SIMULATION OF POINT AND NON-POINT SOURCE POLLUTION IN MAHANADI RIVER SYSTEM LYING IN ODISHA, INDIA

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DISSERTATION

Submitted in Partial Fulfilment of the Requirements for the Award of the Degree of

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By
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CERTIFICATE

This is to certify that the Dissertation entitled "**SIMULATION OF POINT AND NON-POINT SOURCE POLLUTION IN MAHANADI RIVER SYSTEM LYING IN ODISHA, INDIA** " submitted by **NIBEDITA GURU** to the National Institute of Technology, Rourkela, in partial fulfillment of the requirements for the award of **Master of Technology** in **Civil Engineering** with specialization in **Water Resources Engineering** is a record of bonafide research work carried out by her under my supervision and guidance during the academic session 2011-12. To the best of my knowledge, the results contained in this thesis have not been submitted to any other University or Institute for the award of any degree or diploma.

Guide

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Dated (Nibedita Guru)

ABSTRACT

Assessment of point and non-point source pollution in a river system plays an important role for proper water resources management/utilization/protection, reducing environmental/health degradation, suitable waste load allocation and decision-making for pollution monitoring networks. It has been observed that most of the water resources have been utilized for the disposal of municipal and industrial wastes since early days in addition to influx of non-point source pollution. To address the non-linearity, subjectivity, transfer and transformation rule of the pollutants and complexity of the cause-effect relationships between water quality variables and water quality status, development and use of water quality model is of utmost importance. Since the concentration of the quality constituents is reliant on the quantity of flow, entry of point and non-point source pollutants, reaction kinetics, etc., it is essential to supervise and use suitable mathematical models for predicting water quality variables. Owing to the random discharge of point and non-point pollution from various sources has not only rendered such water bodies eutrophic but also their advantageous uses such as water supply, irrigation, recharge of ground water, recreation and habitat for flora and fauna have been adversely affected.

Oxygen-demanding substances are major contaminants in domestic and municipal wastewater. The main indicators of river pollution which deals with the oxygen domestic conditions of the river are Biochemical oxygen demand (BOD) and dissolved oxygen (DO).To manage the quality of natural water bodies that are subjected to pollutant inputs; one must be able to predict the degradation in quality that results from such inputs. The non-point source pollution is another imperative variable responsible for increasing pollutant load in a stream/river. Recognizing the magnitude of assessing non-point source pollution in river system, copious studies intended at understanding the processes controlling nutrient concentration, fluxes in the river systems and the quantification of the nutrient loads of rivers have been proficient in past.

In the present study, attempts have been made to use different water quality models for Mahanadi river system lying in Odisha, establish model parameters values and test the

applicability of the model for different Spatio-temporal conditions. Different water quality data namely, discharge, BOD, DO, water temperature, pH, turbidity, electrical conductivity, nitrate a

Most commonly used BOD-DO model have been used to simulate the point source pollution at different reaches of Mahanadi river system lying in Odisha and model parameters deoxygenation coefficient (k_1) and reaeration rate coefficient (k_2) have been established. Various empirical equations used for estimating and reaeration rate coefficient were used and a modified equation suitable for estimating reaeration rate coefficient has been derived.

Further, the Multi-layer Perceptron (MLP) neural network techniques was used to estimate for the analysis of point source pollution in terms of BOD and DO concentration and the neural network model is developed using the data collected from the upstream and downstream stations on Mahanadi river system lying in Odisha. The accuracy performance of training, validation and prediction of seasonal water quality parameters has been tested.

Another important variable responsible for increasing pollutant load in the river system is non-point source pollution. For recognizing the importance of influx of nutrients (nitrate and ortho-phosphate) from non point sources and their simulation, an analytical model has been used and non-point source pollution entering the river has been estimated.

To test the validity of generalized model and ANN model, different statistical errors, the root mean square error (RMSE), mean multiplicative errors (MME), correlation coefficient (R) were used.

