.O.D, Dissolved Oxygen ,River Water Pollution

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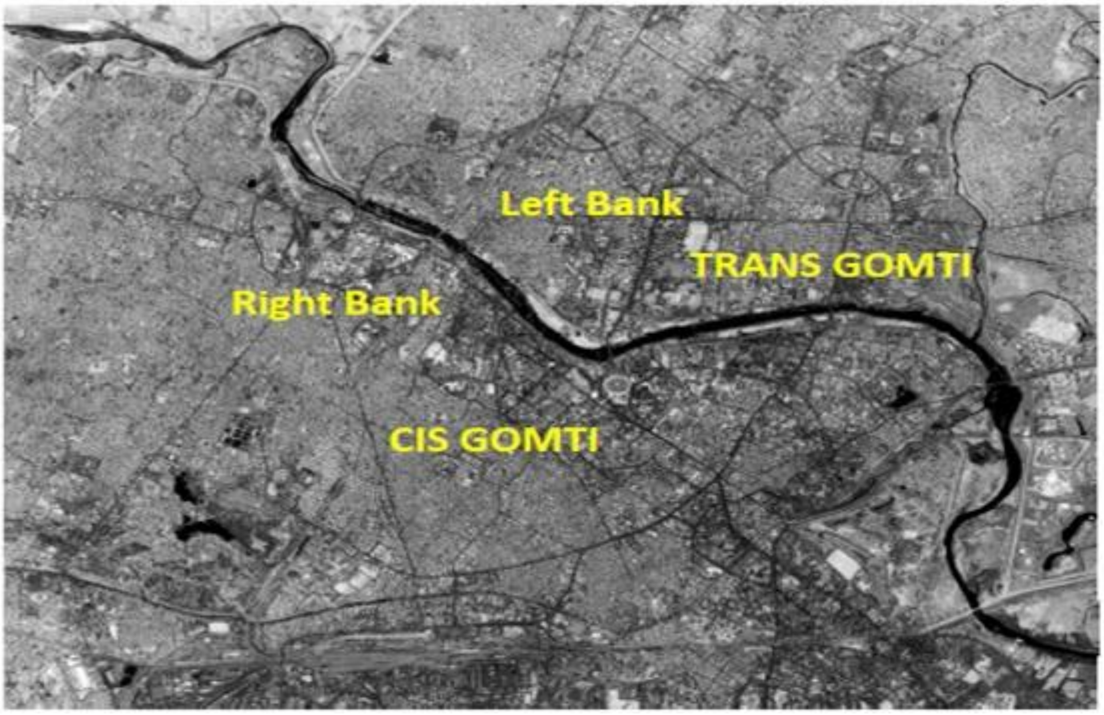
INTRODUCTION

CHAPTER-1
INTRODUCTION

Lucknow district is a part of Central Ganga Plain in the state of Uttar Pradesh covering an area of 2,528 km^2 and lies between North latitudes 26°30' and 27°10' and East longitudes 80°30'and 81°13'. The Gomati River, the chief geographical feature, meanders through the city, dividing it into the Trans-Gomati and Cis-Gomati regions. The climate of Lucknow city is of subtropical type with three distinct seasons namely summer, monsoon and winter. The maximum temperature remains 45°C during month of May and minimum temperature remains 5°C during January. The average annual rainfall of the city is 1014.7 mm.

Gomti river is one of the important tributaries of Ganga river which originates from a lake Fulhar Jheel near Mainkot in Madhotanda, Uttar Pradesh. Gomti is an alluvial river, that meets the Ganga river in Ghazipur bordering Varanasi. The river is perennial in nature and is characterised by stagnant flow throughout the year except during the monsoon season when heavy rainfall causes high increase in BOD and decrease in DO. It also results in transportation of sediments along the river. Besides Lucknow , river receives the untreated waste water and industrial effluents from more than 45 drains and there are many tributaries that carry industrial waste from different towns. Some of the stretches of the river looks like a drain due to heavy pollution . Day by day the condition of the river has become worse. Studies showed that the level of dissolved oxygen become lower at many places. Water at Gaughat i.e upstream of Lucknow was good for all beneficial uses but as we go downstream of Lucknow stretch it is severely polluted due to 26 drains resulting in the lowest dissolved oxygen at Pipraghat. The river water is polluted with various heavy metals like copper , chromium, zinc, cadmium, nickel and lead. It is found that there is increase in dissolved oxygen content during the winter season while during summer DO decrease drastically except at Gaughat. River is highly polluted along the Lucknow stretch having high value of BOD and COD during summer and rainy season. Higher concentration of heavy metals were found during rainy season as compared to summer and winter. Due to dumping of garbage along the river bed and disposal of untreated waste, the site of river Gomti showed increasing trend of turbidity from Gaughat to Pipraghat. Estimates show that 25 nullahs, including Sarkata, Pata nullah, and Wazirganj, pour around 350 MLD of wastewater daily into the Gomti.



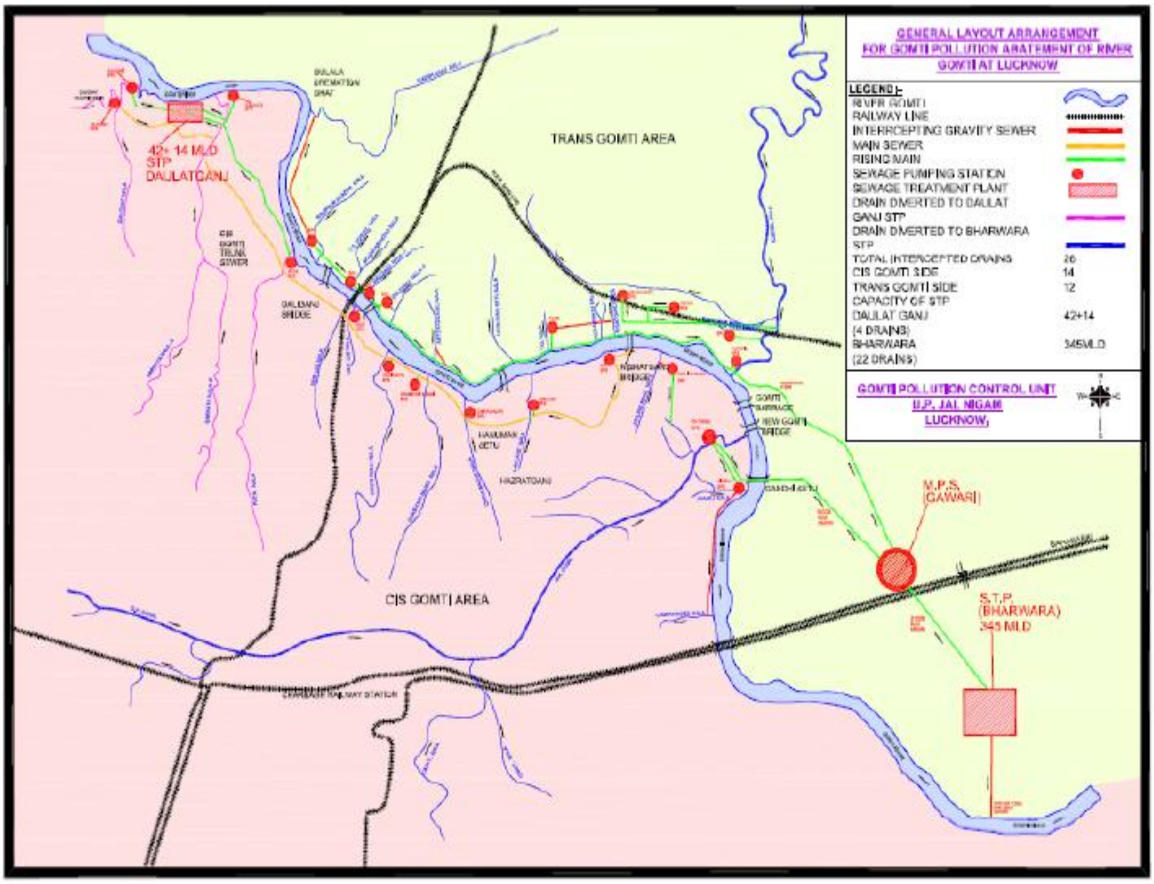


Fig 1.1 Various Cis and Trans drains entering Gomti river

Source : Gomti Pollution Control Board and U.P.Jal Nigam

1.1 Wastewater generation

- Around 85%of the land area of Lucknow city is situated on the central Ganga alluvial plain and stretches across both the banks of the Gomti river.
- 26 drains affects the water quality of river Gomti in Lucknow city, which submerged from Cis side (14 drains) and Trans side (12 drains).
- Number of drains are like Gaughat Drain, Sarkata Drain, Pata Drain, NER U/S, NER D/S, Wazirgang Drain, Ghasiare Mandi Drain, China Bazar Drain, LA-PLACE, Parag Dairy Drain, GH Canal, I.G.Nivas, Jiamau Drain, Lamartenier, Khadra Drain, MohanMeakin, Daliganj no.1, Daliganj no.2,, Arts college, Hanuman Setu, TGPS, kedarnath, Nishatganj Drain, Baba ka purva, Kukrail Drain and Rahimnagar Drain.
- Cis-Gomti side are comparatively lower than the areas on Trans- Gomti side.
- Out of 14 Cis-Gomti side drains, 12 drains are located in the upstream and 2 are located into downstream of Barrage.
- All of the 12 Trans-Gomti drains merge into river Gomti in the upstream of Barrage.
- The gross available water supply in the city is about 490 MLD.
- Around 240 MLD of the total supply is taken from up to 500 tube wells and 250 MLD from Gomti river.
- The combined discharge of the 26 drains was estimated for the year 2004 as 390 MLD.
- Currently it is estimated to be in the range of 425 - 450 MLD.
- It does not include areas that are not connected by sewerage systems of the city.
- The river is hardly able to dilute the incoming sewage of the city resulting in a steep rise in bacterial count.

Table 1.1 : Estimation of sewerage system at Lucknow

	Lucknow city	
Census 2001 **(**Population)	21.86	Lacs
Census 2011 **(**Population)	28.13	Lacs
Design population	42.43/64.22	Lacs
Area of ULB	340	Sq.km

Sewerage generation(yr 2010/2040)	344/787	MLD
Existing sewerage system		
Length of sewer	1950	Km
SPS (Nos)	30	
STP (no/capacity)	2/401	MLD
Status of STP	Working	

Source: Gomti Pollution Control Board

Table 1.2 : Sewage treatment plants in Lucknow city

District	Sewer	SPS	STP	Location of STP
I	Complete network	1	42+14 MLD	Daulatganj
II	Complete network	1	108 MLD	Khwajapur
III	Complete network	3	345 MLD	Bharwara
IV	Complete network	2	270 MLD	Mastemau
		Total	779 MLD	

Source :Gomti Pollution Control Board

Table 1.3 : Operational STP

STP	Capacity	Technology	Drains	Length of trunk and branch sewer lines
Daulatganj	56 MLD	FAB	Waste water from Gaughat,Sarkata ,Pata,Nargaria-treated waste	339 km

			water is discharged in Gomti river through Sarkata Nala	
Bharwara	345 MLD	UASB		860 km
Total	401 MLD			

Source Gomti Pollution Control Board

1.2 Reasons behind continuous increase in waste water in Gomti river :

- Removal of solid waste from the drain at the pumping stations is still manual.
- Sewage is by-passed to River Gomti when Pumping **Station** doesn’t work, or when flow exceeds.
- Most of the branch and old trunk sewers have become defunct- natural drains are used as carriers of wastewater.
- The Gomti barrage constructed at downstream end of the town impounds most of the sewage entering the river. This also stops the river from flowing.

Fig 1.2 : Showing the condition of nullahs or drains that enters the Gomti river

Fig 1.3 Showing Gomti barrage at downstream of Lucknow

1.3 Objectives of the study

- To study the concept of water quality modeling .
- To study various water quality modeling software in use.
- To develop DO – BOD model.
- To study the physico-chemical characteristics of Gomti River at Lucknow stretch.
- To calculate the variation of dissolved oxygen for the river Gomti at Lucknow stretch using generalized modeling equations and MATLAB as a programming tool.

CHAPTER-2

LITERATURE REVIEW

CHAPTER-2
LITERATURE REVIEW

2.1 General

Mathematical modeling of natural systems begins with the identification of the important physical, chemical and biological processes relevant to the system under study. A mathematical expression can then be developed in the form of a simple single equation or complex set of equations for the system. The results from analytical or numerical solutions of these equations are then verified with the actual field data. The whole process sometimes needs to be repeated in case of unsatisfactory results (Kiely 1998). DO is one of the most important parameter for the aquatic health of a river and relates to a number of important processes such as, settling and oxidation of CBOD and NBOD, sediment oxygen demand, photosynthesis and respiration and atmospheric reaeration. Mathematical models are extensively used to develop appropriate strategies to maintain adequate dissolved oxygen levels in the rivers. Low DO levels or anaerobic conditions can kill fish and unbalance the aquatic ecosystems. These conditions usually occur under low flow periods in freshwater bodies. To cater for such conditions, wastewater control strategies based on calibrated and verified water quality models need to be formulated to meet desired water quality standards.

Mathematical formulations of watershed characteristics, tributaries and river flows, wastewater characteristics and water quality in the rivers are used to manage optimally the freshwater bodies. Waste loads enter into the rivers from both Point Sources (PS) and Non Point Sources (NPS). A Total Maximum Daily Load (TMDL) is the sum of the allowable loads of a single pollutant from all contributing point and non point sources. The total load estimation must include a margin of safety for model uncertainties and seasonal variations to ensure that the water body can be used for the designated purposes (USEPA 1991).

2.2 Geological and Geomorphological set up of the Gomti Basin

In the Indian sub-continent, the Indo-Gangetic Plain is one of the largest fluvial sedimentary basins of the world. It is located between the world's most tectonically active regions, the Himalaya in the north and stable Indian Craton in the south. The entire Gomti basin is underlain by thick alluvial sediments of the Quaternary age. The alluvial sediments consist of boulders, pebbles, gravels, sand, silt, clay and *kankars*. The unconsolidated unit may be further subdivided into younger alluvium. The younger alluvium occupies the present day flood plains while the older group occupies elevated portions mainly the *doab* portions. The older alluvium is characterized by *kankar* nodules at depth otherwise it is similar to the younger alluvium. Incision of the Gomti river and its valley has been studied using characteristics of longitudinal profile, escarpment heights, valley morphology and channel sediment characteristics by Thakur *et al.* (2009). The tectonic-driven incision is younger and superimposed over the base level-linked incision. The role of climate-derived factors in fluvial incision is secondary and not easy to evaluate.

Longitudinal profile of the Gomti river runs from 185 to 60 m above mean sea level and shows three prominent breaks in slope. The conspicuous convexity in the profile is located above the sub-surface Faizabad Ridge and may be related to the movement along this ridge. Downstream wave-like variation in average escarpment height reveals undulating topography with prominent upwarps and downwarps attributed to the compressional tectonics of the Ganga Plain.

Monsoon-controlled climate of the Ganga Plain controls rainfall received by the Gomti river Basin and discharge of the Gomati river. The discharge of the Gomati river increases downstream due to contributions from surface runoff and groundwater. In the upper segment of the Gomti river, incision is low, although rainfall is high; on the contrary in the middle and lower segments, incision is high, while rainfall is low. In the middle segment, water discharge is less than in the lower segment, but it shows maximum incision. Further, there is wave-like pattern of incision. Indicating that rainfall alone can not explain the incision pattern of the Gomti river.

Extensive aquifers occur in the quaternary alluvium formations at various depths. The phreatic aquifers are unconfined in nature and main source of water from drinking purposes. These are classified as follows:

a). Phreatic aquifers up to depth of 50 m below the ground level

b). shallow aquifers between 50 m to 150 m below the ground level

c). medium depth aquifers between 150 m to 300 m below the ground level

d). deep aquifers between 300 to 500 m below the ground level

The river is divided into three segments:

(i) The upper segment of the river till u/s of Sitapur

(ii) The middle segment of the river – from d/s of Sitapur to u/s of Sultanpur

(iii) The lower segment of the river – from d/s of Sultanpur to the confluence with the Ganga

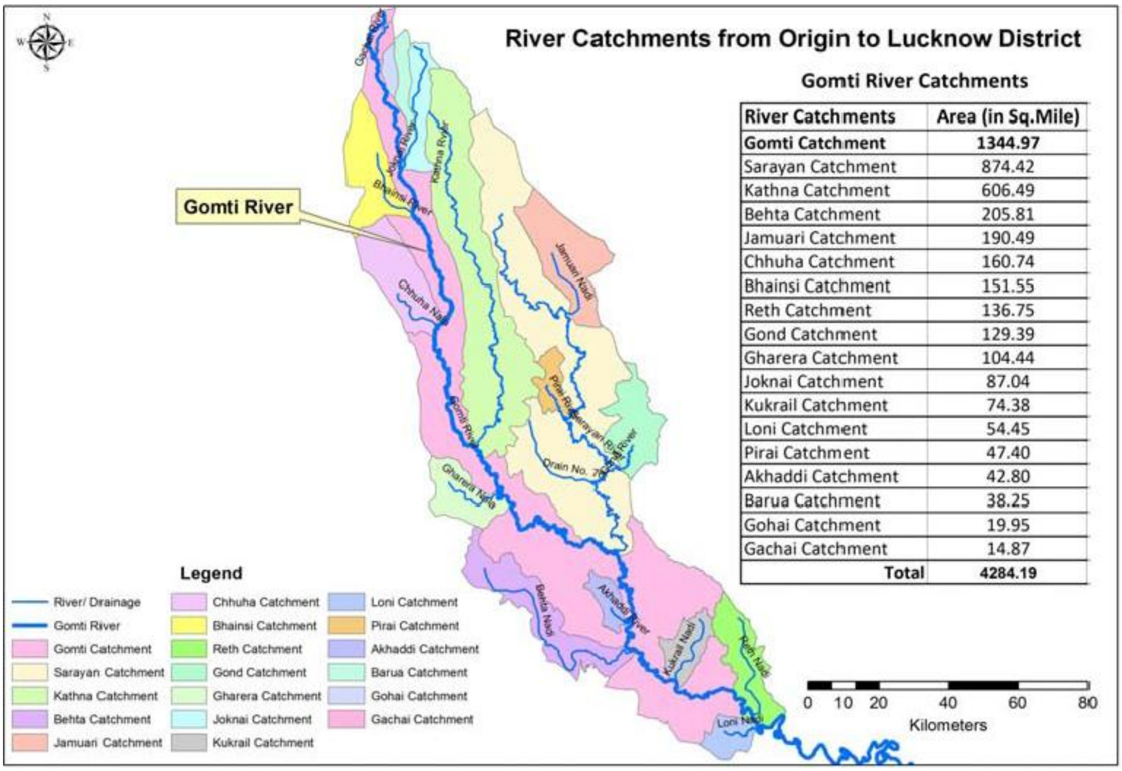


Fig. 2: The upper and middle segment showing major tributaries from origin to Lucknow district. (Venkatesh Dutta et al.,2011)

2.3 Pollution load due to various drains entering river Gomti (Lucknow stretch)

Srivastava Shivani et al.,2011 concluded that the anthropogenic discharges constitute a constant polluting source, whereas surface runoff is a seasonal phenomenon, largely affected by climate within the basin. On comparing, the mean level of Total Solids, Total Dissolved Solids, Total Suspended Solids, conductivity, and sulphate at Trans side were found to be significantly different and higher than the respective level at Cis side. (Karbassi et al.,2007; Nazafpour et al., 2008; Singh et al.,2004) .

The 26 drains form 5 different clusters of similar physico-chemical characteristics.

- The 6 drains viz, Gaughat, Arts College, Baba ka Purva, Ghasiare mandi, NER U/S, and Sarkata which form the first cluster (cluster1) were the least polluted and considered to be safe.

- Similarly, five drains: GH canal, Mohan-Meakin, IG Nivas, Hanuman setu, and Jiamau forms the second cluster (cluster 2), which comprises relatively high pollution than cluster 1 considered to be "low polluted".
- The four drains Pata, Wazirganj, Parag dairy, and Kedarnath forms the third cluster stated to be "moderately polluted".
- The fourth cluster of five drains, NER D/S, China bazaar, Dialiganj No. 1, Lamartenier, Daligang No.2, and TGPS stated to be "high polluted".
- The fifth cluster which comprises 5 drains, Khadra, Rahim nagar, Nishatganj, Kukrail, and LA-PLACE stated to be "severely polluted".

Bhaskaran et al. (1965 in Trivedi, 2001) carried out physico-chemical studies on the river Gomti at Lucknow and concluded that the river water was significantly polluted showing lower value of DO at many places. Arora *et al.,* (1973 in Trivedi, 2001) observed that the river Gomti at Lucknow was severely polluted. Bhargawa and Ram Tirath (1982) studied water quality of river Gomti at Lucknow and concluded that water quality at upstream of Gaughat was good for almost all beneficial uses, and water quality downstream of Lucknow was heavily polluted and it was not suitable for bathing, drinking without treatment, fishing, recreation etc. Kuwar and Kant (1987) analyzed the water of river Gomti at Lucknow at several place for few heavy metals and observed that it was polluted with copper (Cu), zinc (Zn), and chromium (Cr). Pathak (1991) analysed the physico-chemical parameters and heavy metal contents of river Gomti from Gaughat to Malhar. The authors observed increased DO during winter season with its drastic depletion during the summer months at all station, except at Gaughat. The author also concludes that the cadmium (Cd) and nickel (Ni) in Gomti river was little on the higher side respectively during monsoon and winter. Bhatt and Pathak (1992) concluded that river got highly polluted downstream of Lucknow due to human interference and input of municipal and industrial wastewater. Mishra, *et al.* (1994 in Trivedi, 2001) concluded that the river Gomti was highly polluted at Sahjahanpur, Kheri and Lucknow having high value of BOD and COD during summer seasons. Gaur *et al.* (2005) studied the impacts of domestic/industrial waste on the water and sediment chemistry of river Gomti with special references to heavy metals in different seasons (summer, winter and rainy). High concentration of all the six heavy metals namely Cd, Cr, Cu, Ni, Pb and Zn were noticed in water and sediments in rainy season compared to summer and water. Kuwar and Kant (1987) analyzed the water of river Gomti at Lucknow at several place for few heavy metals and observed that it was polluted with copper (Cu), zinc (Zn), and chromium (Cr). The authors observed increased DO during winter season with its drastic depletion during the summer months at all station, except at Gaughat. High concentration of all the six heavy metals namely Cd, Cr, Cu, Ni, Pb and Zn were noticed in water and sediments in rainy season compared to summer and winter.