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LIST OF ABBREVIATIONS

ANN	- Artificial Neural Network
BOD	- Biochemical Oxygen Demand
BOD_5	- Five day Biochemical Oxygen Demand
D	- Dissolved Oxygen Deficit at the downstream end of the Stretch (mg/l)
D_0	- Dissolved Oxygen Deficit at the upstream end of the Stretch (mg/l)
$D_{(sat)}$	- Saturation oxygen concentration of water
DEM	- Digital Elevation Model
DO	- Dissolved Oxygen
F	- Froude Number
H	-Depth of Flow
k_1	- Deoxygenation Rate Coefficient (per day)
k_2	- Re-aeration Rate Coefficient (per day)
$k_{1(T)}$	- Rate coefficient at water temperature
$k_{1(20^0 c)}$	- Rate coefficient at water temperature T= 20^0 C
L	- First stage BOD at the downstream end of the stretch (mg/l)
L_0	- First stage BOD at the upstream end of the stretch (mg/l)
m	- Number of surrounding stations
MME	- Mean Multiplicative Error
M_o and M_p	- The mean of the observed and estimated concentrations
N	- Number of values
N_i	- Normal annual precipitation of surrounding stations
N_x	- Normal annual precipitation of x stations
NO_3	- Nitrate
Pi	- Rainfall values of raingauge used for estimation
Px	- Rainfall values of raingauge estimated for ungauged stations
o-PO_4	- Ortho-phosphate

Q	- Discharge in m^3/s
Q_d and Q_u	- Upstream and Downstream flow
Q_0 and Q_p	- Observed and estimated concentrations
RMSE	- Root Mean Square Error
R	- Correlation coefficient
S	- Slope
t	- River Water Temperature
V	- Velocity of Stream Water in m/s

Chapter 1
INTRODUCTION

Water is important to individuals, society and natural ecosystems as life cannot exist without a dependable supply of suitable quality water. The water in rivers plays an important role in meeting the essential requirements for the development of a country and serves as a source of water supply for domestic and industrial purposes, for agriculture, fisheries and hydro-power development. With growth and development, the demand for water has increased tremendously and its uses have become much more varied.

The quality of water can be negatively influenced by natural phenomena, but the main reason for impaired water quality is contamination caused by human activities. Urban and industrial development, use of chemical and fertilizers in farming, mining activities, combustion of fossil fuels, stream-channel alteration, animal feeding operations, and other human activities has changed the quality of natural waters.

It has been found that the global freshwater consumption raised by six times at above twice the rate of population growth from the literature during 1900 and 1995 (WMO, 1997). In Africa and West Asia water quality problems are most sensitive but in many other areas, including China, India and Indonesia water deficient is a major limitation to industrial and socio-economic growth (Roger, 1998). Indian rivers are polluted due to discharge of organic sewage and industrial effluents. The water quality monitoring of major rivers indicates that organic pollution and almost all the water sources from surface are infected to some extent.

Water pollution is separated into two broad categories called point and non-point sources of pollutants. The term point source pollution refers to the pollutants discharged from one discrete location, such as an industry and municipal waste water treatment plant to the river and

the pollution that enters the receiving surface water diffusely at intermittent intervals refers to the non-point source pollution. According to Central Pollution Control Board's data water quality of major rivers varied widely with respect to DO, BOD, TC, and FC. The pollution strength and potential demand for oxygen of effluent is indicated by the BOD concentration. The amount of oxygen that consumed by microorganisms to decompose the organic matter from a unit volume of water, during a specified period of time is termed as BOD. Another most important constituent of water systems is dissolved oxygen (DO) and a river must have about 2 mg/l of DO to maintain higher life forms. In addition to these life-sustaining aspects, oxygen is important because it produces aesthetically displeasing colours, tastes, and odours in water during chemical and biochemical reactions in anaerobic systems. The rate at which dissolved oxygen is used will depend on the quantity of the organics, the ease with which they are biodegraded and the dilution capacity of the stream. Mainly, the dissolved oxygen in water bodies is dependent upon temperature, salinity, turbulence and atmospheric pressure. Bio-depletion and re-aeration processes also control dissolved oxygen contents. If the dissolved oxygen concentration drops below that required by certain organisms living in the water, these organisms will die. This is sometimes evidenced by fish kills, and in the extreme, by the production of obnoxious gases such as methane and hydrogen sulfide.

Nonpoint source of pollution are the hydrologic rainfall-runoff transformation processes which is basically attached with water quality components (Notovny, V. and Chesters, G., 1981) and mainly derived from activities on land, from urban runoff, waste disposal, construction, irrigation modification in hydrology, agriculture, and individual sewage disposal (Robinson and Ragan, 1993). Mainly in aquatic environments both nitrates and ortho- phosphate is present in small amount to maintain the growth and metabolism of plants and animals. Intolerable levels of nitrates and phosphates have been depleting the dissolved oxygen levels by causing algae blooms. High amounts of phosphates and nitrates due to eutrophication, is a main source of lake ecosystems destruction around the world.

To manage the quality of natural water bodies that are subjected to pollutant inputs, one must be able to predict the degradation in quality that results from such inputs. In recent years, several water quality models have been developed to describe the processes that affect the water quality of streams/rivers. In the literature, biochemical oxygen demand and dissolved oxygen modeling has established a lot of consideration. Traditional water quality BOD-DO model initiated with the Oxygen-Sag Curve developed by Streeter and Phelps (1925). Many investigators developed and modified the Streeter and Phelps model including various parameters and empirical methods to estimate de-oxygenation and re-aeration coefficients, which were not considered earlier. In the development of water quality models, non-point source pollution were also considered as it plays a vital role in urban and agricultural areas. In recent year, Artificial Neural Network (ANN) models with various numerical analysis techniques are being used to develop non-linear functions for water quality modeling.

Keeping this in view, the main objectives of the present study are:

- To carry out time series analysis, primary and secondary validation of the flow and water quality of Mahanadi river system lying in Odisha.
- Comparison of magnitude of pollution in urban area of Cuttack town with upper reaches of Mahanadi river system lying in Odisha and with Tel sub-basin.
- Development of BOD-DO water quality model by establishment of coefficients deoxygenation rate co-efficient (k_1) and reaeration rate co-efficient (k_2) suitable for different river reaches.
- Application of ANN to simulate water quality at different river reaches using non-linear function and BPNN approach.
- To delineate land use/ land cover map, soil map, digital elevation model, slope map, flow direction and flow accumulation map for the Mahanadi river basin lying in Odisha.
- Development of non-point source models for estimating pollution contributing from agricultural areas and their periodic changes.
- To test the validity of developed models for point and non-point sources of pollution using various error statistics such as standard error, mean multiplicative error, root mean square error, coefficient of correlation, etc.

Organization of the Dissertation

The thesis has been organized in chapter wise with a view to meet the above objectives.

Chapter 1 focuses the introduction of the work related to stream/river water quality modeling. The importances of the present work and objectives have been explained.

Chapter 2 presents significant state-of art contributions to various aspects of water quality modeling with special emphasis to BOD-DO models, ANN models, de-oxygenation rate co-efficient , reaeration rate coefficient and non-point source pollution on river Mahanadi in past.

Chapter 3 focuses on geographical location, the characteristics of the study area, and sources of pollution in river Mahanadi and description of the sampling stations were considered in the present work. The databases used in the present study, plates illustrating the sampling locations, plots of water quality parameters have also been presented. Also, the applications of remote sensing and GIS for water quality modeling have been stated in this chapter.

Chapter 4 covers the mathematical models and Artificial Neural Network to simulate the effects of river pollution using modeling approach and modifying model structure, to derive the de-oxygenation and reaeration coefficients and dissolved oxygen deficit, estimate non-point source pollutant entry in a river reach. The methodology for estimation of basin characteristics using remote sensing and GIS is also discussed.

Chapter 5 incorporates the results and discussion on the present study, time series graphs, the de-oxygenation and reaeration rate coefficients, and dissolved oxygen levels in different reaches of river Mahanadi after applying the dissolved oxygen mass balance equation, assessment of non-point source pollution and delineated maps using remote sensing and GIS.

Chapter 6 provides the summary, important conclusions and specific contribution made in the present work.