Srivastava Anukool et al.,2011 concluded that the sites of Gomti river from Gaughat to Pipraghat showed an increasing trend in COD. The measure of COD determines the quantity of organic matter found in water. This makes COD useful as an indicator of organic pollution in surface water. Spatial Variations shows comparatively higher values at Lucknow (Mohan Meakin, and Piperaghat) in contrast to other sites. Spatial analysis reveals that BOD value was found to be more at Lucknow (that is Mohan Meakin(MM) and Piperaghat). The sites from Gaughat to Nishatganj showed significantly decreased Ph. Temperature of river water ranged from a minimum of 19.77 ± 0.98^{o}C to 32.59 ± 0.61^{o}C at different locations and in different seasons. Seasonal variations revealed total solids showed significantly higher values in post monsoon season and lower in pre monsoon season due to accumulation of carbonates and bicarbonates after heavy rainfall. Brijendra Pratap Singh and P.K. Tandon,2008 collected the water sample from the various sampling points of river Gomti were analysed at specific time intervals in the month of January, May and August in year 2007 and 2008. In the month of January, the sites of Gomti river showed a marked decrease in pH values and increase in conductivity from Gaughat to Pipraghat. In the month of January, May and August, the sites of Gomti river from Gaughat to Pipraghat showed an increasing trend in turbidity. The sites of Gomti river showed the significantly decrease values of dissolved oxygen from Gaughat to Pipraghat in both the years and an increasing trend in BOD and TDS from Gaughat to Pipraghat. Vivek k. Gaur,et al.2005 have selected the seven sampling sites for the study. All the sites cover only the Lucknow region. The names of the sites are Gaughat (I), Mohan Meakin (II), Martyr’s Memorial (III), Hanuman Setu (IV), Nishatganj bridge (V), Pipraghat (VI) and Malhaur (VII). Sources of heavy metals including tannery, sugar, beverages, paints, chemicals, fertilizers, batteries, automobiles, factories, food processing units, cement thermal power plants, petroleum refineries and sewage. The concentration of chromium ranged from 0.021–0.061 μg/ml in summer, 0.0–0.014 μg/ml in winter and 0.046–0.236 μg/ml in rainy season. The concentration of copper ranged from 0.012–0.019 μg/ml in summer, 0.0–0.006 μg/ml in winter,0.016–0.035 μg/ml in rainy season. Zn ranged from 0.056–0.083 μg/ml in summer, 0.030–0.091 μg/ml in winter and 0.042–0.064μg/ml in rainy season. The concentration of lead ranged from 0.005–0.038 μg/ml in summer, 0.004– 0.018μg/ml in winter and 0.020–0.055μg/ml in rainy season. The concentration of Ni ranged from 0.023–0.044 μg/ml in summer, 0.008–0.014 μg/ml in winter and 0.048–0.105 μg/ml in rainy season.

2.4 Hydrodynamic Modeling of Rivers

Hydro-geometry of a river is based on the hydrological characteristics and its geometry. Hydrological characteristics of any river are its velocity, flow and dispersion, whereas, the geometry consists of depth, width, cross-sectional area and slope of the river (Chapra, 1997). River flow is usually described by the continuity equation. Saint Venant equations are generally used for water quality modeling pruposes (Mahmood and Yevjevich 1975, Abbott 1979). Amongst the different forms of these steady and unsteady equations, a simplified form of steady state Manning equation is more commonly used (Rauch et al. 1998).The water quality models are coupled with hydrodynamic models to determine the resultant concentrations of the pollutants at any given location and time based on the mean velocity, depth and width and flow of the river (Palmer 2001).

The DO concentration is a function of numerous physical and biochemical processes . The principle inputs affecting the DO are municipal and industrial waste discharges, partially combined sewer overflows and separate sewer discharges that include: i) Reaeration from the atmosphere, ii) Photosynthesis oxygen production, iii) DO in incoming tributaries or effluents, whereas the sinks of DO include; i) Oxidation of CBOD, ii) Oxidation of NBOD, iii) Oxidation demand of sediments of water body, SOD and iv) Use of oxygen for respiration of aquatic plants. For appropriate DO modeling in any river CBOD must be distinguished from NBOD (Thomann & Mueller 1987). Moreover DO phenomenon in rivers and streams sometimes is also associated with ambient environmental conditions like wind speed, tides and morphology of the river. All these processes either act as sources of DO or as sinks of it. Different researchers have very well established these processes with respect to the overall DO phenomenon in rivers. River water quality models are used extensively in research. The application of mathematical models for the purpose dates back to the initial studies of oxygen depletion due to organic waste pollution by Streeter and Phelps (1925).

In India, limited river water quality modeling efforts have been made during the recent past for BOD and DO simulations. Bhargava 1983; Choudhary 1992; Ghosh and McBean 1998;

Jain 1996; Jain 1998; Jha 2001, 2004, 2005, Sharma 2000, have made their contributions towards it. Refined models for BOD and DO simulations in river Kali (Jha,Ojha and Bhatia 2007), which is one of the most polluted rivers in India , use of STREAM II as a modeling package to determine the pollution load due to organic matter in the River Yamuna during its course through Delhi, India (Sharma and Singh 2008) are some of the studies which were carried out few years back. Most of these studies are either carried out with limited input data sets or with limited parameters.

Yamuna being a major tributary to river Ganga has specially been focused for water quality conservation initiatives due to its grossly polluted status. The Ministry of Environment and Forest, to revitalize the river launched the Yamuna Action Plan, implemented under Ganga Action Plan (1985) on realizing the contribution of river Yamuna to the total load of river Ganga. Delhi has been identified with 26 industrial areas contributing their load to the river Yamuna (Paliwal and Sharma et al. 2007). The river has been getting a large amount of partially treated and untreated wastewater during its course through National Capital Territory (NCT) of Delhi, especially between Wazirabad and Okhla (Paliwal and Sharma et al. 2007).

Jha and Ojha (2007) developed a refined model to simulate BOD and DO form both point and non-point sources for Kali River, India . Their model excluding non-point sources is similar to the model proposed by Camp (1963). They observed very strong coefficient of correlation of 0.996 for calculated DO and observed DO in the field. One of the reasons for this strong correlation could be that, about 50 % of the reach is anaerobic, therefore, for zero DO no comparison can be made between observed and model values. Mladenov et al. (2005) included the effect of non-point source BOD (Sd) loads for DO modeling of Notwane River, Botswana. The non-point source BOD loading was calculated by multiplying estimated population of livestock with BOD loading rates ranging between 0.045 to 0.45kg/animal day (USEPA). Song and Brown (1990) used modified form of Streeter-Phelps to assess the uncertainty with correlated inputs using sensitivity analysis, First Order Error Analysis (FOEA) and Monte Carlo Simulation (MCS) on a hypothetical stream (Chadderton et al. 1982). Canale & Ownes (1995) used equation to model DO in river Seneca, New York.The model calibration showed strong correlation with the monitoring data.

Table 2.1: BOD and DO models for rivers

Name	BOD model	DO model
Camp (1963)	$L = Lo\, e^{-Kd\, t}$	$D = Do\, e^{-Ka\, t} + \frac{K_d\, Lo}{K_a - K_d}(e^{-Kd\, t} - e^{-Ka\, t})$
Gundelach & Castillo (1976)	$L = Lo\, e^{-(Kd+Ks)t} + \frac{B(1 - e^{-(Kd+Ks)t})}{K_d + K_s}$	$D = Lo\, e^{-Kat} + \frac{K_d\, Lo}{K_a - (K_d + K_s)}(e^{-(Kd+Ks)\, t} - e^{-Ka\, t}) + \frac{K_d\, B}{Ka(K_d + K_s)}(1 - e^{-Kd\, t}) - \frac{K_d\, B}{(Ka - (K_d + K_s))(K_d + K_s)}(e^{-(Kd+Ks)\, t} - e^{-Ka\, t}) - \frac{(P-R)}{K_a}(1 - e^{-Kat})$
Mladenov et al. (2005)	$L = Lo\, e^{-(Kd+Ks)t} + \frac{S_d(1 - e^{-(Kd+Ks)t})}{K_d + K_s}$	$D = Do\, e^{-Ka\, t} + \frac{K_d\, Lo}{K_a - K_r}(e^{-Kr\, t} - e^{-Ka\, t}) + \frac{K_n\, L_{no}}{K_a - K_n}(e^{-Kn\, t} - e^{-Ka\, t}) + \frac{S(1 - e^{-Kat})}{K_a\, H} - \frac{(P-R)}{K_a}(1 - e^{-Kat}) + \frac{K_d\, S_d}{K_r\, K_a}(1 - e^{-Kat}) - \frac{K_d\, S_d}{K_r(K_a - K_r)}(e^{-Kr\, t} - e^{-Ka\, t})$

where L is the BOD in the water at any point downstream of a river, mg/l; L_0 is the initial BOD in the river below the wastewater discharge, mg/l; K_d is the biochemical decomposition rate coefficient of organic matter, day^{-1}; Ka is the reaeration rate coefficient, day^{-1}; t is the travel time in the river, days ;D is the DO deficit of the river, mg/l; L_d is the distributed source, mg/l; (P-R) = net difference between oxygen production; Ks is the removal rate due to settling; K_r is the removal rate of carbonaceous organic matter; B=benthic oxygen demand in mg/l .

CHAPTER-3

WATER QUALITY OF GOMTI RIVER AT LUCKNOW STRETCH

CHAPTER-3
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The total stretch of Gomti river at Lucknow is divided into number of reaches: Gaughat to Kudyaghat , Kudyaghat to Mohan Meakin, Mohan Meakin to Nishatganj drain, Nishatganj drain to Upstream barrage, Upstream barrage to Pipraghat. Pollution of River Gomati has taken place due to disposal of sewage from various drains due to which water quality has deteriorated. Various water quality parameters of river Gomati has been discussed below.

3.1Dissolved oxygen (DO)

The stretch of Gomti river from Gaughat to Pipraghat showed decreasing trend of dissolved oxygen. Gaughat showed the maximum content whereas Pipraghat showed the minimum. The DO at Gaughat is maximum because the water at this site is least polluted from industrial, sewage and domestic waste. However, when river reaches the Gomti barrage and Pipraghat, it gets heavily polluted due to discharges from various cis and trans drains emptying into the river round the year. During rainy season dissolved oxygen decreases as compared to summer and winter as in rainy season runoffs from the agricultural fields and industries directly enter into the river without any treatment. At Gaughat , the water of the river is clean and no turbidity has been found. The water at Kudyaghat is slightly polluted due to the discharge from drain but the content of dissolved oxygen is sufficient enough so that the fishes can survive here. The dissolved oxygen level at Mohan Meakin during the winter and summer seasons is high as compared to the rainy season because of the heavy runoff. At this sampling location dissolved oxygen level decreases because of the pollution from drains and industries. At Nishatganj drain sampling location there is heavy depletion of dissolved oxygen because of the higher BOD level. This sampling site is almost at the middle of the city, therefore sullage content is high. The Gomti barrage constructed at downstream end of the town impounds most of the sewage entering the river. This also stops the river from flowing. The flow will become stagnant and there is high depletion of dissolved oxygen.

3.2 Biological oxygen demand (BOD)

Increasing trend of BOD was observed from upstream to downstream sites of Lucknow. Decomposition of organic matter is largely an aerobic process, so the demand and requirement of oxygen increases resulting decrease in the dissolved oxygen, thereby increasing BOD and COD. Lower value of BOD at Gaughat was found because of the negligible pollution at the upstream site. BOD content was found to be complementary to the DO values for entire stretch which can be referred from the figures given below. Detergents used by the washemen leads to increase in the phosphate content in the river water that causes growth of algae. Algal growth in water resulted in lowering of DO due to which the demand of oxygen increases which leads to the decomposition of organic matter incomplete. The content of BOD increases from Nishatganj drain to Pipraghat due to heavy disposal of industrial wastes. At Nishaganj the sullage content is very high because of the disposal of household wastes.

3.3 Chemical oxygen demand (COD)

The sites of Gomti river from Gaughat to Pipraghat also showed an increasing trend in COD. The demand of oxygen for the decomposition of biodegradable and non biodegradable organic matter increases from upstream to downstream. COD content was to be higher at Upstream barrage and Pipraghat sites.

3.4 pH

The pH is an important indicator of the water quality and the extent of the pollution in the river water. The sites from Gaughat to Nishatganj showed significantly decreased pH values. During the month from December to May, Gomti becomes highly polluted because the flow of river becomes minimum in dry weather as compared in monsoons. This was reported by the U.P. State Pollution Control Board in 1995. PH value becomes high due to the heavy runoff from industries, agricultural fields and other contaminated sites during the rainy season. It has been observed that pH of water gets drastically changed with time due to temperature changes, exposure to air and biological activity.

3.5 Total Solids (TS)

Study showed that there are significantly higher values of total solids in post monsoon season and lower in pre monsoon season. Due to high runoff from industrials and agricultural fields during the rainy season, total solids have been increased. It has been studied that Pipraghat and Upstream barrage showed higher total solids concentration as compared to other sampling sites because of the heavy industrial and sewage pollution.

3.6 Total Dissolved Solids (TDS)

In water, total dissolved solids are composed mainly of carbonates, bicarbonates, chlorides, phosphates and nitrates of calcium, magnesium, sodium, potassium and manganese, organic matter, salt and other particles. Study revealed that there are slightly higher values in post monsoon season which may be due to accumulation of carbonates. Its concentration is maximum at downstream of Lucknow as compared to other sampling sites.

3.7 Total suspended solids (TSS)

The analysis showed higher values of suspended solids at Lucknow i.e. Mohan Meakin, Upstream barrage, Piperaghat. It might be due to presence of high organic matter. The total suspended solids are composed of carbonates, bicarbonates, chlorides, phosphates and nitrates of calcium, magnesium, sodium, potassium, manganese, organic matter, salt and other particles. Higher values of suspended solids were found in post monsoon which might be due to run off from many bathing ghats, drain water discharge, industries, agricultural fields and garbage dump sites. Study showed lower values during winter and summer seasons.

3.8 Conductivity

Increasing levels of conductivity and cations are the products of decomposition and mineralization of organic materials. Due to dilution with rain water higher value was found at Mohan Meakin and Pipraghat during rainy season.

3.9 Hardness

Sulphates and chlorides of the metal caused permanent hardness in water. Carbonate and bicarbonate are also responsible for the temporary hardness. As the presence of organic matter increases, the level of dissolved oxygen decreases thereby increasing the concentration of carbon dioxide which gives more carbonate which when combine with calcium and magnesium ion gives hardness to the water . The sites of Gomti from Gaughat to Pipraghat showed the increasing trend in hardness. The reason behind this may be the use of soaps and detergents by washer men at various ghats, also because of high alkalinity in nearby drains, discharge of the domestic wastes through the drains and acid wastes. Increase in dissolved solids also increases the hardness as dissolved solids are composed of mainly carbonates, bicarbonates, phosphates etc of calcium and magnesium.

Table 3.1: Water quality data for river Gomti (summer average March to June for 1994-2010 data). (CPCB Delhi)

Location	DO(mg/l) 1994	BOD(mg/l) 1994	DO(mg/l) 2010	BOD(mg/l) 2010
Gaughat	8.9	2.5	8.35	3.34
Pipraghat	0.4	11	1.40	13.25

Table 3.2: Monthly variation of total coliform (MPN/ 100 ml) for the year 2014

Site	Jan	feb	Mar	Apr	May	June	july	aug	Sept	oct	nov	dec
Manjhighat	2400	2800	3200	-	-	2800	2200	2400	2300	2200	2100	2000
Gaughat	3500	4000	4700	5400	4900	3500	3200	3500	3300	2800	2400	2200
Kudyaghat	4900	7000	9400	-	-	17000	9200	9400	7900	7000	6300	4900
Mohan Meakin	17 $x10^3$	21 $x10^3$	22 $x10^3$	-	-	34 $x10^3$	32 $x10^3$	26 $x10^3$	21 $x10^3$	17 $x10^3$	14 $x10^3$	14 $x10^3$
Nishatganj	49 $x10^3$	70 $x10^3$	94 $x10^3$	-	-	70 $x10^3$	79 $x10^3$	94 $x10^3$	79 $x10^3$	70 $x10^3$	63 $x10^3$	46 $x10^3$
U/s barrage	70 $x10^3$	94 $x10^3$	110 $x10^3$	-	-	110 $x10^3$	94 $x10^3$	110 $x10^3$	94 $x10^3$	94 $x10^3$	79 $x10^3$	70 $x10^3$
Pipraghat	110 $x10^3$	130 $x10^3$	140 $x10^3$	94 $x10^3$	110 $x10^3$	140 $x10^3$	140 $x10^3$	130 $x10^3$	110 $x10^3$	110 $x10^3$	94 $x10^3$	79 $x10^3$
Bharwara	110 $x10^3$	140 $x10^3$	170 $x10^3$	-	-	170 $x10^3$	210 $x10^3$	140 $x10^3$	130 $x10^3$	110 $x10^3$	110 $x10^3$	94 $x10^3$

Source : Gomti Pollution Control Board

Table 3.3: The pysico-chemical characteristics summary(Mean±SD) of drains of Cis side and Trans side (Srivastava Shivani et al.,2007)

Characteristics	Cis side (n =14)	Trans side (n=12)	Total (n=26)	Permissible Limit(BIS)	Permissible Limit(WHO)
Temperature (degree C)	30.21 ± 0.79	30.83±0.94	30.50± 0.60	-	-
Ph	8.12 ± 0.15	8.16 ± 0.11	8.14 ± 0.09	6.5-8.5	-
DO(mg/l)	2.04 ± 0.41	1.14 ± 0.29	1.63 ± 0.27	6	>5
BOD (mg/l)	232.57 ± 34.05	293.75 ± 38.11	260.81 ± 25.63	<3	<3
TS (mg/l)	778.99 ± 77.68	1141.58 ± 73.07	946.34 ± 63.88	1000	1500
TDS (mg/l)	565.43 ± 58.63	796.17 ± 61.75	671.92 ± 47.60	500	1000
TSS (mg/l)	213.56 ± 35.30	345.42 ± 37.89	274.42 ± 28.52	500	500
Conductivity (mg/l)	1028.05 ± 106.60	1447.58 ± 112.27	1221.68 ± 86.55	-	-
Total alkalinity (mg/l)	307.93 ± 8.65	287.33 ± 9.96	298.42 ± 6.73	200	-
Total hardness (mg/l)	277.57 ± 9.42	291.17 ± 8.76	283.85 ± 6.50	300	-
Chlorine (mg/l)	89.24 ± 3.89	92.25 ± 2.63	90.63 ± 2.39	250	-
Phosphorus (mg/l)	126.37 ± 19.72	155.75 ± 16.85	139.93 ± 13.23	0.1	-
Sulphate (mg/l)	55.64 ± 10.84	102.08 ± 16.48	77.08 ± 10.47	200	-

CHAPTER-4

MODELING OF WATER BODIES

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4.1 Model

A model is a representation of natural or artificial systems and it may be of many types , including physical (scale)models, statistical models which represents mathematical relationship between variables and mechanistic models which uses mathematical equations that attempt to approximate physical, chemical or biological phenomena.

4.2 Models are particularly useful when:

- Pollutant sources are highly variable in quantity and quality and its been very difficult to predict their behaviour in space or time using the simple computation tools.
- The dynamics of the receiving water is complex.
- The behaviour of the systems like storm or sanitary sewer or sewerage treatment plant are complex where several unit processes are involved between influent and effluent.
- In order to produce accurate loading or concentration estimates for specific pollutant.

4.3 Models may be of several types:

- **Mathematical Model**: Uses symbolic notation and the mathematical equations to represent a system.

- **Static Model**: Represents a system at a particular point of time and also known as Monte-Carlo simulation.

- **Dynamic Model**: Represents systems as they change over time.

- **Deterministic Model**:. They have a known set of inputs which will result in a unique set of outputs.

- **Stochastic Model**: Has one or more random variable as inputs.

- **Discrete & Continuous Model**: Used in an analogous manner. Simulation models may be mixed both with discrete and continuous.

4.4 Mass transport

The general equation for the mass balance in a given volume of water:

Rate of mass increase = rate of mass entering – rate of mass leaving + rate of mass created internally – rate of mass lost internally

Transport processes are of two types **:**

1) **Advection:** Transport of material by the flow of water into or out of control volume of the system in consideration.
   It may be of one two or three dimension.
2) **Diffusion:** Transport of constituent by the turbulence in water.
   It is always a three dimension.

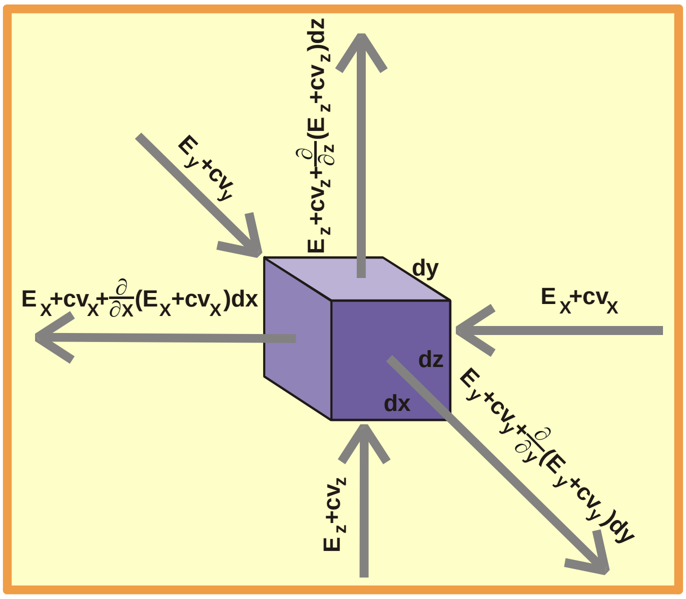


Fig4.1: Basic mass transport and transformation processes (Jolánkai 1979, Jolánkai, 1992)

The quality of water within this elementary water body depends on the mass of a polluting substance present there. Water quality models then should describe the change of the mass of a polluting substance within this water body. The change of the mass of this substance is calculated as the difference between mass-flows (mass fluxes) entering and leaving this water body, considering also the effects of internal sources and sinks of the substance, if any. The mechanism of mass transfer into and out of this water body includes the following processes:

- Mass transported by the flow, by the v_x, v_z, and v_z components of the flow velocity vector. This process is termed the advective mass transfer. The transfer of mass, that is the mass flux (in mass per time, M T^{-1}, dimension) can be calculated in the direction x as $C*v_x*dy*dz$, where C is the concentration of the substance in the water (in mass per volume dimension, M L^{-3}).

- The other means of mass transfer is termed the dispersion or dispersive transport. Dispersion is a term used for the combined effect of molecular diffusion and turbulent diffusion, and both of these latter processes is caused by pulsating motion, that

  (a) by the "Brownian" thermally induced motion of the molecule (molecular diffusion), and

  (b) by the pulsation of the flow velocity around its mean value, caused by turbulence (called the turbulent diffusion).

  The dispersive mass transfer (E_x, E_y, E_z) has the dimension of mass per time per area (M T^{-1} L^{-2}) and it is usually expressed by the law of Fick which states that the transport of the substance in a space direction is proportional to the gradient of the concentration of this substance in that direction the proportionality factor being the coefficient of dispersion.

4.5 Steps involved in modelling

Model is used as a planning tool and the analyst should go through following four steps:

1) **Model verification**: Determination of the appropriate algorithm for the system.
2) **Model calibration**: Tuning the model so that it gives high degree of accuracy.
3) **Model validation**: Checking the validity of different set of data without changing any input variables or rate kinetics.
4) **Sensitivity analysis**: Determine which input variables most influence model output.

Table 4.1 : Basic river and lake model forms and their uses

Description	General equation	Use
3-D models	$\frac{\partial C}{\partial t}+v_x\frac{\partial C}{\partial x}+v_y\frac{\partial C}{\partial y}+v_z\frac{\partial C}{\partial z}=$ $=\frac{\partial}{\partial x}\left(D_x\frac{\partial C}{\partial x}\right)+\frac{\partial}{\partial y}\left(D_y\frac{\partial C}{\partial y}\right)+\frac{\partial}{\partial z}\left(D_z\frac{\partial C}{\partial z}\right)+S(x,y,z,t)\pm S_{internal}$	Oceans, seas, large lakes
2-D, horizontal river or lake models	$\frac{\partial C}{\partial t}+v_x\frac{\partial C}{\partial x}+\left(v_y\frac{\partial C}{\partial y}\right)=$ $=\frac{\partial}{\partial x}\left(D_x\frac{\partial C}{\partial x}\right)+\frac{\partial}{\partial y}\left(D_y\frac{\partial C}{\partial y}\right)+S(x,y,t)\pm S_{internal}$	Wind induced circulation (in lakes), transversal mixing (in rivers)
2-D vertical plane lake models	$\frac{\partial C}{\partial t}+v_y\frac{\partial C}{\partial y}+v_z\frac{\partial C}{\partial z}=$ $=\frac{\partial}{\partial y}\left(D_y\frac{\partial C}{\partial y}\right)+\frac{\partial}{\partial z}\left(D_z\frac{\partial C}{\partial z}\right)+S(y,z,t)\pm S_{internal}$	Wind induced currents in deep lakes (in a cross section)
1-D river models	$\frac{\partial C}{\partial t}+v_x\frac{\partial C}{\partial x}=\frac{\partial}{\partial x}\left(D_x\frac{\partial C}{\partial x}\right)+S(x,\ t)\pm S_{internal}$	Longitudin-al dispersion (pollutant spill) model

4.6 The basic water quality model equation

The basic equation describes the variation of the concentration of a quality constituent C with the time and space. The basic equation describes the variation of the concentration of a quality constituent C with the time and space. Internal source/sink term, or internal reaction term are also called the transformation processes with the meaning that the substance in concern is being transformed by various physical, chemical, biochemical and biological processes resulting in the change of the quantity of the substance in an elemental water body. This change is either a "loss" or sink term caused by processes such as settling, chemical-biochemical decomposition, uptake by living organisms or a "gain", a source term, such as scouring from the stream bed, product of chemical-biochemical reactions, biological growth, that is the "build-up " of the substance in concern on the expense of other substances present in the system. The actual form of these transformation processes will be presented in relation to concrete model equations such as the BOD-DO models, the models of the oxygen household and the plant nutrient (phosphorus) transformation processes of the lake models.

$$\frac{\partial C}{\partial t} + v_x \frac{\partial C}{\partial x} + v_y \frac{\partial C}{\partial y} + v_z \frac{\partial C}{\partial z}$$

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

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, ($M L^{-3} T^{-1}$)

4.7 Finding the concentration of matter in the river:

4.7.1 <u>Stream and river models</u>: These include inputs:

- Flow of water and pollutant loadings
- Dispersion and advection terms in modeling equations

- Physical, chemical and biological reactions

Modeling equations:

At any point X, upstream (X<0) or downstream (X>0) which is the distance from the discharge of pollutants, the change in concentration over time is given as:

$$\partial C/\partial t = (1/A)\,[\partial(EA(\partial C/\partial X) - UAC)/\partial X] \pm \Sigma\ S_k \qquad \text{.....}\mathbf{(1)}$$

where, $\partial C/\partial t$ **=** the change in concentration over time

U= net downward velocity

E= dispersion factor (m^2/sec) depends upon amplitude and frequency of tide and turbulence.

$EA(\partial C/\partial X)$-UAC = total flux (m/sec)

flux due to dispersion $EA(\partial C/\partial X)$ is assumed to be proportional to concentration gradient over distance

X =direction (upstream X<0 or downstream X>0)

UAC = advective flux due to the movement of water containing the concentration C at velocity rate U across cross sectional area A .

ΣS_k = sources or minus any sinks, S_k. (kg/m^3/sec)

4.7.2 Steady-state single constituent models:

(a) Condition of advection and dispersion:

Steady state means $\partial C/\partial t = 0$

Assume natural decay of the constituent is the only sink which is defined as kC , where k is the decay rate constant.

Now Equation (1) becomes

$$0 = E\,\partial^2 C/\partial X^2 - U\,\partial C/\partial X - kC \qquad \text{......}\ \mathbf{(2)}$$

For a constant loading, W_C (MT^{-1}) at site X = 0, the concentration C :

$$C(X) = (W_C/Qm)\exp[(U/2E)(1 + m)X] \; ; X \le 0 \text{ (upstream)} \quad \text{.....}\mathbf{(3)}$$

$$(W_C/Qm)\exp[(U/2E)(1 - m)X] \; ; X \ge 0 \text{ (downstream) ....} \mathbf{(4)}$$

where, m and Q are assumed as constants

$$m = (1 + (4kE/U^2))^{1/2}$$

parameter m is always equal or greater than 1.

Therefore exp <0. Hence either X>0 or X<0, the concentration C(X) will decrease as distance X increases. The maximum concentration C occurs at X = 0 and is W_C/Qm.

$$C(0) = W_c/Qm$$

(b) <u>Condition of advection only:</u>

In this, flow of river is not under the influence of tides . Therefore, dispersion is small.

Assuming the dispersion coefficient E is 0, then parameter m =1. Hence when E =0, the maximum concentration at X = 0 is W_C/Q.

$$C(0) = W_C/Q \; ; \text{if } E = 0.$$

Now, $(1-m) = -2kE/U^2$

Equation (3),(4) becomes

$$C(X) = 0 \qquad ; X \le 0 \text{ ....}\mathbf{(5)}$$

$$(W_C/Q)\exp[-kX/U] \qquad ; X \ge 0\text{............}\mathbf{(6)}$$

(c) <u>Condition of dispersion only:</u>

As rivers approach the sea then the turbulence in the water increases. The dispersion coefficient E increases and the net downstream velocity U decreases. The flow Q = AU, and since the parameter $m = (U^2 + 4kE)^{1/2}/U$,

then as the velocity U approaches 0,

=> the term $Qm = AU(U^2 + 4kE)^{1/2}/U = 2A(kE)^{1/2}$

and exp[UX(1±m)/2E] in equation (3) and (4) approaches $\pm\exp[X(k/E)^{1/2}]$.

Hence **for small velocities**, Equation (3), (4) becomes:-

$C(X) = (W_C/2A(kE)^{1/2})\exp[+X(k/E)^{1/2}]$; $X \leq 0$ **………(7)**

$(W_C/2A(kE)^{1/2})\exp[-X(k/E)^{1/2}]$; $X \geq 0$ **……….(8)**

The above equations are plotted as :-

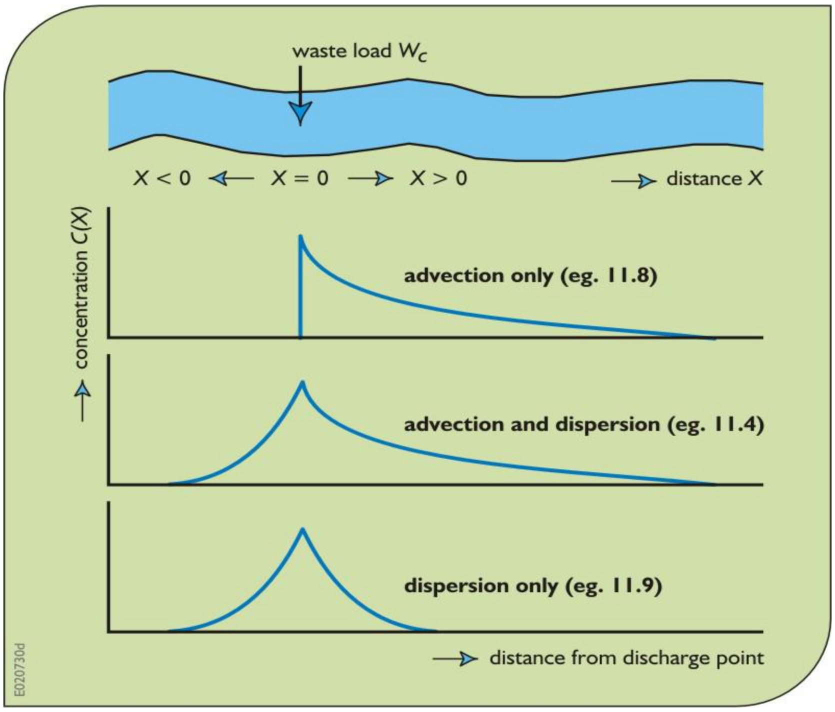


Fig 4.2: Showing variation of concentration with respect to distance

4.8 QUAL2E

QUAL2E is an modeling software which simulates upto 15 water quality parameters in branching stream system. The model uses mathematical equations like finite-difference solution. It consists of advective- dispersive mass transport reactions and equations. The program or code simulates changes in flow conditions and computes a series of steady-state water surface profiles along the stream. The model is applicable only to dendritic streams that are well mixed and it assumes that the major transport mechanism, advection and dispersion are significant only along the main direction of flow of the stream. QUAL2E can operate as either a steady state or a dynamic model and it simulates a dynamic diel heat budget and water quality kinetics for a one dimensional and steady flow system. QUAL2E program performs dissolved oxygen balance by including source and sink terms in mass balance equation and is used to quantify the non point sources loading rate, determine the pollutants, calculate the phosphorus and estimate the natural conditions. In addition to local climate factors it consists of four types of hydraulic and mass load functions: headwater-inputs, point sources, inflow/outflow and downstream boundary conditions.

QUAL2K is a modernized version of the QUAL2E which was developed by Brown and Barnwell (1987) and it employs Microsoft Excel as the graphical user interface. At present there are total two versions of QUAL2K available: version 2.11b8 of QUAL2K an updated version based on QUAL2K 2.04 which was first developed by Chapra et al. (2006) and the QUAL2Kw model supported by the Washington State Department of Ecology (Washington State Department of Ecology 2007). QUAL2Kw contains a genetic algorithm for the automatic calibration of kinetic rate parameters and generic algorithm used in this is the PIKAIA algorithm while QUAL2K does not (Pelletier et al. 2006). QUAL2K has the ability to model a main channel with several tributaries whereas QUAL2K only be used to model a main channel without a branching network of the stream. Both versions of the QUAL2K model have been used in order to assess the fate and transport of conventional pollutants to estimate river pollution loading for input into a river model (Capodaglio et al. 2005). QUAL2K is a time-variable, steady flow model with constant coefficients in each designated reach of the stream and it simulates various constituents such as temperature, carbonaceous BOD, DO, phytoplankton, phosphorus and nitrogen. It also simulates pH, alkalinity, inorganic suspended solids, pathogenic bacteria and bottom algae of river stream. The advantage of the QUAL2K model is its ability to incorporate hourly data. It has the ability to simulate a system stream which is comprised of a main branch and several tributaries. This model is one dimensional with the assumption that the channel is well mixed in the vertical and lateral directions and simulates the impacts of point and non point pollutant loadings. All hydraulic characteristics are simulated as one dimensional, steady state with non-uniform flow i.e. water depth and velocity may vary depending on location in the channel. The model captures diel variations as water quality kinetics and the heat budget are determined on a diel time scale as the calculations are dynamic for diel heat budget. QUAL2K divides a study river stream into segments which are called reaches, that are further divided into elements and these elements are the basic computational unit (spatial step, P*x*). Reaches are assigned based on the hydraulic characteristics present in the study river having the sections of river with similar slope, Manning roughness coefficient, bottom width, and side slope will be defined as a reach. Some other factors which also define reaches are constant longitudinal dispersion, bottom algae coverage, bottom sediment oxygen demand (SOD) coverage, and the rate constants for mass transfer (to the air and sediment) of oxygen, methane, ammonium, and inorganic phosphorus. Representation of QUAL2K model for the study of river is created by sequentially numbering the reaches starting from the headwaters of the main channel.

4.8.1 Material and method used in this model:

QUAL2Kw can simulate number of constituents that includes temperature, pH, carbonaceous biochemical demand, sediment oxygen demand, dissolved oxygen, organic nitrogen, ammonia nitrogen, nitrite and nitrate nitrogen, organic phosphorus, inorganic phosphorus, total nitrogen, total phosphorus, phytoplankton and bottom algae.

Water quality parameters measured from QUAL2K model are : flow, water temperature, pH, electrical conductivity (EC), dissolved oxygen (DO), total suspended solids (TSS), total alkalinity as $CaCO_3$ (alkalinity), orthophosphates as phosphorus (PO_4P), total phosphorus (TP), ammonium as nitrogen (NH_4N), nitrate as nitrogen (sum of NO_3N and NO_2N), 5 days biochemical oxygen demand as O_2 (CBOD or BOD) and chemical oxygen demand as O_2 (COD).

4.8.2 Hydraulic modelling: Once the boundaries of each reach are defined, QUAL2K will determine the water depth and velocity using Manning's equation

$$Q = \frac{So^{1/2}\ Ac^{5/3}}{n\ P^{2/3}}$$

where, Q is the discharge in $m^3\ s^{-1}$, S_0 is the bottom slope, Ac is the cross-sectional area in m^2, n is Manning's roughness coefficient, and P is the wetted perimeter in meters. QUAL2K can also determine water depth and velocity based on weir heights and rating curves.

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

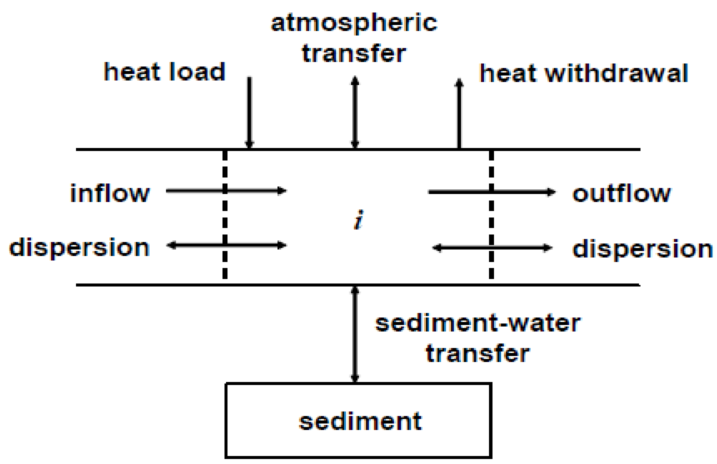


Fig 4.3: Heat balance for an element

4.8.4 Modeling tool:

QUAL2Kw has a general mass balance equation for a constituent concentration in the water column of reach(Pelletier et al.,2006) which is given by:

$$\frac{dC_i}{dt} = \frac{Q_{i-1}}{V_i} C_{i-1} - \frac{Q_i}{V_i} C_i - \frac{Q_{out,i}}{V_i} C_i + \frac{E'_{i-1}}{V_i}(C_{i-1} - C_i) + \frac{E'_i}{V_i}(C_{i+1} - C_i) + \frac{W_i}{V_i} + S_i$$

The general mass balance for the model constituents in element i is written as follows: where $Q_{i\text{-}1}$ is flow rate from the i - 1th element, L^3 T^{-1}, Qi is flow rate from the ith element, L^3 T^{-1}, $Q_{out,i}$ is total out flow from the ith element due to point and non-point withdrawals, L^3 T^{-1}, V_i is the volume of the i th element, L^3, $E'_{i\text{-}1}$ is the bulk dispersion coefficient between elements i - 1 and i, L^3 T^{-1}, E'_i is the bulk dispersion coefficient between elements i and i + 1, L^3 T^{-1}, $C_{i\text{-}1}$ is the constituent concentration in the i – 1th element, M T^{-1}, C_i is the constituent concentration in the ith element, M T^{-1}, C_{i+1} is the constituent concentration in the i + 1th element, M T^{-1}, W_i is the external point and non- point source loading of the constituent to the ith element, M T^{-1}, and S_i is sources and sinks of the constituent due to reactions and mass transfer mechanisms in the ith element, M L^{-3} T^{-1}. The S_i term in the mass balance is the generic term for a variety of different biological, chemical, and physical reactions which may occur in each model element.

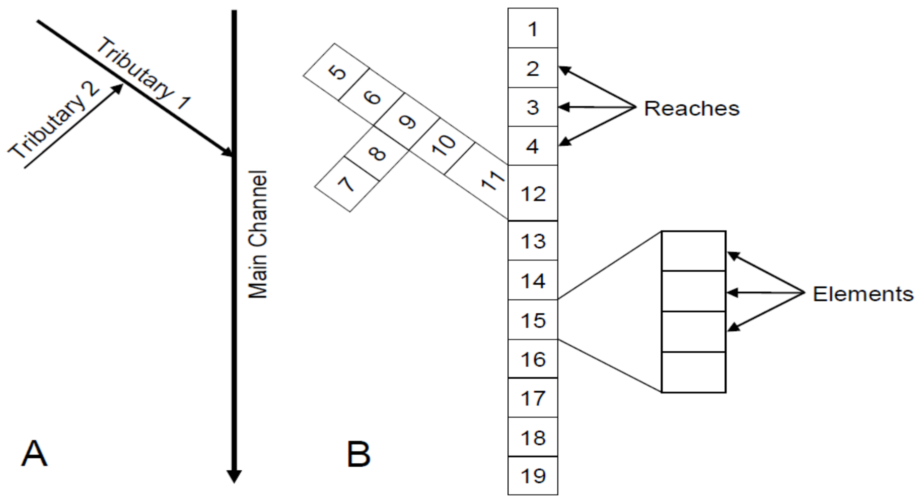


Fig 4.4 : Transformation of a hypothetical river (A) into the QUAL2K representation of that river (B) (Adapted from Chapra et al. 2006).