Chapter 2
REVIEW OF LITERATURE

India's major, minor and several hundred small rivers receive a large amount of sewage, industrial and agricultural wastes. Most of the rivers in India's have been degraded to sewage flowing drains in recent years. There are serious water quality problems in the towns and the villages due to flow of un-hygienic water through these areas. The organic wastewaters have the greatest detrimental effect on the dissolved oxygen of the stream. Models are required to predict the outcome of various processes operating within a system and the change in concentration of substances within fluid systems. The analysis of biochemical oxygen demand and dissolved oxygen interaction in a reach of a river has occupied a large portion of the literature on water quality modeling. Biochemical oxygen demand is principally responsible for the reduction of dissolved oxygen levels in the river and, therefore, the dynamic interaction between biochemical oxygen demand and dissolved oxygen is an important factor to be considered in the implementation of water quality control schemes.

The biochemical oxygen demand of wastes is stabilized through bacterial action in the presence of oxygen and has been studied in considerable details, after Streeter and Phelps (1925) who first developed biochemical oxygen demand formulation model. Streeter (1935) considered the effect of sedimentation in biochemical oxygen demand removal.

The combined effects of biochemical oxygen demand exertion, and the reaeration resulting in a dissolved oxygen sag curve were modeled by Fair (1939) and Ginnerson et al. (1936).

The classical equations of Streeter and Phelps for the biochemical oxygen demand and dissolved oxygen profiles along a natural stream to take into account various sources of oxygen supply and demand, was modified and extended by Dobbins (1964), the effects of which were not included in the original equations.

The effect of algal growth and bacterial action on oxygen deficit was studied by O'Connor and Di Toro (1970).

Effects of paper mill wastes on river Hindon have been studied by Verma and Mathur (1971). It was found that the waste of the pulp and paper mill changes the water quality of river Hindon.

A lumped parameter differential equation for the description of the dynamic interaction between biochemical oxygen demand and dissolved oxygen in a non- tidal stream and improved the model by including a pseudo-empirical term, which accounts for the effects of algal populations on BOD and DO were presented by Beck and Young (1975).

The biochemical oxygen demand exertion rate exhibits a higher value at higher concentration of microorganisms was shown by Agarwal and Bhargava (1977).

A detailed limnological studies of Hindon river in relation to fish and fisheries was conducted by Verma et al. (1980).

Traditionally, river quality monitoring has focused upon surface water concentrations to safeguard drinking water supplies and to characterize the contaminative state of the aquatic environment. Changes in water discharge and variations in suspended solids loading have a considerable effect upon pollutant loadings (Forstner and Wittmann, 1983).

EI-Shaarawi et al. (1983) studied the temporal trend of Niagara River with respect to pH, alkalinity, total phosphorous and nitrates using statistical approach.

A hydro-chemical study of natural waters with reference to the waste effluent disposal in the upper part of Hindon basin in Saharanpur area by Patel (1985).

The changes in the concentrations of BOD and DO due to non-point sources within the river was studied by The Thomman and Muller model (1987).

The modeling of dissolved oxygen conditions in streams with dispersion and the presumption that advection is the dominant but not exclusive transport mechanism, was studied by Koussis et al. (1990).

The chemical characteristics of surface water of the Hindon river system and the ground water with the objective to assess the synoptic quality of the water for various specified uses by Seth (1991).

The spatial and temporal variations in different water characteristics of river Hindon was analyzed by Khare (1994).

The carbonaceous biochemical oxygen demand deoxygenation rate dropped after treatment upgrade and the algal growth was within the range used in previous calibration of model was checked by Wu-Seng Lung (1996).

A comparative study between different trace elements of major rivers of Orissa state has been done (Konhauser et al, 1997).

A one-dimensional water quality model addressing nutrient transport and kinetic interactions of phytoplankton, nitrogen, phosphorus, carbonaceous biochemical oxygen demand and dissolved oxygen into the water column in river system by adopting a finite segment approach were developed by Karim and Budruzzaman (1999).

Dissolved oxygen mass balance was computed for different reaches of river Kali to obtain the reaeration coefficient (k_2) a refined predictive reaeration equation for the river Kali was developed by Jha et al. (2001).

The efficiency of the model using differential standard errors and coefficient of determination by applying biochemical oxygen demand and dissolved oxygen models for the river Pachin in Arunachal Pradesh was studied by Hussain and Jha (2003).