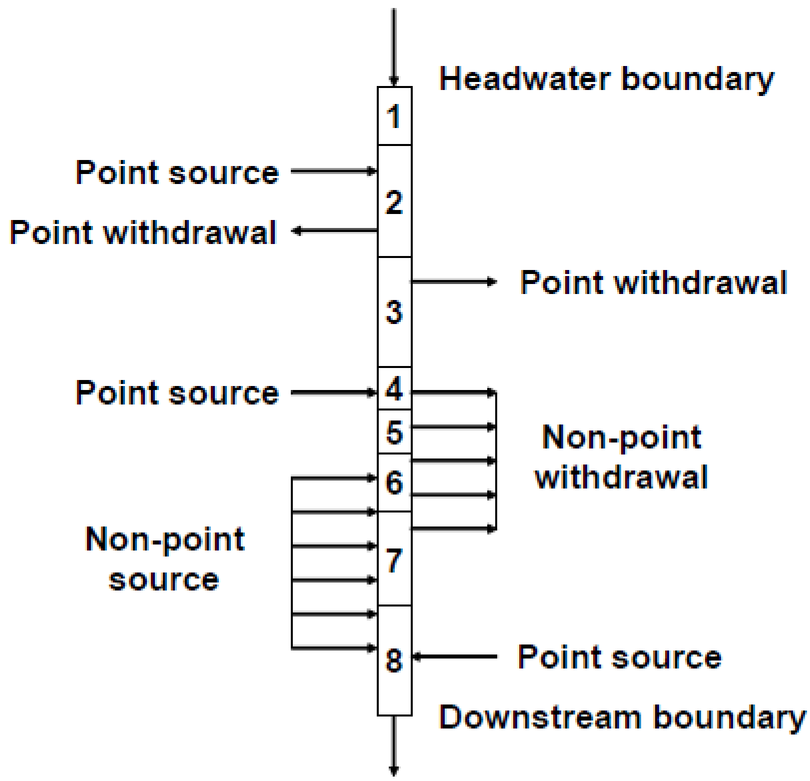


Fig 4.5 : QUAL2K segmentation scheme for a river with no tributaries

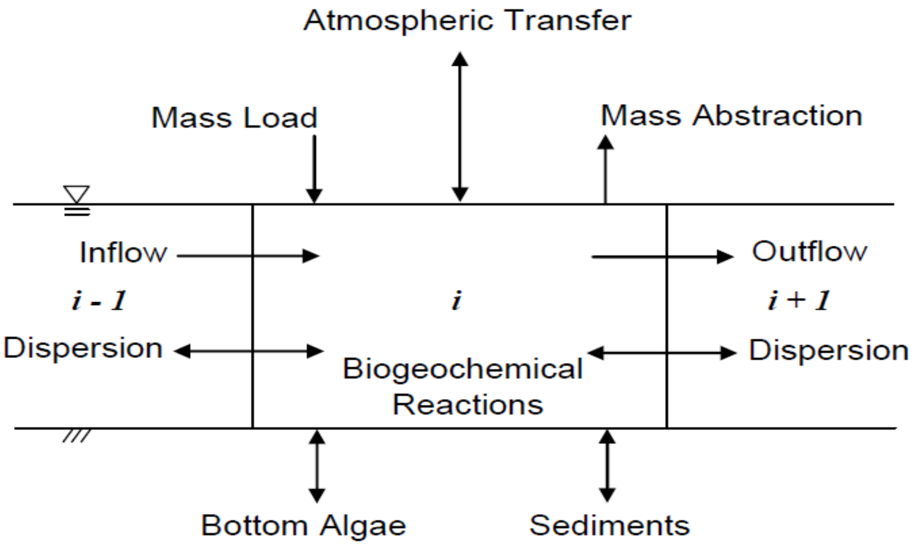


Fig 4.6 : Processes included in the general mass balance in the modeling of QUAL2K water quality parameters for a segment without a tributary (Adapted from Chapra et al. 2006).

Table 4.2: Kinetic processes and mass transfer processes incorporated in the QUAL2K model.

Kinetic process	Mass transfer process
Dissolution	Reaeration
Hydrolysis	Settling
Oxydation	Sediment oxygen demand
Nitrification	Sediment exchange
Denitrification	Sediment inorganic flux
Photosynthesis	
Death	
Respiration/Excretion	

4.8.5 <u>Prototype representation:</u>

QUAL2E permits simulation of one-dimensional stream system. It can even analyse the stream having many branches. The first step of modelling in QUAL2E is to divide the system into the number of reaches having the uniform hydraulic characteristics. Each reach is then subdivided into computational elements which have equal length.

There are total seven computation elements:

i. Headwater element
ii. Standard element
iii. Element just upstream from the junction
iv. Junction element
v. Last element in the system
vi. Input element
vii. Withdrawal element

4.8.6 Model limitations :

- Reaches : maximum of 25
- Computation elements: no more than 20 per reach or total of 250
- Headwater elements : maximum of 7
- Junction elements : maximum of 6
- Input and withdrawal elements : maximum of 25

4.8.7 Systematic parameters :

Mathematical model: Used to simulate the prototype behaviour by applying a mathematical model on a digital computer proceeds through three phases:

1. **Conceptual representation**: It involves a graphic idealization of the prototype by description of geometric properties and by the identification of boundary conditions.
2. **Functional representation**: Formulation of physical features, processes and boundary conditions into set of algebraic equations.
3. **Computational representation** : Functional model is transformed into mathematical forms.

4.8.8 Program language and operating requirements:

QUAL2K and QUAL2Kw are open sources, which are very cost-effective and the main advantage of these modelling softwares are that they are packaged as an Excel Workbook. It is implemented within the Microsoft Excel. Excel is used as an interface for the input , output and running of the model. And because of this major quality, sharing of the model become very simple and quick because no special software needs to be purchased and no installation is necessary. The programming of the model is written entirely in Visual Basic for Applications (VBA) programming language, which is Excel's Macro coding language and numerical integration during modelling is performed by a compiled FORTRAN 95 program which is run by Excel VBA program. FORTRAN execution has proven to be very time efficient during multiple model runs as it is much faster than the VBA execution (seconds vs. minutes). The genetic algorithm used in QUAL2KW is called PIKAIA which essentially models natural selection to derive the optimal rate parameters and fitness of the model (Charbonneau & Knapp, 1995; Pelletier et al., 2006; Pelletier & Chapra 2008). PIKAIA is incorporated into QUAL2Kw as an Excel VBA Macro.

Some of the major limitations include:

1. Non-uniform mixing (2D or 3D);
2. Unsteady flow;
3. Watershed processes;
4. Reservoirs;
5. Sediment adsorption/desorption.

4.9 WASP, HSPF and MIKE

These are highly complex tools with requirement of extensive user training. WASP7 or HSPF are less accurate because large number of state variables used in modeling are needed to be calibrated. MIKE is very well supported and easy to use the tools of modeling.

The WASP series of models originated as part of US EPA's framework for modeling contaminant fate and transport in surface waters. The model includes three sub models, the toxics model, TOXI-WASP, dissolved oxygen/eutrophication model EUTRO (adapted from the Potomac Eutrophication Model developed by Thomann and Fitzpatrick, 1982); and the WASP hydrodynamic model, DYNHYD. WASP represents a body of water as a series of boxes (control volumes), with hydraulic characteristics, environmental properties and chemical concentrations considered to be uniform within each box or element or reach.

HSPF consists of number of sub models that allows the user to find the runoff and pollutant loading. It is one of the few models which currently available that allows integrated simulation of land based runoff and pollutant loading processes.

CHAPTER-5

DEVELOPMENT OF RIVER WATER QUALITY MODEL

CHAPTER - 5
DEVELOPMENT OF RIVER WATER QUALITY MODEL

5.1 Development of BOD Model

Consider a river of node or reach length '*l*' which is receiving only non point source pollution and due to the addition of effluents from non point sources, there may be some lateral inflows. It is assumed that the lateral inflow 'Q_l' and BOD concentration in lateral inflow, L_i are uniformly distributed over the reach length.

The differential equation is as follows:

$$\frac{dL\,(Q + Q_l\, l)}{dt} = -(k_1 + k_3)\, L\; Q + L_i\, Q_l\, l + B\, Q \quad \text{....(1)}$$

where L= BOD in water (mg/l); k_1 = rate coefficient of biochemical decomposition of organic matter(day^{-1}); k_3 = coefficient of BOD removal by sedimentation(day^{-1}); L_i = concentration of BOD in the lateral inflow (mg/l); Q = rate of flow at the beginning of the river reach (m^3/s); Q_l = lateral inflow rate (m^2/s); B= benthic oxygen demand (mg/l); t= travel time (day)

for the steady state , lateral inflow is zero eq (1) becomes

$$\frac{dL}{dt} = -(k_1 + k_3)\, L + B \quad \text{....(2)}$$

The above equation is similar to the differential equation proposed by Camp (1963) as well as by Thomann and Muller (1987).

If the benthic oxygen demand B and rate constant k_3 are considered negligible then,

$$\frac{dL}{dt} = -\, k_1\, L \quad \text{....(3)}$$

The above equation is similar to the equation given by Streeter and Phelps (1925).

The generalized differential equation (1) for BOD can be solved analytically and the equation becomes:

$$L = \frac{L_i\, Q_l\, l\,(1- e^{-(k_1 + k_3)t})}{(k_1 + k_3)\;(2Q + Q_l\, l)} + \frac{B\, Q\,(1- e^{-(k_1 + k_3)t})}{(k_1 + k_3)\;(2Q + Q_l\, l)} + L_o\, e^{-(k_1 + k_3)t}$$

This equation is used to find out the BOD at downstream point .

5.1.1 Generalization of BOD model

In the steady state condition $Q_l = 0$;

$$L = Lo\, e^{-(k_1+k_3)\,t} \quad + \quad \frac{B\,(1- e^{-(k_1+k_3)\,t})}{2(\,k_1+k_3)}$$

If the benthic oxygen demand B and rate constant k_3 are neglected then,

$L = Lo\, e^{-k_1 t}$ which is similar to Streeter and Phelps equation(1925) .

5.2 Development of DO model

The reach of length 'l' is receiving point and non point sources and dissolved oxygen is affected by reaeration process, by respiration and by photosynthesis of aquatic plants.

The differential equation is as follows:

$$\frac{dD_t\,(Q + Q_l\, l)}{dt} = k_1 L\, Q - k_2\, D_t\, Q + D_i\, Q_l\, l - (P\text{-}R)\, Q \ldots\ \ldots\ldots(1)$$

where D_t = dissolved oxygen deficit concentration of water (mg/l); D_i=dissolved oxygen deficit concentration in the lateral inflow to the stream(mg/l) ; k_2=reaeration rate coefficient day^{-1} ; and $(P\text{-}R)$ = net difference between oxygen production by the photosynthesis and respiration of aquatic plants (mg/l);

For the steady state condition $Q_l = 0$

$$\frac{dD_t}{dt} = k_1 L - k_2\, D_t - (P\text{-}R) \ldots\ldots(2)$$

Now if the net difference between oxygen production by the photosynthesis and respiration are negligible , then

$$\frac{dD_t}{dt} = k_1 L - k_2\, D_t \ldots\ldots(3)$$

The differential equation (1) is solved analytically as follows:

$$\frac{dD_t\,(Q + Q_l\, l)}{dt} = k_1 L\, Q - k_2\, D_t\, Q + D_i\, Q_l\, l - (\,P\text{-}R)\, Q$$

$$\frac{dD_t\,(Q + Q_l\, l)}{dt} + k_2\, D_t\, Q = k_1 L\, Q + D_i\, Q_l\, l - (\,P\text{-}R)\, Q$$

multiply each side by $e^{k_2 t}$

$$\frac{dD_t (Q + Q_l\, l)}{dt} e^{k_2 t} + k_2 D_t Q e^{k_2 t} = k_1 L Q e^{k_2 t} + D_i Q_l\, l\; e^{k_2 t} - (P-R) Q e^{k_2 t}$$

$$\frac{dD_t Q}{dt} e^{k_2 t} + \frac{dD_t\; Q_l\, l}{dt} e^{k_2 t} + k_2 D_t Q e^{k_2 t} = k_1 L Q e^{k_2 t} + D_i Q_l\, l\; e^{k_2 t} - (P-R) Q e^{k_2 t}$$

using the value of L from the BOD model, then equation becomes

$$\frac{dD_t Q}{dt} e^{k_2 t} + \frac{dD_t\; Q_l\, l}{dt} e^{k_2 t} + k_2 D_t Q e^{k_2 t} = k_1 \{ Lo\, e^{-(k_1+k_3) t} + \frac{L_i Q_l\, l (1- e^{-(k_1+k_3) t})}{(k_1 + k_3)(2Q + Q_l\, l)} + \frac{B Q (1- e^{-(k_1+k_3) t})}{(k_1+k_3)(2Q + Q_l\, l)} \} * Q e^{k_2 t} + D_i Q_l\, l\; e^{k_2 t} - (P-R) Q e^{k_2 t}$$

$$\frac{dD_t Q}{dt} e^{k_2 t} + \frac{dD_t\; Q_l\, l}{dt} e^{k_2 t} + k_2 D_t Q e^{k_2 t} = k_1 Q e^{k_2 t}\; Lo\, e^{-(k_1+k_3) t} + \frac{k_1\; Q e^{k_2 t} L_i Q_l\, l (1- e^{-(k_1+k_3) t})}{(k_1 + k_3)(2Q + Q_l\, l)} + \frac{k_1 B Q^2 e^{k_2 t} (1- e^{-(k_1+k_3) t})}{(k_1+k_3)(2Q + Q_l\, l)} + D_i Q_l\, l\; e^{k_2 t} - (P-R) Q e^{k_2 t}$$

$$\frac{dD_t Q}{dt} e^{k_2 t} + \frac{dD_t\; Q_l\, l}{dt} e^{k_2 t} + k_2 D_t Q e^{k_2 t} = k_1 Q e^{(k_2-(k_1+k_3)) t}\; Lo + \frac{k_1\; Q e^{k_2 t} L_i Q_l\, l}{(k_1 + k_3)(2 Q + Q_l\, l)} - \frac{k_1\; Q e^{(k_2-(k_1+k_3)) t} L_i Q_l\, l}{(k_1 + k_3)(2Q + Q_l\, l)} + \frac{k_1\; B\; Q^2\; e^{k_2 t}}{(k_1+k_3)(2Q + Q_l\, l)} - \frac{k_1 B Q^2 e^{(k_2-(k_1+k_3)) t})}{(k_1+k_3)(2Q + Q_l\, l)} + D_i Q_l\; l\; e^{k_2 t} - (P-R) Q e^{k_2 t}$$

Integrating both sides

$$D_t (Q + Q_l\, l) e^{k_2 t} + D_t Q e^{k_2 t} = \frac{k_1 Q e^{(k_2-(k_1+k_3)) t}\; Lo}{(k_2-(k_1+k_3))} + \frac{k_1\; Q e^{k_2 t} L_i Q_l\, l}{k_2 (k_1 + k_3)(2Q + Q_l\, l)} - \frac{k_1\; Q e^{(k_2-(k_1+k_3)) t} L_i Q_l\, l}{(k_2-(k_1+k_3))(k_1 + k_3)(2Q + Q_l\, l)} + \frac{k_1\; B\; Q^2\; e^{k_2 t}}{k_2 (k_1+k_3)(2Q + Q_l\, l)} - \frac{k_1 B Q^2 e^{(k_2-(k_1+k_3)) t})}{(k_2-(k_1+k_3))(k_1+k_3)(2Q + Q_l\, l)} + \frac{D_i Q_l\, l\; e^{k_2 t}}{k_2} - \frac{(P-R) Q e^{k_2 t}}{k_2} + A$$

....................................(4)

At $t = 0, D_t = Do$ then equation becomes

$$A = D_0 (2Q + Q_l\, l) - \frac{k_1 Q\ Lo}{(k_2-(k_1+k_3))} - \frac{k_1\ Q\ L_i Q_l\, l}{k_2 (k_1 + k_3) (2Q + Q_l\, l)} +$$

$$\frac{k_1\ Q\ L_i Q_l\, l}{(k_2-(k_1+k_3)) (k_1 + k_3) (2Q + Q_l\, l)} - \frac{k_1\ B\ Q^2}{k_2 (k_1+k_3) (2Q + Q_l\, l)} +$$

$$\frac{k_1 B Q^2}{(k_2-(k_1+k_3)) (k_1+k_3) (2Q + Q_l\, l)} - \frac{D_i Q_l\, l}{k_2} + \frac{(P\text{-}R) Q}{k_2}$$

After putting the value of A in equation (4) and rearrangement of terms by dividing the whole equation by $(2Q+ Q_l\, l) e^{-k_2 t}$

Then the equation becomes,

$$D_t = Do\, e^{-k_2 t} + \frac{k_1 Q (e^{-(k_1+k_3) t} - e^{-k_2 t})Lo}{(k_2-(k_1+k_3))\ (2Q+ Q_l\, l)} - \frac{k_1\ Q (e^{-(k_1+k_3) t} - e^{- k_2 t}) L_i Q_l\, l}{(k_2-(k_1+k_3)) (k_1+k_3) (2Q + Q_l\, l)^2}$$

$$+ \frac{k_1\ Q(1- e^{- k_2 t}) L_i Q_l\, l}{k_2 (k_1+k_3)\ (2Q+ Q_l\, l)^2} - \frac{k_1 B Q^2 (e^{-(k_1+k_3) t} - e^{-k_2 t})}{(k_2-(k_1+k_3)) (k_1+k_3) (2Q + Q_l\, l)^2}$$

$$+ \frac{k_1\ B\ Q^2 (1- e^{-k_2 t})}{k_2 (k_1+k_3) (2Q + Q_l\, l)^2} + \frac{D_i Q_l\, l\ (1-e^{-k_2 t})}{k_2 (2Q + Q_l\, l)} - \frac{(P\text{-}R) Q (1- e^{-k_2 t})}{k_2 (2Q + Q_l\, l)}$$

1.4.4 Generalization of DO model

For the steady state condition $Q_l=0$ and

$$D_t = Do\, e^{-k_2 t} + \frac{k_1 (e^{-(k_1+k_3) t} - e^{-k_2 t})Lo}{2(k_2-(k_1+k_3))} - \frac{k_1 B\ (e^{-(k_1+k_3) t} - e^{-k_2 t})}{4 (k_2-(k_1+k_3)) (k_1+k_3)}$$

$$+ \frac{k_1\ B (1- e^{-k_2 t})}{4 k_2 (k_1+k_3)} - \frac{(P\text{-}R) (1- e^{-k_2 t})}{2 k_2}$$

CHAPTER-6

DO MODELING OF GOMTI RIVER AT LUCKNOW STRETCH

CHAPTER-6
DO MODELING OF GOMTI RIVER AT LUCKNOW STRETCH

6.1 Dissolved oxygen modeling

DO was originally modeled by Streeter and Phelps in 1925.The model depends upon the no of sinks and sources of the DO being considered .The sources of dissolved oxygen in a water body include reaeration from the atmosphere, photosynthetic oxygen production and DO inputs. Sinks include oxidation of carbonaceous and nitrogenous material, sediment oxygen demand and respiration by aquatic plants. Camp (1963) developed expanded BOD and DO models and this model involves four new parameters sedimentation rate constant 'k_3', benthic oxygen demand 'B', photosynthesis 'P' and respiration 'R'. The Thomann and Muller (1987) includes all the parameters used by Champ and in addition to that , they considered the distributed source of BOD in a reach of a river and included the changes in DO and BOD due to non point sources.

The generalized equations solved in the previous chapter for BOD and DO are as follows:

$$L = Lo\, e^{-(k_1+k_3)\,t} + \frac{B\,(1- e^{-(k_1+k_3)\,t})}{2(k_1+k_3)}$$

$$D_t = Do\, e^{-k_2 t} + \frac{k_1\,(e^{-(k_1+k_3)\,t} - e^{-k_2 t})Lo}{2(k_2-(k_1+k_3))} - \frac{k_1 B\,(e^{-(k_1+k_3)\,t} - e^{-k_2 t})}{4\,(k_2-(k_1+k_3))\,(k_1+k_3)}$$

$$+ \frac{k_1\, B\,(1- e^{-k_2 t})}{4\,k_2\,(k_1+k_3)} - \frac{(P-R)\,(1- e^{-k_2 t})}{2\,k_2}$$

where L= BOD in water (mg/l) ; D_t = dissolved oxygen deficit concentration of water (mg/l); D_o= initial oxygen deficit (mg/l) ; L_0 = ultimate BOD (mg/l) ; k_1 = rate coefficient of biochemical decomposition of organic matter(day^{-1}); k_2 = reaeration rate coefficient (day^{-1}) ; k_3 = coefficient of BOD removal by sedimentation(day^{-1}) ; (P-R) = net difference between oxygen production by the photosynthesis and respiration of aquatic plants (mg/l) ; Q = rate of flow at the beginning of the river reach (m^3/s) ; B = benthic oxygen demand (mg/l) ; t = travel time (day).