The nutrient characteristics of the study area exhibited drastic temporal variation indicating highest concentration during the summer season compared to winter and rains. The persistence of dissolved oxygen (DO) deficit and very high biochemical oxygen demands (BOD) all along the water courses suggest that the de-oxygenation rate of lotic water was much higher than reoxygenation (Das and Acharya , 2003) .

A reaeration coefficient (k_2) predictive equation based on Froude number criteria and least square algorithms by evaluating different commonly used predictive equations for the reaeration rate coefficient using 231 data sets obtained from the literature and 576 data sets measured at different reaches of the river Kali in western Uttar Pradesh was developed by Jha et al. (2004).

The re-aeration coefficient (k_2) using data sets measured at different reaches of the Kali River in India by using the artificial neural network (ANN) method was estimated by Jain and Jha (2005).

In Udhampur district (Jammu and Kashmir) water samples were collected from wells, springs and rivers in parts of the during pre and post monsoon seasons were analyzed to evaluate drinking water quality on the basis of BIS and irrigation water quality on the basis of salinity, residual sodium carbonate and concentration of toxic elements by Singh et al. (2005).

A modified approach based on the conservation of mass and reaction kinetics has been derived to estimate the inflow of non-point source pollutants from a river reach. Two water quality variables, namely, nitrate (NO_3) and ortho-phosphate (o-PO_4), which are main contributors as non-point source pollution, were monitored at four locations of River Kali, western Uttar Pradesh, India, and used for calibration and validation of the model (Jha et al. 2005).

The current applications of geographic information systems (GIS) applications to non-point-source pollution modeling for agricultural area were reviewed by Wu et al. (2005).

In Coimbatore city along the Noyyal River, the ground water quality during pre-monsoon and post-monsoon seasons in 2005 has been analyzed for the water samples were collected from 12 wells (Sundar et al, 2008).

Hydrochemistry of surface water (pH, specific conductance, total dissolved solids, sulfate, chloride, nitrate, bicarbonate, hardness, calcium, magnesium, sodium, potassium) in the Mahanadi river estuarine system, India was used to assess the quality of water for agricultural purposes. Chemical data were used for mathematical calculations (SAR, Na%, RSC, potential salinity, permeability index, Kelly's index, magnesium hazard, osmotic pressure and salt index) for better understanding the suitability river water quality for agricultural purposes(Sundaray et al., 2008).

The iron content in the water and its impact on the river Godavari at Nanded was studied by Bhosle et al, (2009).

An estimation of the water quality of Mahanadi and its distributary rivers and streams, Atharabanki River and Taldanda Canal adjoining Paradip was studied in three different seasons namely summer, premonsoon and winter by (Samantray, 2009).

An artificial neural network was used to predict the biochemical Oxygen Demand as indicator of river pollution s was studied by Talbia et al., (2009).

An artificial neural network technique was done for modeling biological oxygen demand of the Melen River in Turkey using by Dogan et al. (2009).

The modeling of BOD and DO in the River Kali involving derivation and solution of the governing equations that describe concentration change with time and space brought on by advective, decay, settling and loading functions was done by Jha et al. (2008).

A Neural Network Model for the prediction of dissolved oxygen in canals was studied by Areerachakul et al. (2011).

Chapter 3

THE STUDY AREA AND DATA COLLECTION

To test the validity and performance of any water quality model, stream/river water quality data, flow data and various parameters are the pre-requisite. The quantum of data and the number of input parameters can be collected on the basis of the objectives of the study and availability of water quality models. River Mahanadi lying in Odisha has been selected for the present work and the details are described hereinafter. The chapter begins with the description of the study area followed by the details of the sampling stations and data, which have been collected from different locations.

3.1 Mahanadi River System

In Odisha River Mahanadi is prime river and largest one (Figure 3.1). The geographical co-ordinates of Mahanadi basin lying in Odisha lies between $85^{0}30'$ to $85^{0}50'$ East longitudes and $20^{0}09'$ to $20^{0}15'$ North latitudes. River Mahanadi raises from a small pool located at about 6 km from Pharsiya village in the Amarkantak hills of Bastar Plateau, which lies on the extreme south east of Raipur district of Chhattisgarh state. It is covering major parts of Orissa, Chattisgarh, small portions of Madhya Pradesh, Maharashtra and Jharkhand.

Out of total length of 851 km, it covers 494 km. in Odisha state. Ib,Ong, Tel, Hariharjore and Jeera are the main tributaries and Kathajodi, Kuakhai, Devi and Birupa are the major distributaries of Mahanadi in Odisha. Major towns located on the bank of this river are Sambalpur, Sonepur, Cuttack and Paradeep. The catchment area of Mahanadi spreads over 141600 square km (65,628 square km in Odisha).

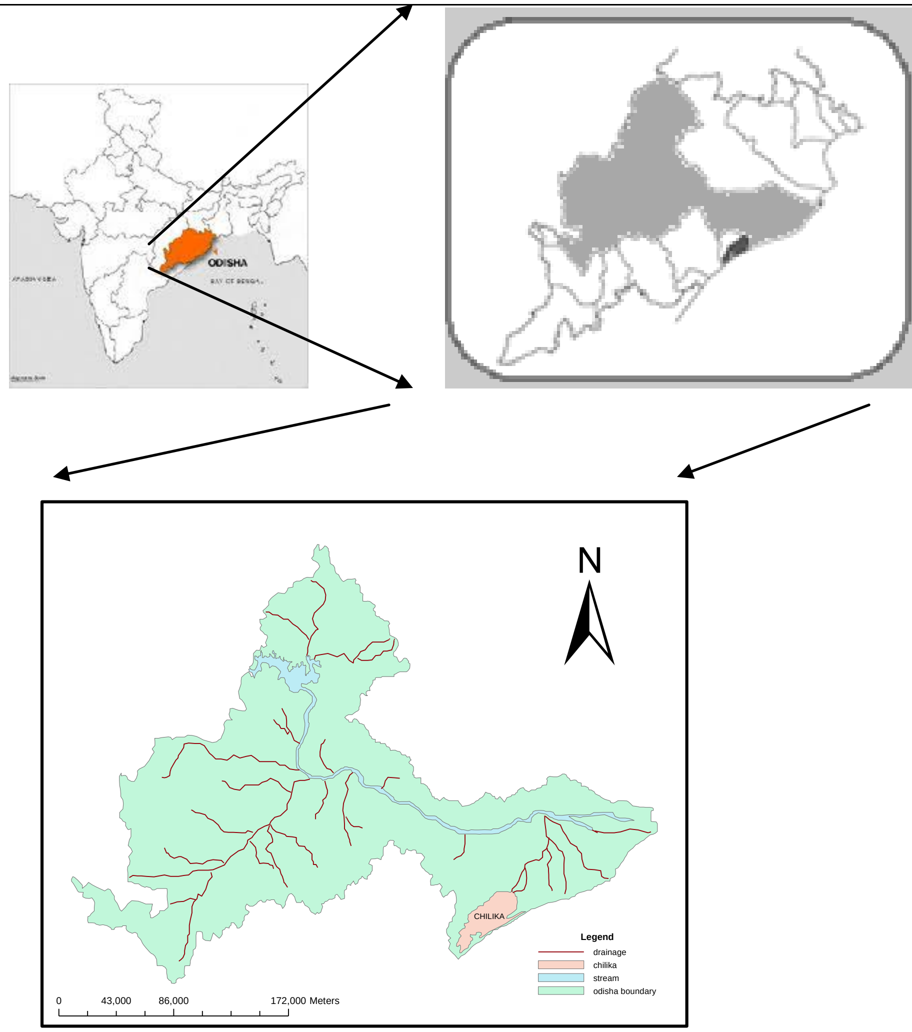


Figure 3.1: Location of River Mahanadi (lying in Odisha)

Hirakud dam constructed in 1957 across Mahanadi near Sambalpur drains an area of 83,400 square km. It is the largest earthen dam in the world measuring 24 km including dykes; having reservoir spread of 743 square km and live storage capacity of 5.37 x 109 cum. However, it is the only such structure to moderate the downstream floods.