Table 6.1 : Monthly variation of chlorine and temperature in Gomti river (2015)

Parameter	Jan	feb	Mar	Apr	may	June	July	Aug	Sept	Oct	nov	Dec
Temp (deg C)	12.0	14.0	20.0	21.0	23.0	30.0	26.5	29.5	33.0	31.5	27.5	22.5
Cl(mg/l)	40.1	38.0	41.9	41.9	24.1	18.3	19.2	14.4	0.0	14.4	0.0	14.4

Source: CWC 2015

6.2 Calculation of DO_{sat}

6.2.1 DO_{sat} in water is a function of the water temperature and salinity (chloride concentration, gm/m^3):

$$DO_{sat} = \{ 14.652 - 0.41022 T + (0.089392T)^2 - (0.042685T)^3\} \{1 - (Cl / 100000)\}$$

Table 6.2.1: Monthly variation of DO_{sat} (mg/l) (2015)

Months	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	nov	Dec
DO_{sat} mg/l	10.73	10.25	9.018	8.837	8.49	7.43	7.943	7.506	7.0219	7.124	7.79	8.58

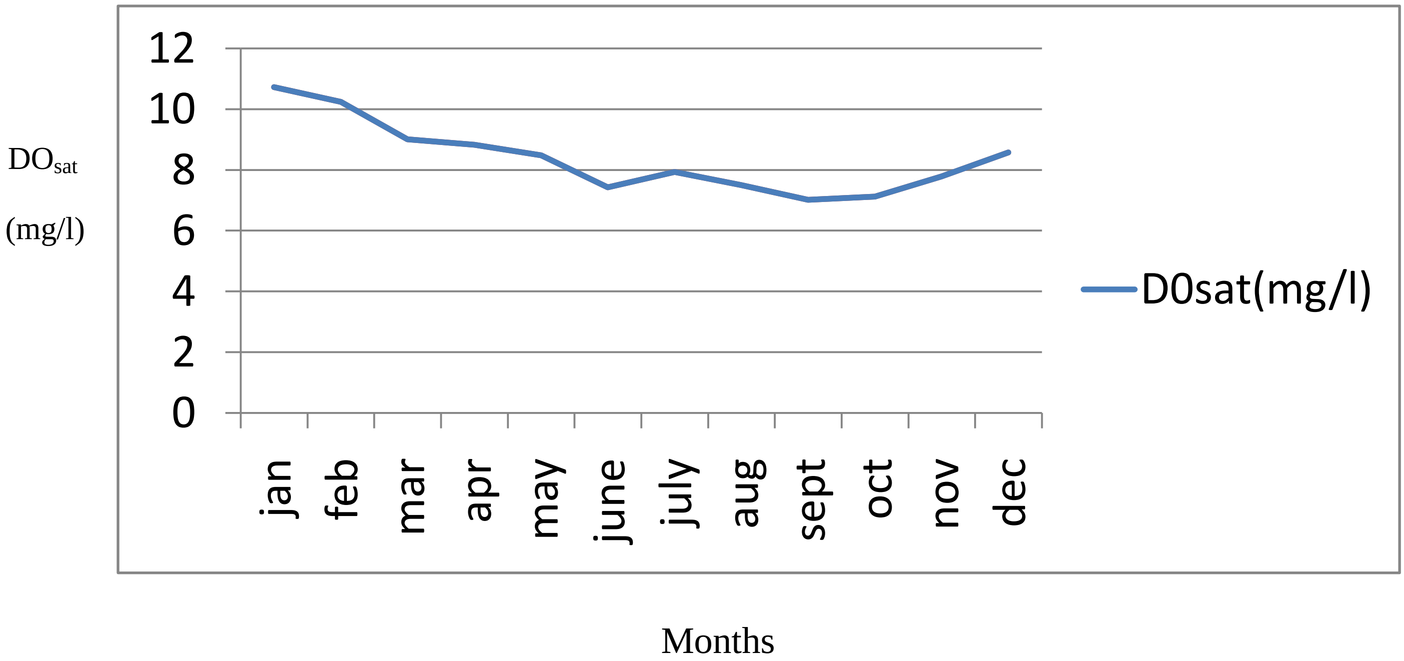


Fig 6.2.1 : Monthly Variation of saturated dissolved oxygen(2015)

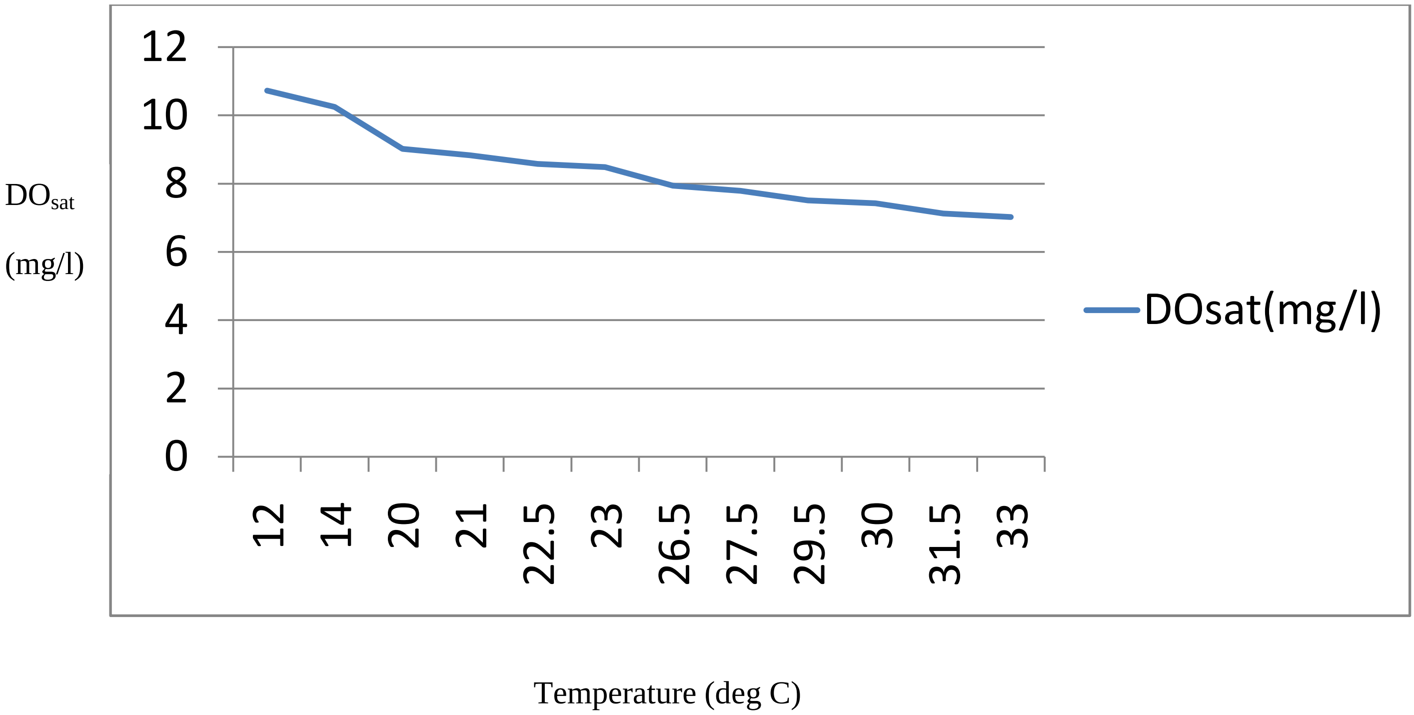


Fig 6.2.2 : Variation of DO_{sat} as per temperature(2015)

6.2.2 <u>Elmore and Hayes (1960) derived the analytical expression for DO_{sat} :</u>

$$DO_{sat} = 14.652 - 0.41022\ T + 0.007991\ T^2 - 0.000077774\ T^3$$

Table 6.2.2: Monthly variation of DO_{sat} (mg/l) (2015)

Months	Jan	Feb	Mar	apr	may	june	July	Aug	Sept	oct	nov	dec
DO_{sat} mg/l	10.74	10.261	9.0218	8.841	8.497	7.437	7.945	7.508	7.0219	7.228	7.79	8.59

6.2.3 <u>Fitting a second order polynomial curve to the data presented as(Chapra, 1997) :</u>

$$DO_{sat} = 14.407 - 0.3369\ T + 0.0035\ T^2$$

Table 6.2.3: Monthly variation of DO_{sat} (mg/l) (2015)

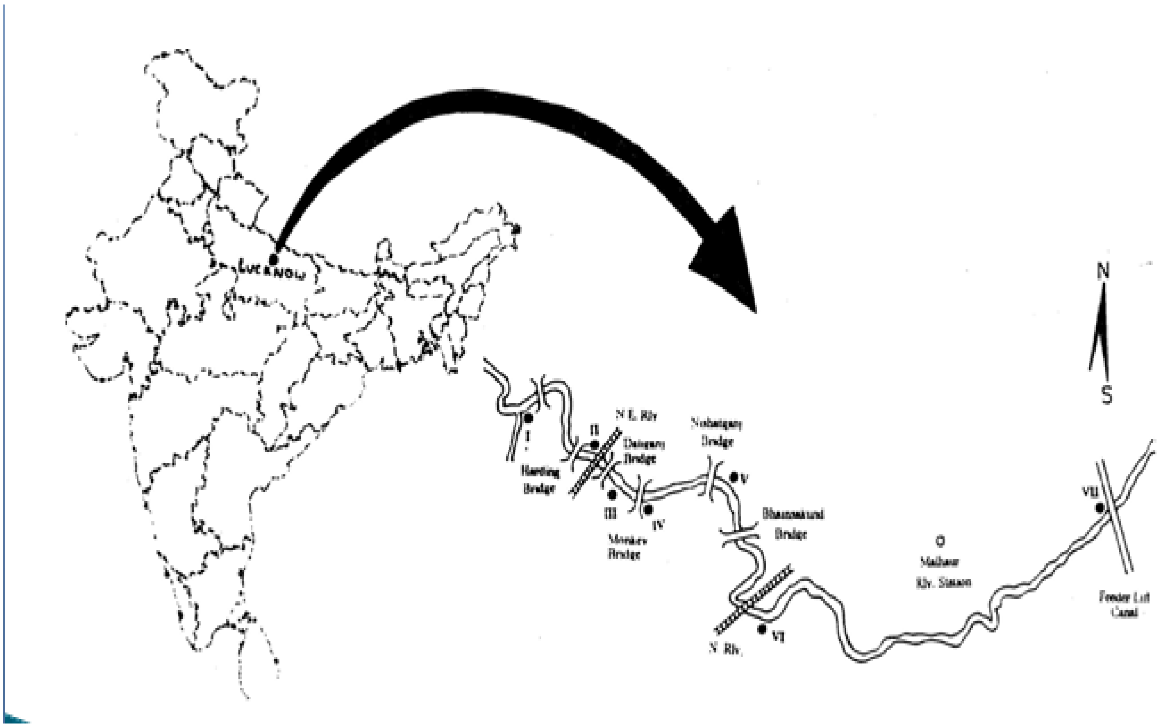
Months	Jan	Feb	Mar	apr	may	June	July	aug	Sept	oct	nov	dec
DO_{sat} mg/l	10.86	10.37	9.069	8.875	8.509	7.45	7.937	7.514	7.100	7.267	7.789	8.598

6.3 Material and method

There are total 26 drains consist of 14 drains from Cis-side and 12 drains from Trans-side situated between Gaughat and Pipraghat . Although all these drains are treated at various STP like Daulatganj and Bharwara STP , still they carry contaminated waste of medical , industrial, sewage and domestic.

6.4 Sampling sites

- Wastewater of 26 major drains situated between Gaughat u/s and Piperaghat d/s discharging their waste into river directly.
- The samples are analysed for 6 major drains: Gaughat , Kudyaghat, Mohan Meakin, Nishatganj drain, Upstream barrage and Pipraghat.



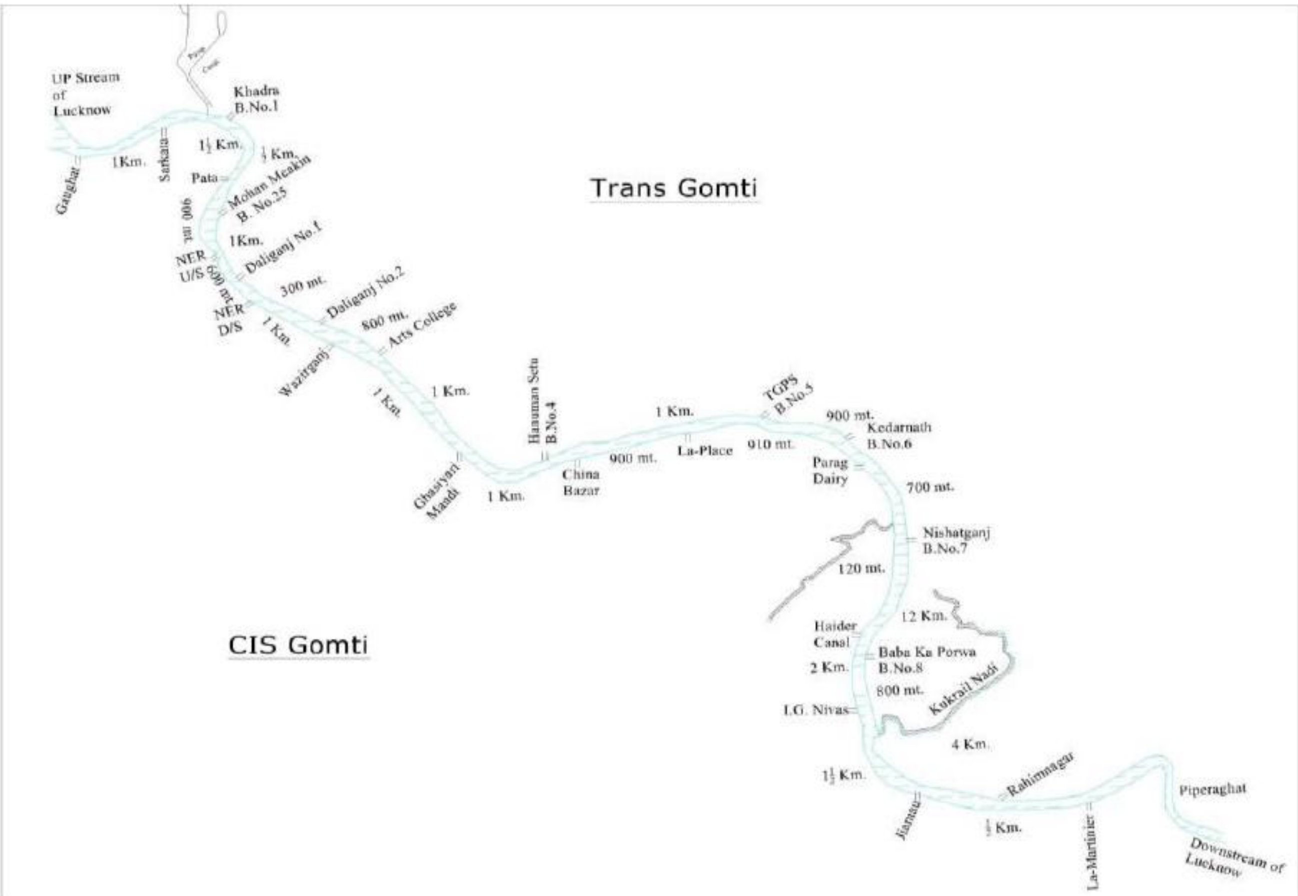


Fig 6.4 : Sampling Locations in Lucknow city.

6.5 Reaches

The total 40.93km length of Gomti river at Lucknow stretch discredited into six reaches.

Six reaches are : 1. Manjhighat to Gaughat

2. Gaughat to Kudyaghat

3. Kudyaghat to Mohan Meakin

4. Mohan Meakin to Nishatganj drain

5. Nishatganj drain to Upstream barrage

6. Upstream barrage to Pipraghat

Table 6.5.1 :Drains and their discharges (Cis side)

Cis Gomti drains (13 nos)	Average dry weather flow in mld
Gaughat	1.0
Sarkata	18.0
Pata	18.0
NER U/S	0.3
NER D/S	0.5
Wazirganj	13.0
Ghasiyari mandi	10.0
China Bazar	2.0
La-Place	1.0
Jopling road	1.0
G.H.canal	78.0
Jiamau	-
La-martiniere	0.5

Table 6.5.2 :Drains and their discharges (Trans side)

Trans Gomti drains (12 nos)	Average dry weather flow in mld
Kudya ghat	18.0
Rooppur khadra	0.5
Mohan meakin	13.0
Daliganj No1	8.0
Daliganj No2	1.0
Arts college	0.5
Hanuman setu	0.5
Nishatganj	10.0
Baba ka purva	-
Kukrail nala	2.0
U/S Barrage	20.0
Pipraghat	25.0

Source : Lucknow Nagar Nigam

Table 6.5.3 : Rate of flow of river

Months	jan	Feb	mar	april	may	june	july	aug	sept	oct	nov	dec
Q(cumec)	35.76	34.62	34.89	33.61	31.23	31.06	35.51	38.92	40.36	39.17	36.25	36.09

Source CWC 2015

6.6 Modeling tool

- **MATLAB** (matrix laboratory) is a numerical computing environmental and fourth-generation programming language. This programming language was developed by Math Works. MATLAB allows matrix manipulations, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs written in other languages, including C, C++, Java, Fortran and Python.
- Although MATLAB is intended primarily for numerical computation and adds graphical multi-domain simulation and model-based design for dynamic and embedded systems.

6.7 Streeter Phelps Equation

Oxygen deficit at any given time for given polluted stream computed as:

$$D_t = \frac{k_1 Lo}{k_2 - k_1}\left(10^{-k_1 t} - 10^{-k_2 t}\right) + Do\, 10^{-k_2 t}$$

t= x/(v*24*60*60) ; t=time required for a certain amount of DO at d/s point in days.

x= distance d/s of point of effluent discharge, in m

v= average flow velocity over river reach, in m/s

When *dDt/dt* =0 , $t=t_c$; then

$$D_c = \frac{k_1}{k_2} Lo\, 10^{-k_1 t}$$

$$t_c = \frac{1}{k_2 - k_1}\log_{10}\left\{\frac{k_2}{k_1}\left[1 - \frac{D_o(k_2 - k_1)}{k_1 L_o}\right]\right\}$$

Where k_1 = Deoxydation constant(day^{-1})

k_2 = Reoxydation constant(day^{-1})

Lo = Ultimate BOD of mixture(mg/l)

D_C = Critical oxygen deficit(mg/l)

D_O = Initial oxygen deficit = $DO_{SATURATION} - DO_{MIX}$

The BOD decay model describes the decomposition of biodegradable organic matter (termed here L) in function of the time (which is the time of travel along the stream, t).

$L = L_0 \times \exp(-k_1 t)$.

$BOD_t = Lo(1 - \exp(-k_1 t))$

L = BOD in the water (mg/l),

k_1 = rate coefficient of biochemical decomposition of organic matter (day^{-1})

The dilution equation for DO:

This dilution equation computes the initial concentration of dissolved oxygen in the river downstream of a point source sewage discharge, with the assumption of instantaneous mixing.

$$DO_{MIX} = \frac{DO_{SEWER} * Q_{SEWER} + DO_{RIVER} * Q_{RIVER}}{Q_{SEWER} + Q_{RIVER}}$$

Generally , $DO_{RIVER} = DO_{SATURATION}$

DO_{SEWER} = Zero

6.8 Input data

The river geometries and discharge are used to determine the hydraulic characteristics. The hydraulic characteristics include coefficient and exponent of velocity and depth. The empirical equations used to estimate the average velocity (V) and depth (D) of the river are: $V = a Q^b$ and $D = c Q^d$

a, c = coefficients for flow on velocity and depth respectively,

b, d = exponents for flow on velocity and depth respectively.

The values of these coefficients a,b,c and d are taken from Chapra (1997).

VARIABLES		VALUES
coefficient on flow for velocity (a)	:	0.032-0.08
exponent on flow for velocity (b)	:	0.300-0.425
coefficient on flow for depth (c)	:	0.126-0.330
exponent on flow for depth (d)	:	0.245-0.47

The **benthic oxygen demand** for the Gomti river is assumed to be 1.32 mg/l and **rate coefficient of BOD removal by sedimentation** k_3 is assumed to be 0.42 (Ojha,2007)

Table6.8.1: River reaeration empirical formulas

Name of Investigator	Formulas	Parameters Range
O'Connor-Dobbins (1956)	$k_2=3.93\frac{U^{0.5}}{H^{1.5}}$	H= 0.3 – 9.14 U= 0.15 – 0.49
Churchill et al. (1962)	$k_2=5.026\frac{U}{H^{1.67}}$	Large rivers H= 0.61 – 3.35 U = 0.55 – 1.52
Owens & Gibbs (1964)	$k_2=5.32\frac{U^{0.67}}{H^{1.85}}$	Small and Large Rivers H= 0.12 – 0.73 U= 0.3 – 0.55
Bennett and Rathburn (1972)	$k_2=5.5773\frac{U^{0.607}}{H^{1.689}}$	Small and Large Rivers H = 0.12 – 3.48 U = 0.04 – 1.52
Langbein and Durum (1967)	$k_2=5.134\frac{U}{H^{1.33}}$	Large rivers

Bansal (1973)	$k_2 = 4.1528 \frac{U^{0.6}}{H^{1.4}}$	Medium to large rivers
Baecheler & Lazo (1999)	$k_2 = 10.046 \frac{U^{2.696}}{H^{3.902}}$	Mountainous rivers
Jha & Ojha(2001)	$k_2 = 5.792 \frac{U^{0.5}}{H^{0.25}}$	River

Where: k_2 = reaeration rate constant (base e), day-1

U = mean stream velocity, m/s

H= mean stream depth, m

(Source: Cox B.A. 2003)

Value of reaeration coefficient:

Reaeration rate coefficient is the rate at which oxygen enters the water from the atmosphere.

k_2 is calculated by (Gromiec 1983, Jolankai 1979):

$k_2 = 2.148\ (V^{0.878} \times H^{-1.48})$

Temperature correction formula for k_2 :

$k_2(\text{at T degree C}) = k_2(\text{ at 20 degree C})\ [1.016]^{T-20}$

T= Temperature of water in degree C

Typical values for k_2 at 20 °C, 1/d (base e) are as follows:

- small ponds and back water 0.10 - 0.23
- sluggish streams and large lakes 0.23 - 0.35
- large streams with low velocity 0.35 - 0.46
- large streams at normal velocity 0.46 - 0.69
- swift streams 0.69 - 1.15

- rapids and waterfalls > 1.15

  Source : Chapra 1997

Assumptions:

1. The terms accounting for dispersion phenomenon has been neglected from the basic equation of water quality modeling.
2. System is fully mixed.
3. Only longitudinal component of velocity has been considered i.e.Vx.
4. The model is considered to be Steady-state model i.e., $\partial S/\partial t = 0$
5. Within the each reach, parameters like k_1, k_2, velocity, depth, etc., remains the same but they are different for different reaches or nodes.
6. Only point sources have been taken into consideration because a point source is single source of pollution which are easily identifiable but non point sources are diffused pollution which occur over wide area.