The basin having soil types are red and yellow soils, laterite soils. The region of northern part as well as the Mahanadi and Tel sub-basin contains red soil which is obtained from Central Land Table. The river and Tel sub-basin are the most densely inhabited and agriculturally affluent part of the area with compact settlements.

The climate of the Mahanadi basin lying in Odisha is a tropical monsoon type and having maximum precipitation in July, August and first half of September. The climatic conditions of river basin are change due to topographical variations. During winter season the minimum temperature is generally varies from 4°C to 12°C. Agriculture is the mainstay of basin's economy and nourishment of the life of the people. The river basin generally irrigates a productive valley whose crops are mainly rice, oilseed, and sugarcane. Forest is dominated some of the lower parts of river having types of tropical moist deciduous, dry deciduous and the coastal forests. The important industries in river basin lying Odisha are aluminum factories at Hirakund and Korba, paper mill near Cuttack and cement industries at Sundargarh.

3.2 Data collection

To collect water quality samples for measurements, thirteen sampling stations at different locations in a stretch of 494 km of river Mahanadi have been selected. A line diagram of Mahanadi river basin along with sampling stations is shown in Figure 3.2. Seasonal water quality data for the years 2000-2006 were collected from Orissa State Pollution Control Board. To add, water samples collected from 12 stations located along Mahanadi, Kathajodi rivers and Taladanda canal during different seasons (winter, summer and rainy) over a period of two years from 1996 to 1997 in Cuttack city (Das and Acharya, 2003) were included in the study used for the analysis. Also, the flow and water quality data obtained from Central Water Commission for the years 2001-2009 were utilized for the analysis. Spatio-temporal variation of discharge, BOD/ DO and nitrate concentration in River Mahanadi lying in Odisha is shown in Figures 3.3, 3.4, and 3.5 respectively. Remote sensing data, a global digital elevation model (DEM) with a horizontal grid spacing of approximately 1 kilometer, have been obtained from URL: (http://edc.usgs.gov/products/elevation/gtopo30/gtopo30.html) and Land use/ Land cover data was derived from Global Land Cover 2000.