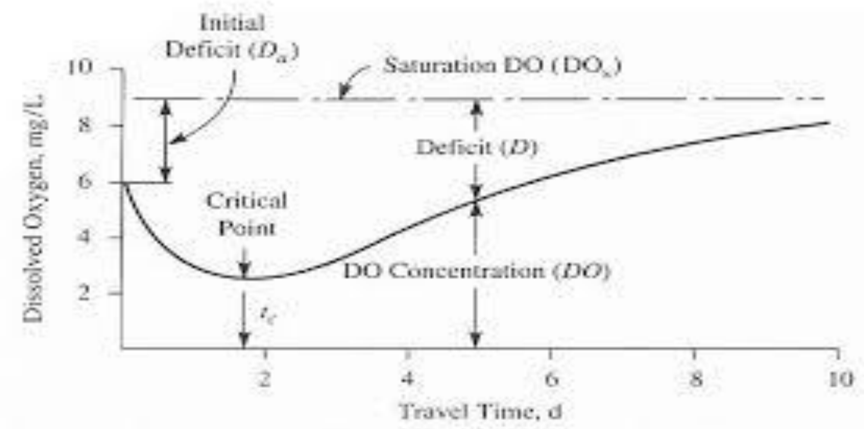


Fig 6.8: Showing variation of DO with respect to distance

Table 6.8.2 : River deoxydation formulas

	Formula	**Parameter ranges**
Hydroscience (1971)	$k_d = 0.3\ (H/8)^{-0.434}$ $k_d = 0.3$	$0 < H < 8$ $H > 8$

Wright and McDonnell (1979)	k_d=10.3Q $^{-0.49}$ (0.08 to 4.24/day)	H= 0.9 – 32 P = 11.8 - 686 Q = 4.6 – 8760 d = 10.3Q

where: k_d= deoxygenation rate constant (base e), day^{-1}

U = mean stream velocity, ft/sec

H= mean stream depth, ft

Q = flow rate, cfs

P = wetted perimeter, ft

(Source: Thomann & Mueller 1987)

Table 6.8.3 : Monthly variation of BOD for different drains

	Months	Jan	Feb	Mar	apr	May	June	July	aug	Sep	oct	nov	Dec
Gau Ghat	BOD (mg/l)	3.1	3.2	3.4	3.8	3.5	3.3	3.2	3.4	3.3	3.3	3.2	3.1
Kudya Ghat	BOD (mg/l)	3.6	4.0	4.4	4.2	4.4	4.6	4.2	4.5	4.4	4.2	4.0	3.8
Mohan Meakin	BOD (mg/l)	4.8	5.0	5.6	5.3	5.4	6.0	5.5	6.0	5.5	5.2	5.4	5.2
Nishat Ganj	BOD (mg/l)	6.6	7.0	7.8	7.5	7.4	8.0	7.0	8.0	7.5	7.0	7.5	7.0
u/s barrage	BOD (mg/l)	7.5	8.5	9.0	8.1	8.3	9.5	9.0	9.5	9.0	8.5	9.5	9.0
Pipra Ghat	BOD (mg/l)	8.5	9.0	10.0	8.6	9.0	10.5	10.0	10.5	9.4	9.8	10.0	9.0

Source: Gomti Pollution Control Board and U.P.Jal Nigam(2015)

Table 6.8.4 : Self purification constant

Water body	$f=k_2/k_1$
Small reservoir or lake	0.5-1.0
Slow sluggish stream , large lake	1.0-2.0
Large slow river	1.5-2.0
Large river of medium flow velocity	2.0-3.0
Fast flowing stream	3.0-5.0
Rapids and water falls	5.0 and above

Source : Jolankai 1979

Table 6.8.5: Classification according to Water Quality(IS:2296-1982)

	A	B	C	D	E
DO(mg/l) min	6	5	4	4	-
BOD(mg/l) max	2	3	-	-	-
TOTAL COLIFORM (MPN/100 ml) mg/l (max)	50	500	5000	-	-
TDS(mg/l)	-	-	-	-	2100

Category A: suitable for drinking after disinfection

Category B: suitable for bathing

Category C: suitable for drinking after treatment and disinfection

Category D: suitable for fisheries

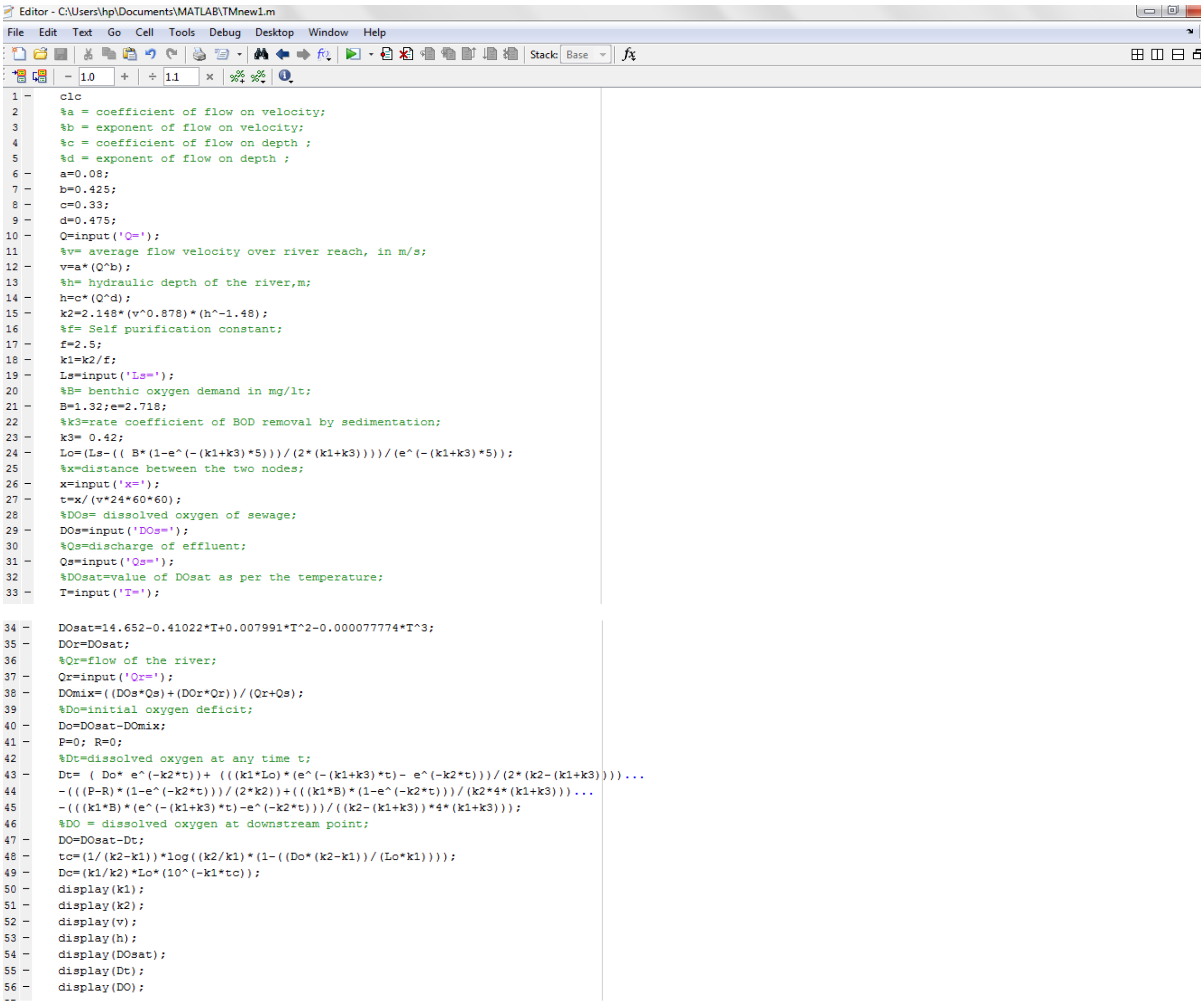
Category E: suitable for irrigation, industrial cooling

Source : Gomti pollution control board

6.9 Matlab coding

```
clc
%a = coefficient of flow on velocity;
%b = exponent of flow on velocity;
%c = coefficient of flow on depth ;
%d = exponent of flow on depth ;
a=0.08;
b=0.425;
c=0.33;
d=0.475;
Q=input('Q=');
%v= average flow velocity over river reach, in m/s;
v=a*(Q^b);
%h= hydraulic depth of the river,m;
h=c*(Q^d);
k2=2.148*(v^0.878)*(h^-1.48);
%f= Self purification constant;
f=2.5;
k1=k2/f;
Ls=input('Ls=');
%B= benthic oxygen demand in mg/lt;
B=1.32;e=2.718;
%k3=rate coefficient of BOD removal by sedimentation;
k3= 0.42;
Lo=(Ls-(( B*(1-e^(-(k1+k3)*5)))/(2*(k1+k3))))/(e^(-(k1+k3)*5));
%x=distance between the two nodes;
x=input('x=');
t=x/(v*24*60*60);
%DOs= dissolved oxygen of sewage;
DOs=input('DOs=');
%Qs=discharge of effluent;
Qs=input('Qs=');
%DOsat=value of DOsat as per the temperature;
T=input('T=');
DOsat=14.652-0.41022*T+0.007991*T^2-0.000077774*T^3;
DOr=DOsat;
%Qr=flow of the river;
Qr=input('Qr=');
DOmix=((DOs*Qs)+(DOr*Qr))/(Qr+Qs);
%Do=initial oxygen deficit;
```

```
Do=DOsat-DOmix;
P=0; R=0;
%Dt=dissolved oxygen at any time t;
Dt=(Do*e^(-k2*t))+(((k1*Lo)*(e^(-(k1+k3)*t)-e^(-k2*t)))/(2*(k2-
(k1+k3))))...
-(((P-R)*(1-e^(-k2*t)))/(2*k2))+(((k1*B)*(1-e^(-k2*t)))/(k2*4*(k1+k3)))...
-(((k1*B)*(e^(-(k1+k3)*t)-e^(-k2*t)))/((k2-(k1+k3))*4*(k1+k3)));
%DO = dissolved oxygen at downstream point;
DO=DOsat-Dt;
tc=(1/(k2-k1))*log((k2/k1)*(1-((Do*(k2-k1))/(Lo*k1))));
Dc=(k1/k2)*Lo*(10^(-k1*tc));
display(k1);
display(k2);
display(v);
display(h);
display(DOsat);
display(Dt);
display(DO);
```




```
clc
%a = coefficient of flow on velocity;
%b = exponent of flow on velocity;
%c = coefficient of flow on depth ;
%d = exponent of flow on depth ;
a=0.08;
b=0.425;
c=0.33;
d=0.475;
Q=input('Q=');
%v= average flow velocity over river reach, in m/s;
v=a*(Q^b);
%h= hydraulic depth of the river,m;
h=c*(Q^d);
k2=2.148*(v^0.878)*(h^-1.48);
%f= Self purification constant;
f=2.5;
k1=k2/f;
Ls=input('Ls=');
%B= benthic oxygen demand in mg/lt;
B=1.32;e=2.718;
%k3=rate coefficient of BOD removal by sedimentation;
k3= 0.42;
Lo=(Ls-(( B*(1-e^(-(k1+k3)*5)))/(2*(k1+k3))))/(e^(-(k1+k3)*5));
%x=distance between the two nodes;
x=input('x=');
t=x/(v*24*60*60);
%DOs= dissolved oxygen of sewage;
DOs=input('DOs=');
%Qs=discharge of effluent;
Qs=input('Qs=');
%DOsat=value of DOsat as per the temperature;
T=input('T=');

DOsat=14.652-0.41022*T+0.007991*T^2-0.000077774*T^3;
DOr=DOsat;
%Qr=flow of the river;
Qr=input('Qr=');
DOmix=((DOs*Qs)+(DOr*Qr))/(Qr+Qs);
%Do=initial oxygen deficit;
Do=DOsat-DOmix;
P=0; R=0;
%Dt=dissolved oxygen at any time t;
Dt= ( Do* e^(-k2*t))+ (((k1*Lo)*(e^(-(k1+k3)*t)- e^(-k2*t)))/(2*(k2-(k1+k3))))...
-((((P-R)*(1-e^(-k2*t)))/(2*k2))+(((k1*B)*(1-e^(-k2*t)))/(k2*4*(k1+k3)))...
-(((k1*B)*(e^(-(k1+k3)*t)-e^(-k2*t)))/((k2-(k1+k3))*4*(k1+k3)));
%DO = dissolved oxygen at downstream point;
DO=DOsat-Dt;
tc=(1/(k2-k1))*log((k2/k1)*(1-((Do*(k2-k1))/(Lo*k1))));
Dc=(k1/k2)*Lo*(10^(-k1*tc));
display(k1);
display(k2);
display(v);
display(h);
display(DOsat);
display(Dt);
display(DO);
```

Fig 6.9.1:Matlab Editor window

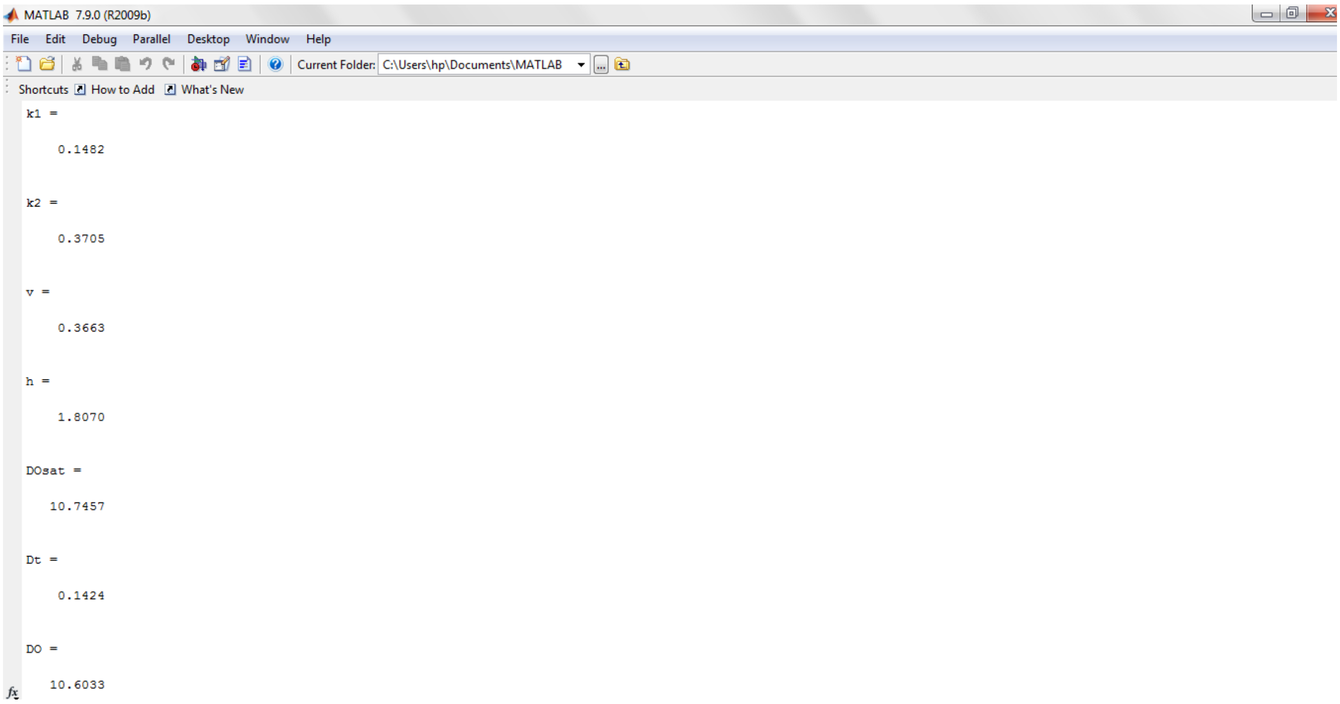


Fig 6.9.2 : Matlab Command Output screen

6.10 Calulation of DO at various locations

<u>REACH: Manjhighat to Gaughat</u>

Example→ Month : January

Temperature : 12 degree C

X= distance between 2 nodes or reach =1.95km

Using the value of coefficients and exponents from the table , a = 0.08(assume)

b= 0.425 (assume)

c= 0.33 (assume)

d=0.475(assume)

Q_r= flow of river = 35.76 cumec (source CWC)

=>V=0.366 m/s , H = 1.8m , k_2 = 0.3714/day

Since Gomti is large river with medium flow velocity, assume f= 2.5 (from table)

=> k_1 = 0.148 /day

since, t = x/v

t = (1.95*10^3)/(0.365*24*60*60)=0.0618 days

T = 12 degree C

BOD_5 = 3.1 mg/l

Using the generalized equation of BOD model

$$L = Lo\, e^{-(k_1+k_3)\,t} + \frac{B\,(1- e^{-(k_1+k_3)\,t})}{2\,(k_1+k_3)}$$

Assume benthic oxygen demand B = 1.32mg/lt and k_3= 0.42

=> Lo = 15.6280 mg/lt

From table : Qs = 1 MLD

DO_{sat} = 10.7457mg/lt (Elmore and Hayes formula)

=> DO_{mix} = 10.736 mg/lt

=> Do = DO_{sat} - DO_{mix} = 0.034mg/lt

Putting these values in generalized equation of DO

$$D_t = Do\, e^{-k_2 t} + \frac{k_1\,(e^{-(k_1+k_3)\,t} - e^{-k_2 t})Lo}{2(k_2-(k_1+k_3))} - \frac{k_1 B\,(e^{-(k_1+k_3)\,t} - e^{-k_2 t})}{4\,(k_2-(k_1+k_3))\,(k_1+k_3)}$$

$$+ \frac{k_1\, B\,(1- e^{-k_2 t})}{4\,k_2\,(k_1+k_3)} - \frac{(P-R)\,(1- e^{-k_2 t})}{2\,k_2}$$

Assume net difference between oxygen produced by photosynthesis and respiration of aquatic plants is zero

=>D_t = 0.1424 mg/l

Therefore , DO at downstream point = 10.7457 - 0.1424 = 10.603 mg/l

Table 6.10.1: Monthly variation of BOD(mg/l) and DO(mg/l) from Manjhighat to Gaughat (2015)

Months	BOD(mg/l)	DO(mg/l)
January	3.1	10.60
February	3.2	10.16
March	3.4	8.93
April	3.8	8.74
May	3.5	8.40
June	3.3	7.36
July	3.2	7.86
August	3.4	7.42
September	3.2	6.94
October	3.3	7.15
November	3.2	7.71
December	3.1	8.46

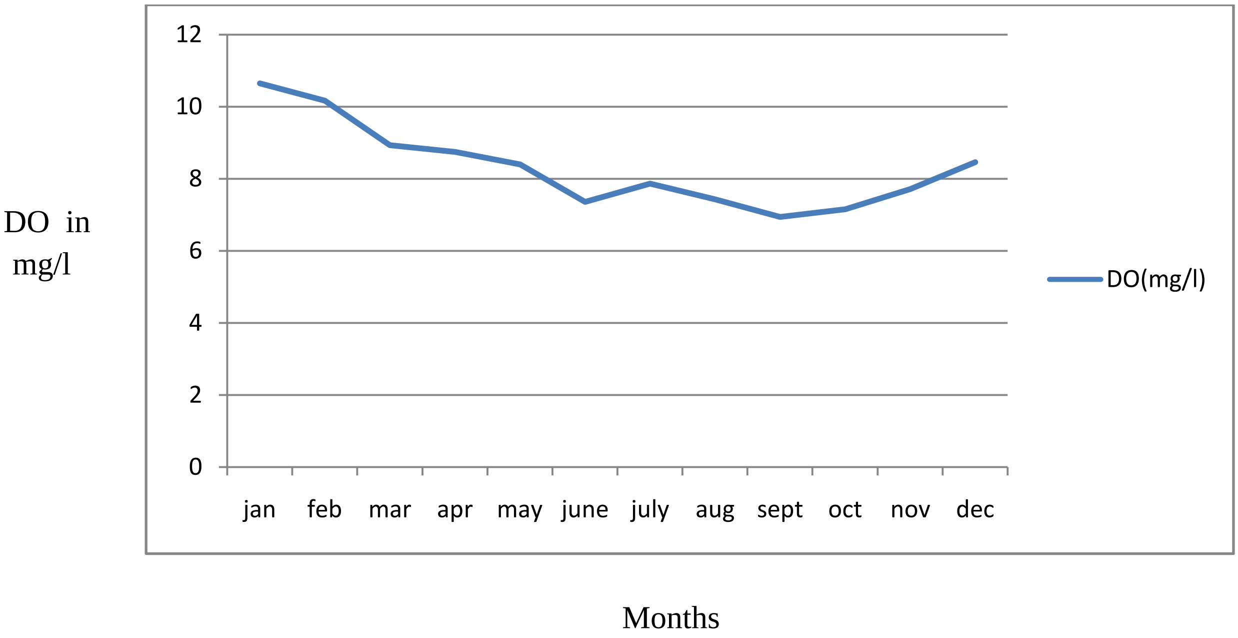


Fig 6.10.1: Variation of DO (mg/l) measured from Manjhighat to Gaughat (u/s of Lucknow) (2015)

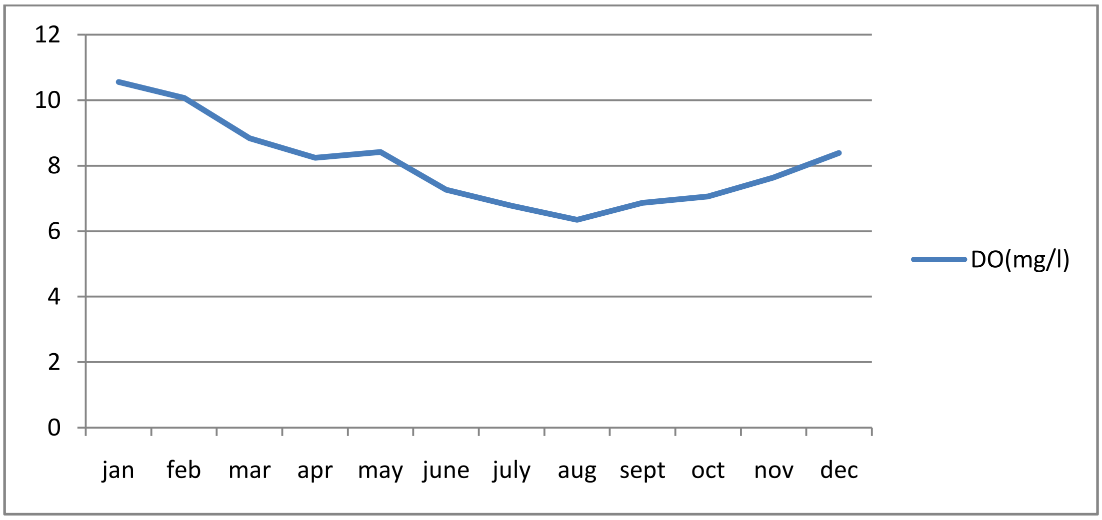
Similarly,

<u>REACH: Gaughat to Kudyaghat</u> (x=2.5km)

Table 6.10.2 : Monthly variation of BOD(mg/l) and DO(mg/l) from Gaughat to Kudyaghat (2015)

Months	BOD(mg/l)	DO(mg/l)
January	3.6	10.54
February	4.0	10.06
March	4.4	8.83
April	4.2	8.23
May	4.4	8.41
June	4.6	7.25
July	4.2	6.77
August	4.5	6.34
September	4.4	6.86
October	4.2	7.05
November	4.0	7.63
December	3.8	8.37

DO in mg/l



Months

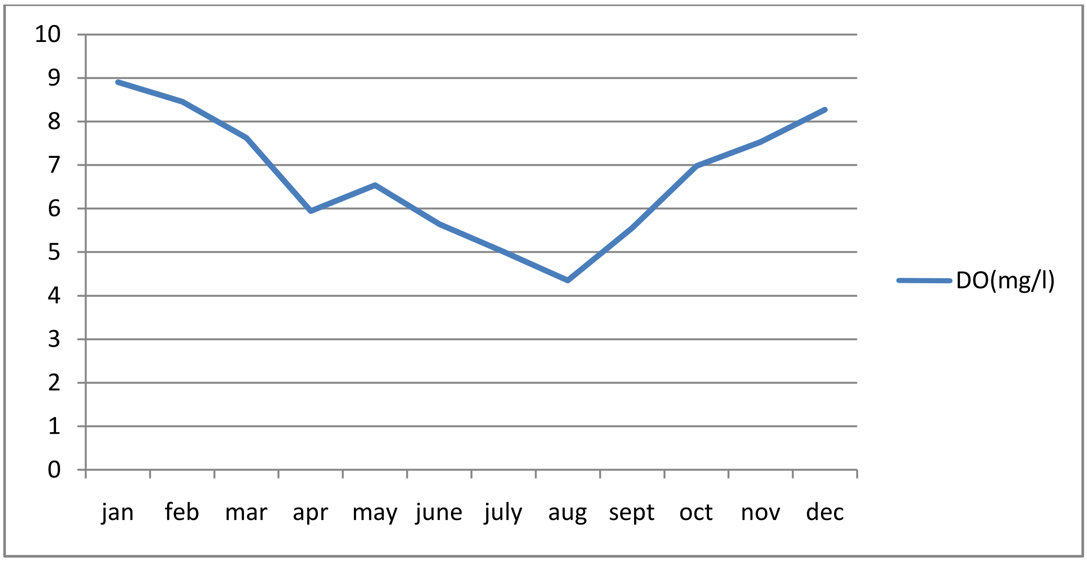
Fig 6.10.2: Variation of DO (mg/l) measured from Gaughat to Kudyaghat (2015)

<u>REACH: Kudyaghat to Mohan Meakin</u> (x=3.9km)

Table 6.10.3: Monthly variation of BOD(mg/l) and DO(mg/l) from Kudyaghat to Mohan Meakin(2015)

Months	BOD(mg/l)	DO(mg/l)
January	4.8	8.90
February	5.0	8.45
March	5.6	7.62
April	5.3	5.94
May	5.4	6.54
June	6.0	5.64
July	5.5	5.01
August	6.0	4.35
September	5.5	5.55
October	5.2	6.98
November	5.4	7.52
December	5.2	8.27

DO in mg/l



Months

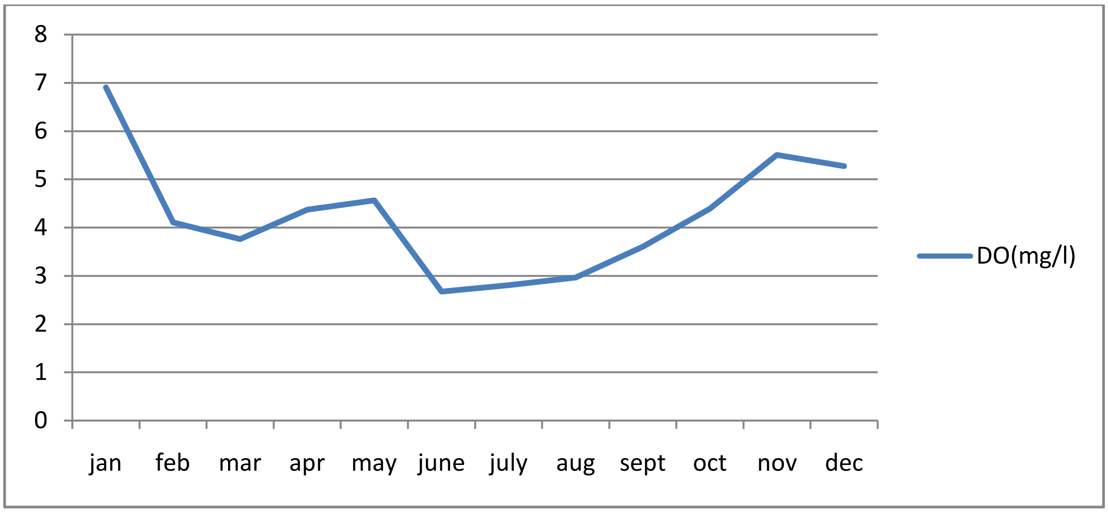
Fig 6.10.3:Variation of DO (mg/l) measured from Kudyaghat to Mohan meakin (2015)

<u>REACH : Mohan Meakin to Nishatganj</u> (x=11.23 km)

Table 6.10.4: Monthly variation of BOD(mg/l) and DO(mg/l) from Mohan Meakin to Nishatganj (2015)

Months	BOD(mg/l)	DO(mg/l)
January	6.6	6.90
February	7.0	4.10
March	7.8	3.76
April	7.5	4.37
May	7.4	4.56
June	8.0	2.67
July	7.0	2.80
August	8.0	2.94
September	7.5	3.60
October	7.0	4.39
November	7.5	5.50
December	7.0	5.27

DO in mg/l



Months

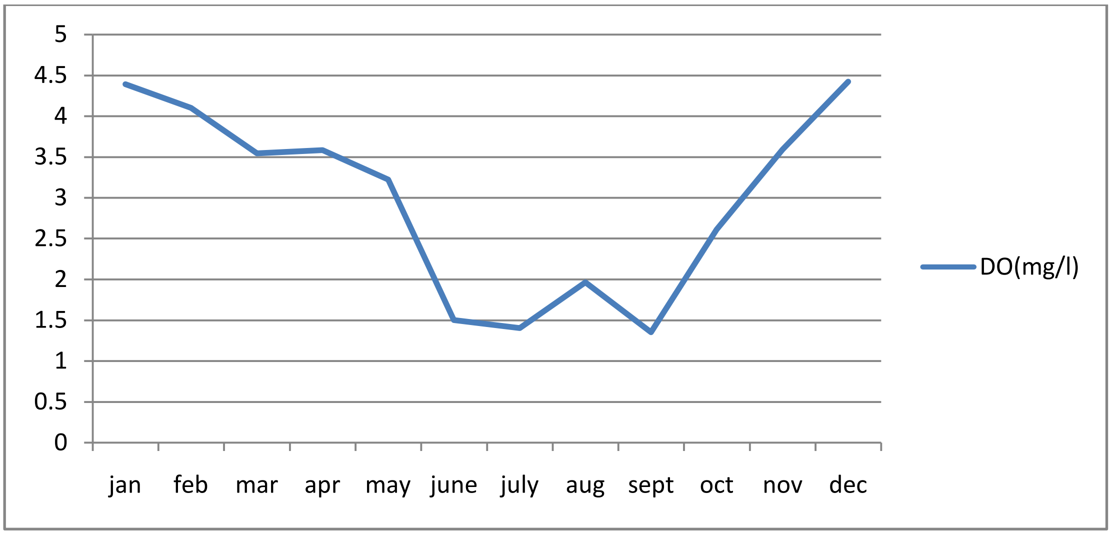
Fig 6.10.4 : Variation of DO (mg/l) measured from Mohan Meakin to Nishatganj drain(2015)

REACH: Nishatganj to U/S barrage (x=16.13 km)

Table 6.10.5 : Monthly variation of BOD(mg/l) and DO(mg/l) from Nishatganj to U/S barrage (2015)

Months	BOD(mg/l)	DO(mg/l)
January	7.5	4.39
February	8.5	4.10
March	9.0	3.54
April	8.1	3.58
May	8.3	3.22
June	9.5	1.50
July	9.0	1.40
August	9.5	1.96
September	9.0	1.35
October	8.5	2.61
November	9.5	3.59
December	9.0	4.42

DO in mg/l



Months

Fig 6.10.5 : Variation of DO (mg/l) measured from Nishatganj to upstream barrage(2015)

<u>REACH : Upstream barrage to Pipraghat</u> (x= 10.5 km)

Table 6.10.6: Monthly variation of BOD(mg/l) and DO(mg/l) from upstream barrage to Pipraghat (2015)

Months	BOD(mg/l)	DO(mg/l)
January	8.5	4.55
February	9.0	3.96
March	10.0	2.71
April	8.6	1.76
May	9.0	2.29
June	10.5	1.51
July	10.0	1.42
August	10.5	1.96
September	9.4	2.32
October	9.8	3.10
November	10.0	3.37
December	9.0	3.92

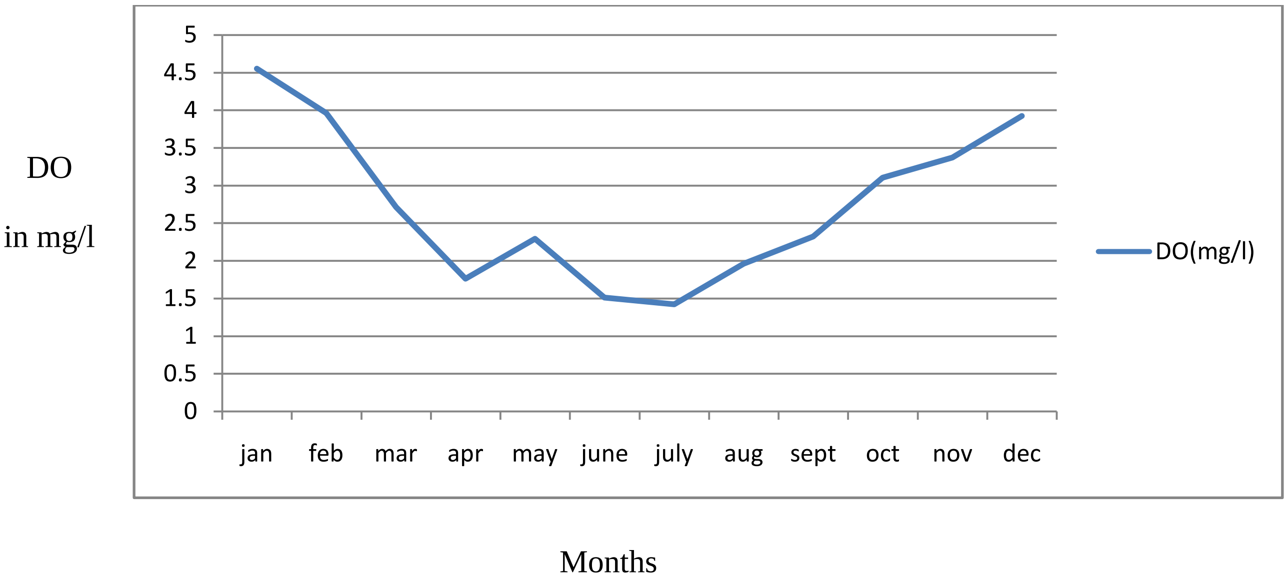


Fig 6.10.6 : Variation of DO (mg/l) measured from upstream barrage to Pipraghat (downstream of Lucknow)

CHAPTER-7

RESULTS AND DISCUSSION

CHAPTER-7
RESULTS AND DISCUSSION

The contents of BOD(mg/l) and DO(mg/l) in Gomti river along the entire stretch at Luckonw city are shown with the help of bar chart and the values of dissolved oxygen calculated or predicted are compared with the observed values given by Gomti pollution control board and U.P. jal nigam for the year 2015.

7.1.1 Monthly variation of BOD(mg/l) and DO(mg/l) from Manjhighat to Gaughat for the year 2015:

At Gaughat that is upstream of Lucknow, the pollution level in the river is almost negligible.The water of the river is clean and no turbidity has been found.

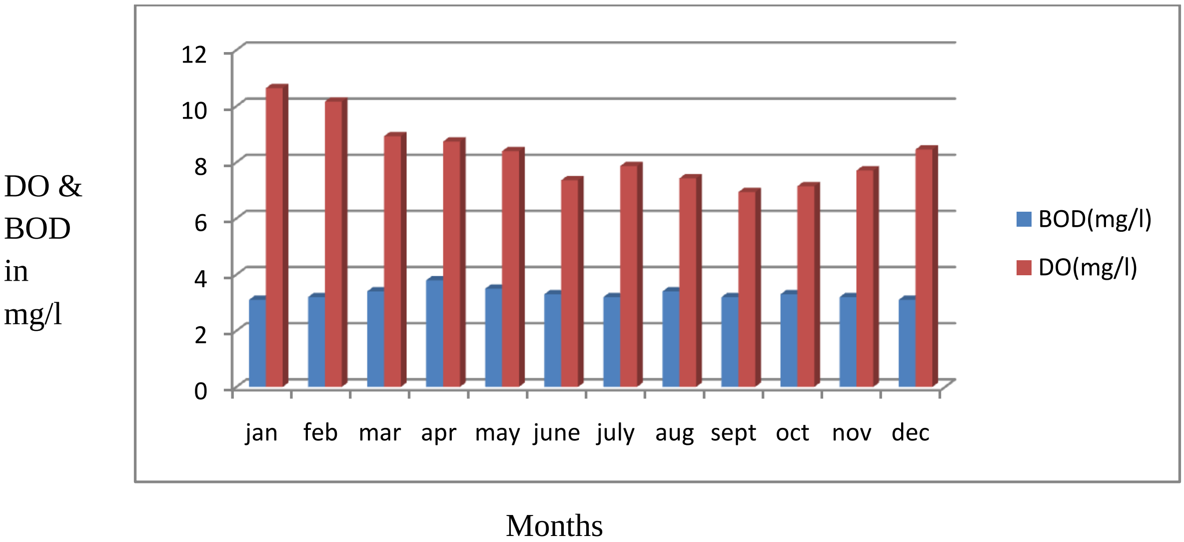


Fig 7.1.1: Bar chart showing the variation of BOD (mg/l) and DO(mg/l) from Manjhighat to Gaughat (2015)

7.1.2 Comparison of predicted and observed values of dissolved oxygen for the node from Manjhighat to Gaughat for the year 2015

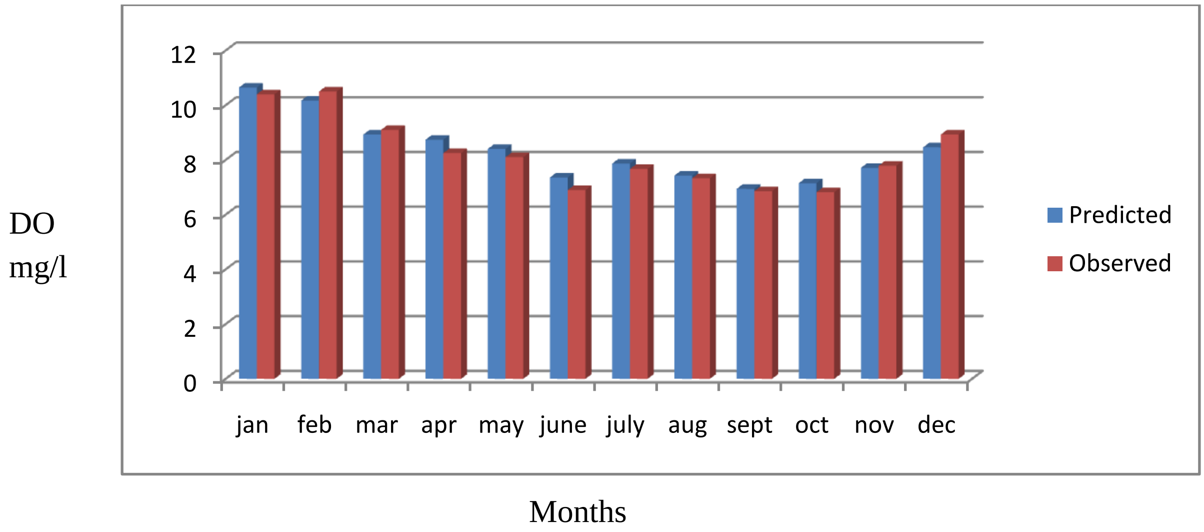


Fig 7.1.2: Predicted and observed DO profile of the river from Manjhighat to Gaughat for the year 2015

7.2.1 Monthly variation of BOD(mg/l) and DO (mg/l) from Gaughat to Kudyaghat for the year 2015 :

The water at Kudyaghat is slightly polluted due to the discharge from drains. But still fishes can survive here because of the sufficient level of the dissolved oxygen.

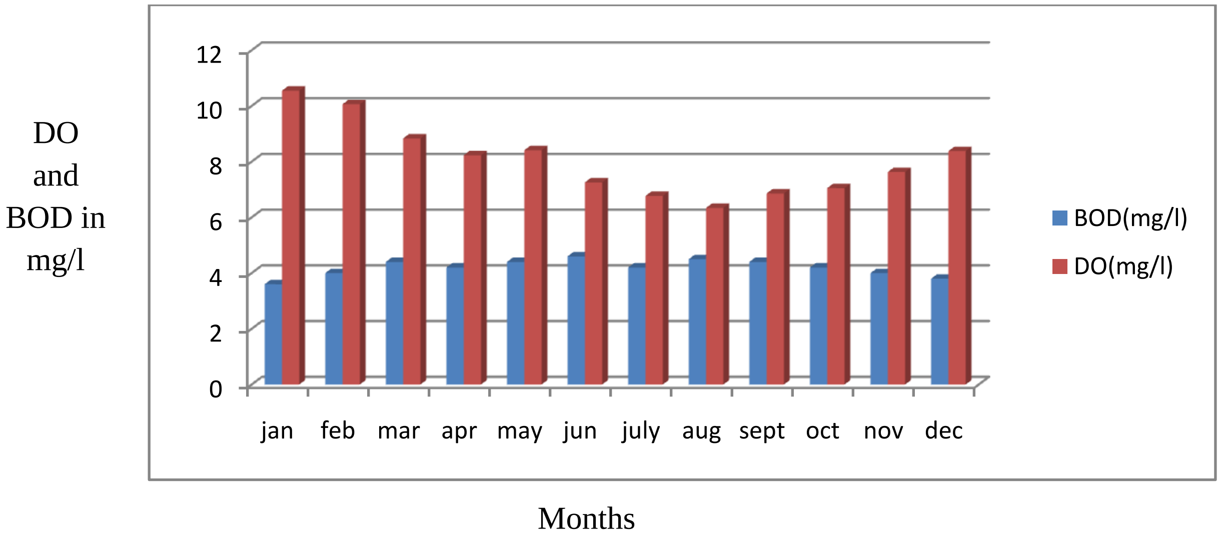


Fig 7.2.1: Bar chart showing the variation of BOD (mg/l) and DO (mg/l) from Gaughat to Kudyaghat (2015)

7.2.2 Comparison of predicted and observed values of dissolved oxygen for the node from Gaughat to Kudyaghat for the year 2015

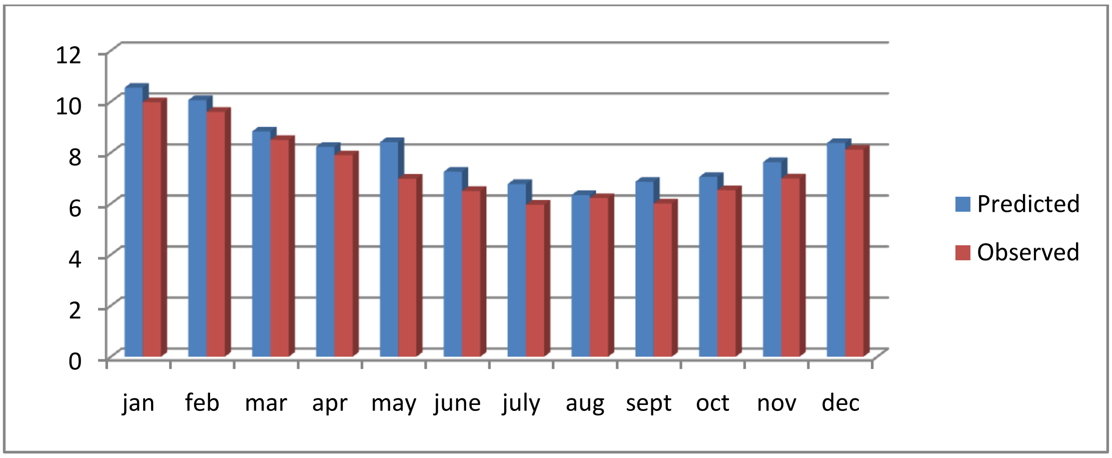


Fig 7.2.2: Predicted and observed DO profile of the river from Gaughat to Kudyaghat for the year 2015

7.3.1Monthly variation of BOD(mg/l) and DO (mg/l) from Kudyaghat to Mohan Meakin for the year 2015:

- During the winter and summer seasons dissolved oxygen level is high as compared to the rainy season because of the heavy runoff.
- At this sampling location dissolved oxygen level decreases because of the pollution from drains and industries.

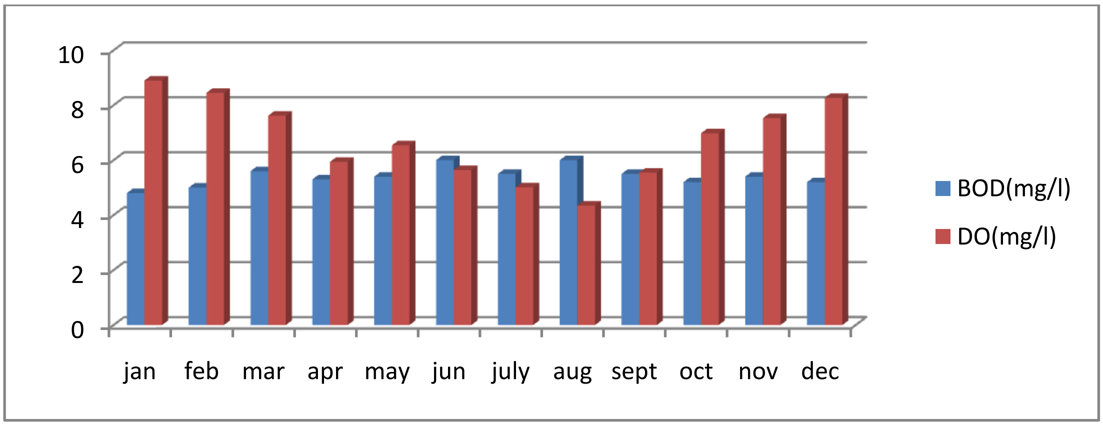


Fig 7.3.1: Bar chart showing the variation of BOD(mg/l) and DO(mg/l) from Kudyaghat to Mohan Meakin(2015)

7.3.2 Comparison of predicted and observed values of dissolved oxygen for the node from Kudyaghat to Mohan meakin for the year 2015

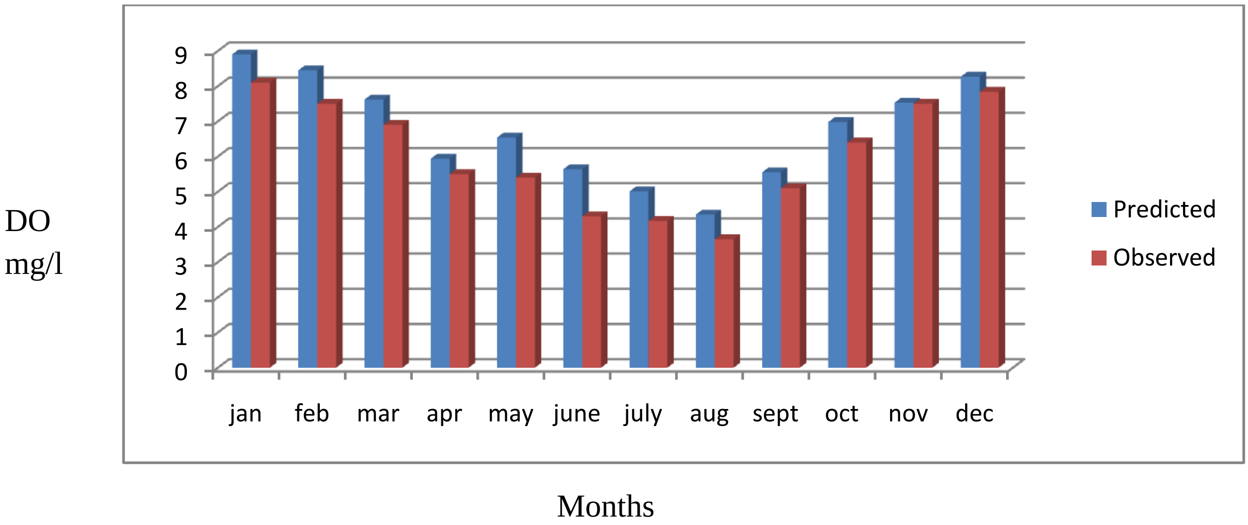


Fig 7.3.2: Predicted and observed DO profile of the river from Kudyaghat to Mohan meakin for the year 2015

7.4.1Monthly variation of BOD(mg/l) and DO(mg/l) from Mohan meakin to Nishatganj for the year 2015

- At this sampling location there is heavy depletion of dissolved oxygen because of the higher BOD level.
- This sampling site is almost at the middle of the city, therefore sullage content is high.

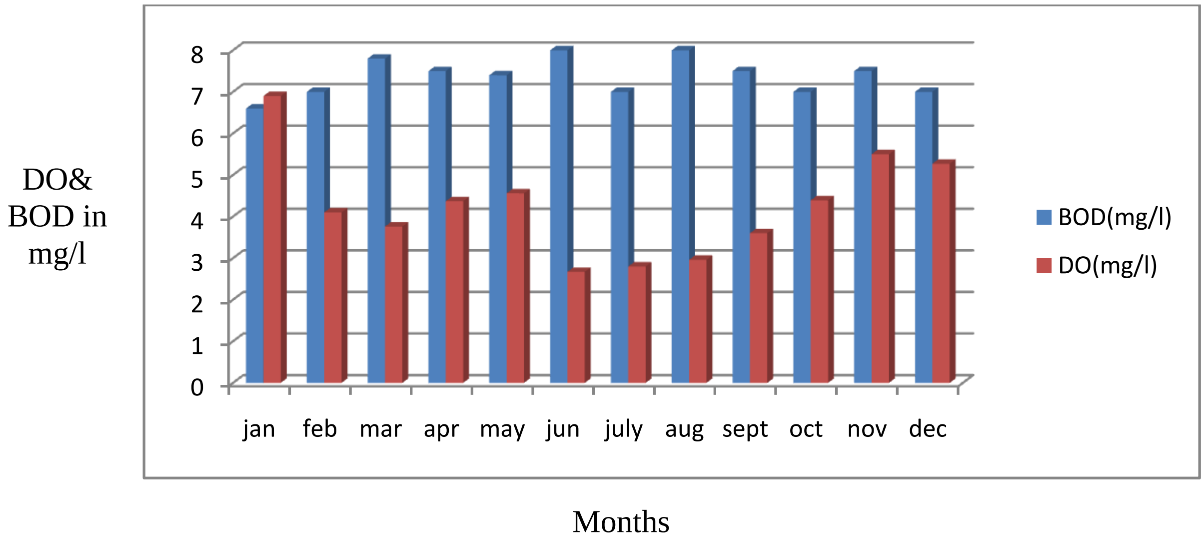
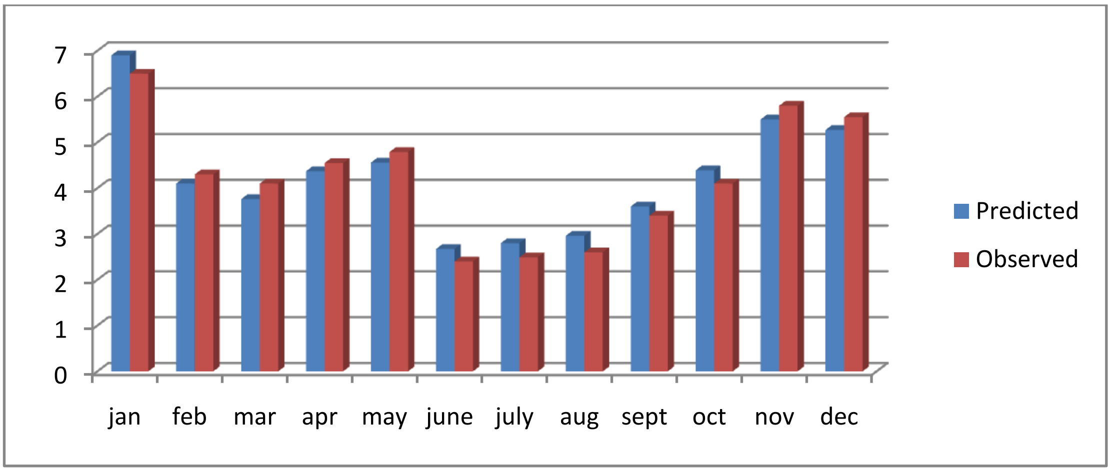


Fig 7.4.1: Bar chart showing the variation of BOD (mg/l) and DO (mg/l) from Mohan meakin to Nishatganj(2015)

7.4.2 Comparison of predicted and observed values of dissolved oxygen for the node from Mohan meakin to Nishatganj drain for the year 2015

DO mg/l



Months

Fig 7.4.2: Predicted and observed DO profile of the river from Mohan meakin to Nishatganj drain for the year 2015

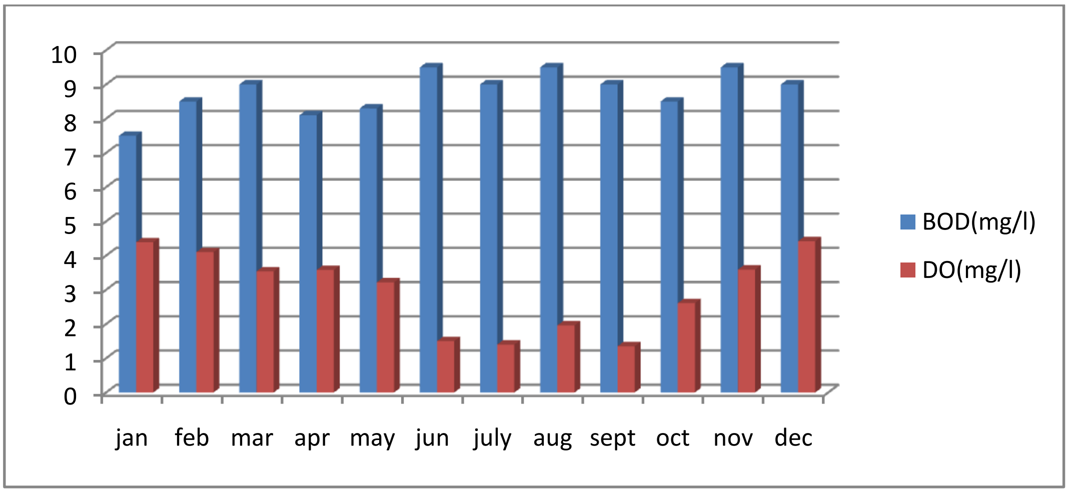
7.5.1 Monthly variation of BOD(mg/l) and DO(mg/l) from Nishatganj to upstream barrage for the year 2015:

- The Gomti barrage constructed at downstream end of the town impounds most of the sewage entering the river. This also stops the river from flowing.
- The flow will become stagnant and there is high depletion of dissolved oxygen.

DO &

BOD

in mg/l



Months

Fig 7.5.1 : Bar chart showing the variation of BOD (mg/l) and DO(mg/l) Nishatganj to Upstream barrage(2015)

7.5.2 Comparison of predicted and observed values of dissolved oxygen for the node from Nishatganj drain to upstream barrage for the year 2015

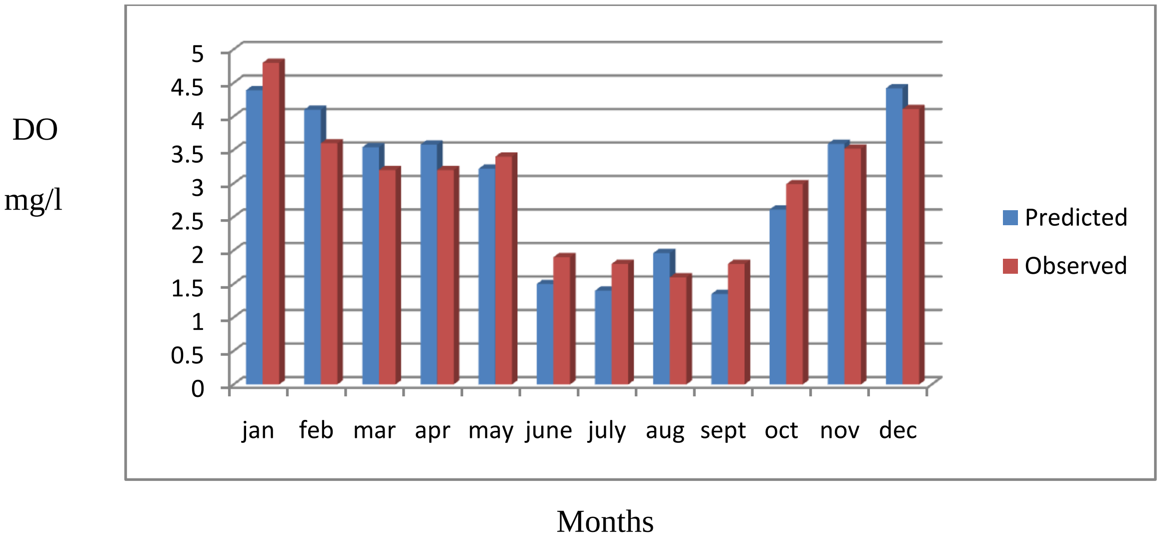


Fig 7.5.2: Predicted and observed DO profile of the river from Nishatganj drain to upstream barrage for the year 2015

7.6.1 Monthly variation of BOD(mg/l) and DO (mg/l) from upstream barrage to Pipraghat for the year 2015

- At this sampling location the dissolved oxygen is found to be minimum because of the maximum content of the BOD.
- This site is found at the downstream of Lucknow, therefore turbidity is very high and no aquatic animal are found.

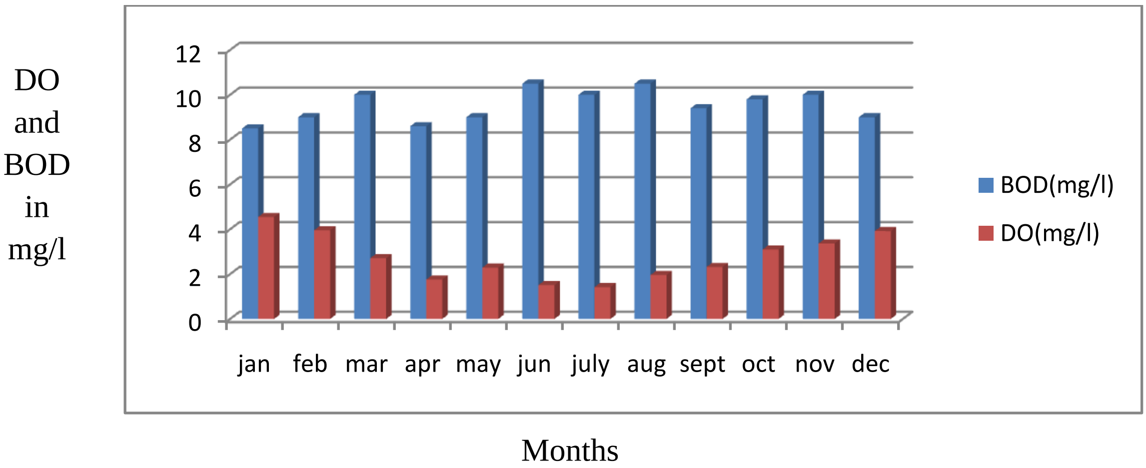


Fig 7.6.1 : Bar chart showing the variation of BOD (mg/l) and DO(mg/l) from upstream barrage to Pipraghat(2015)

7.6.2 Comparison of predicted and observed values of dissolved oxygen for the node from upstream barrage to Pipraghat for the year 2015

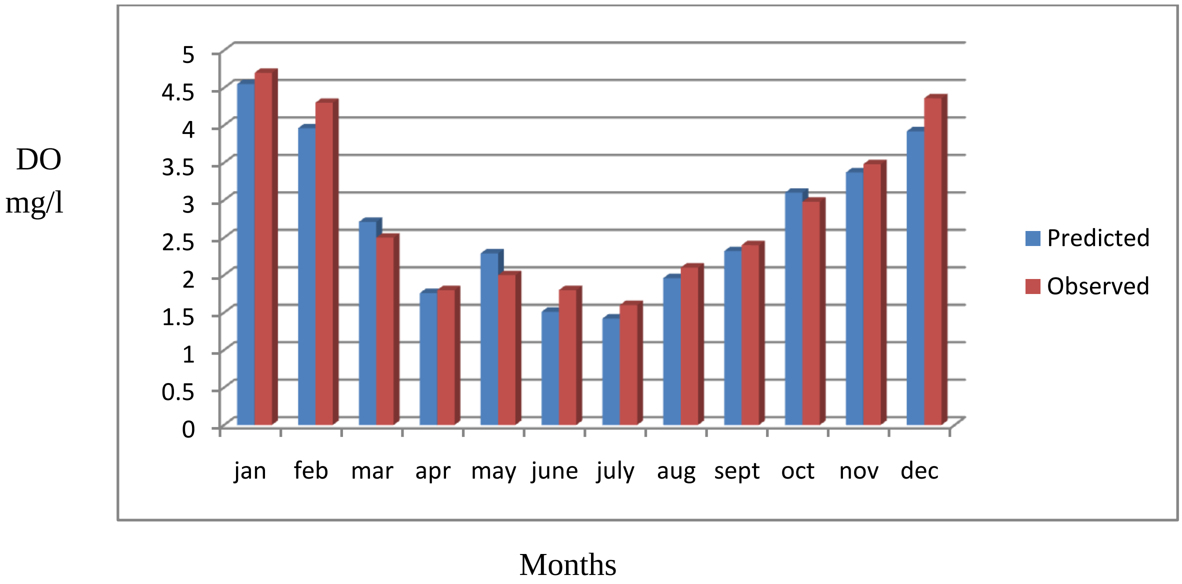


Fig 7.6.2: Predicted and observed DO profile of the river from upstream barrage to Pipraghat for the year 2015

CHAPTER:8

CONCLUSIONS AND RECOMMENDATIONS

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CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusions

Following conclusions are drawn from the study:

- Analysis revealed that water quality of Gomti river was found to be more polluted at the downstream of the stretch as compared to the other sampling sites.

- Physico-chemical and microbiological quality of Gomti river was poor , unsafe and not acceptable for any purpose .

- The level of all the indicators are above the standards which are the serious concern for the ecology of the river.

- The deterioration of water was due 26 drains along its stretch. It leads to increase in the content of heavy metals that results in pollution of river water.

- Various industrial waste, agricultural waste and domestic wastes are the main cause increasing urbanisation and population resulted in the increase in the generation of waste that is being discharged into the river.

- Due to huge amount of organic and inorganic matter, river lost its self purification nature, resulting higher bacterial growth. At the downstream of Lucknow the self purification capacity of Gomti river has become almost nil due to the discharge of treated and untreated waste from various point and non point sources.

- The content of BOD is maximum at Upstream barrage and Pipraghat and dissolved oxygen has become negligible at these sampling sites due to which aquatic animals cannot survive.

- The water at the downstream point showed higher turbidity due to the pollution from various drains and untreated discharge that leads to the river highly contaminated.
- The sullage content in the river at the Nishatganj site location is very high due to the

disposal of domestic waste and from here there is excessive increase in BOD and dissolved oxygen drastically decreases till Pipraghat.

- That is why it is very necessary to treat the waste coming from industries and other sources before merging into the river so that the aquatic as well as human life may not get affected.

- The generalized modeling equations which has been used for finding out the dissolved oxygen for the river Gomti gave the more accurate as compared to Streeter and Phelps (1925) equation. This model is user-friendly , once it is developed it can be used for any river requiring the data suitable for that river and includes the change in the values of the constant.

8.2 Recommendations

Following recommendations are made from the study:

- Waste water should be treated in Bharwara STP before disposing them into the river Gomti as it deteriorates the water quality.

- There are total four STPs in Lucknow city namely Daulatganj, Khwajapur ,Bharwara and Mastemau and only one of them i.e. Bharwara is in function which is a huge problem . So there is a need to make the other STPs work properly as huge amount of waste has been generated daily in the city and its mandatory to treat them before their discharge into the river.

- Removal of wastes from the drains at the pumping stations should not be manual. Sewage should not be by-passed to the river Gomti when pumping station does not work.

- Artificial aeration can also be done for increasing the DO content in river.

- Untreated waste should not be mixed with treated waste and there should be control in discharge of untreated waste that contain huge amount of organic matter in river.

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