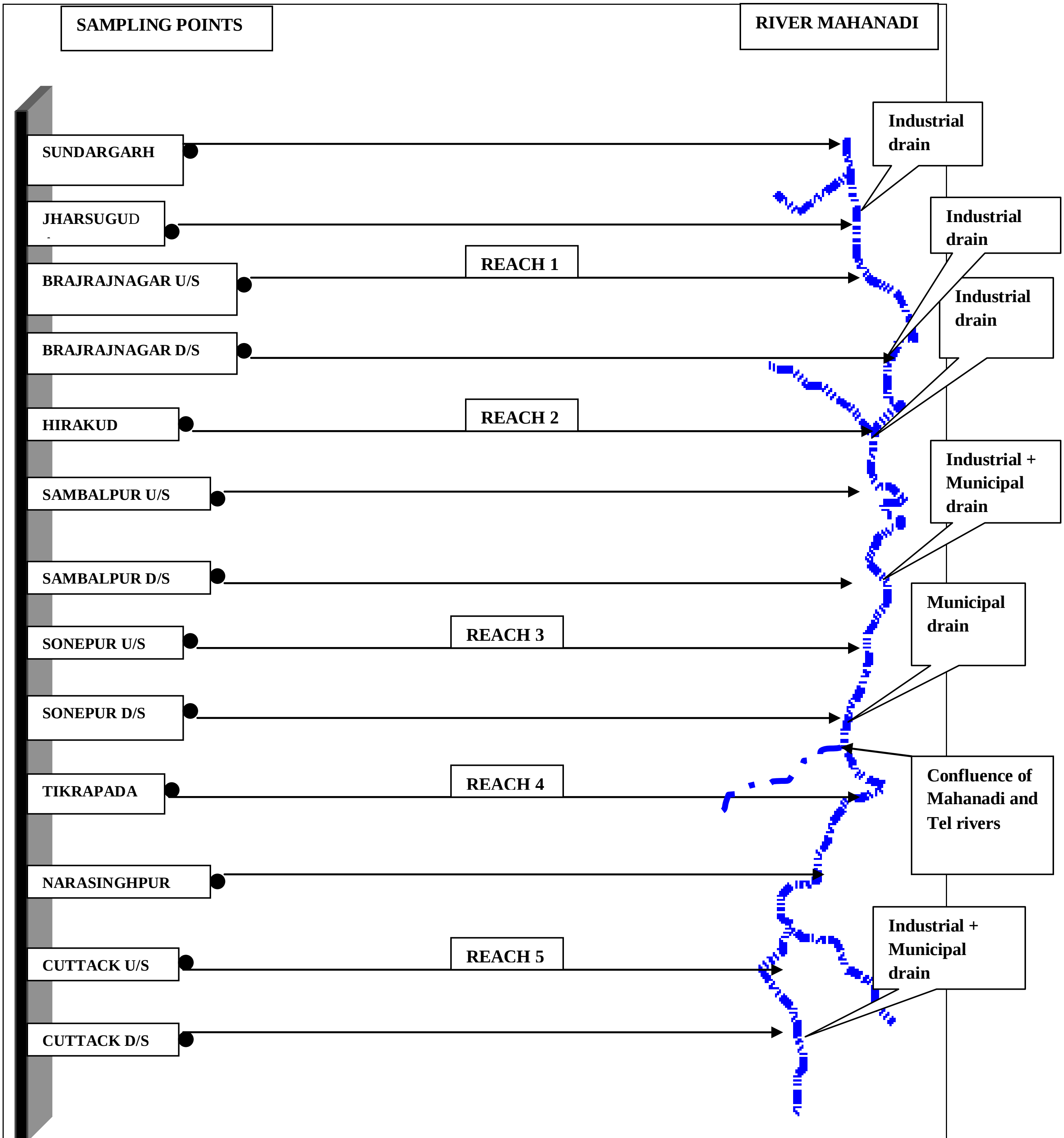


Figure 3.2: General plan of the sampling points in River Mahanadi

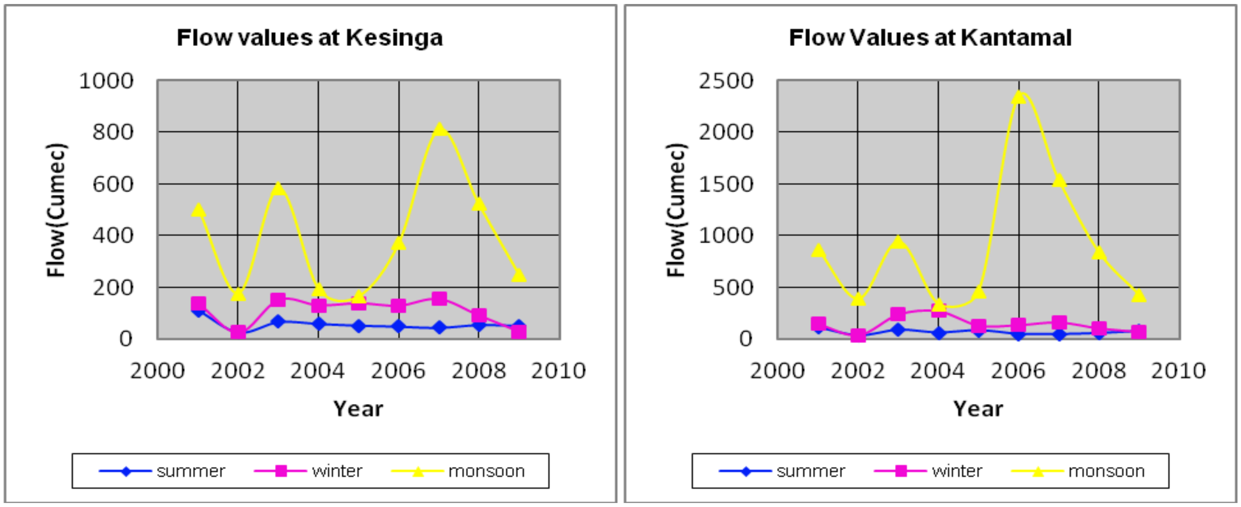


Figure 3.3: Discharge in Mahanadi basin lying in Odisha (source: CWC)

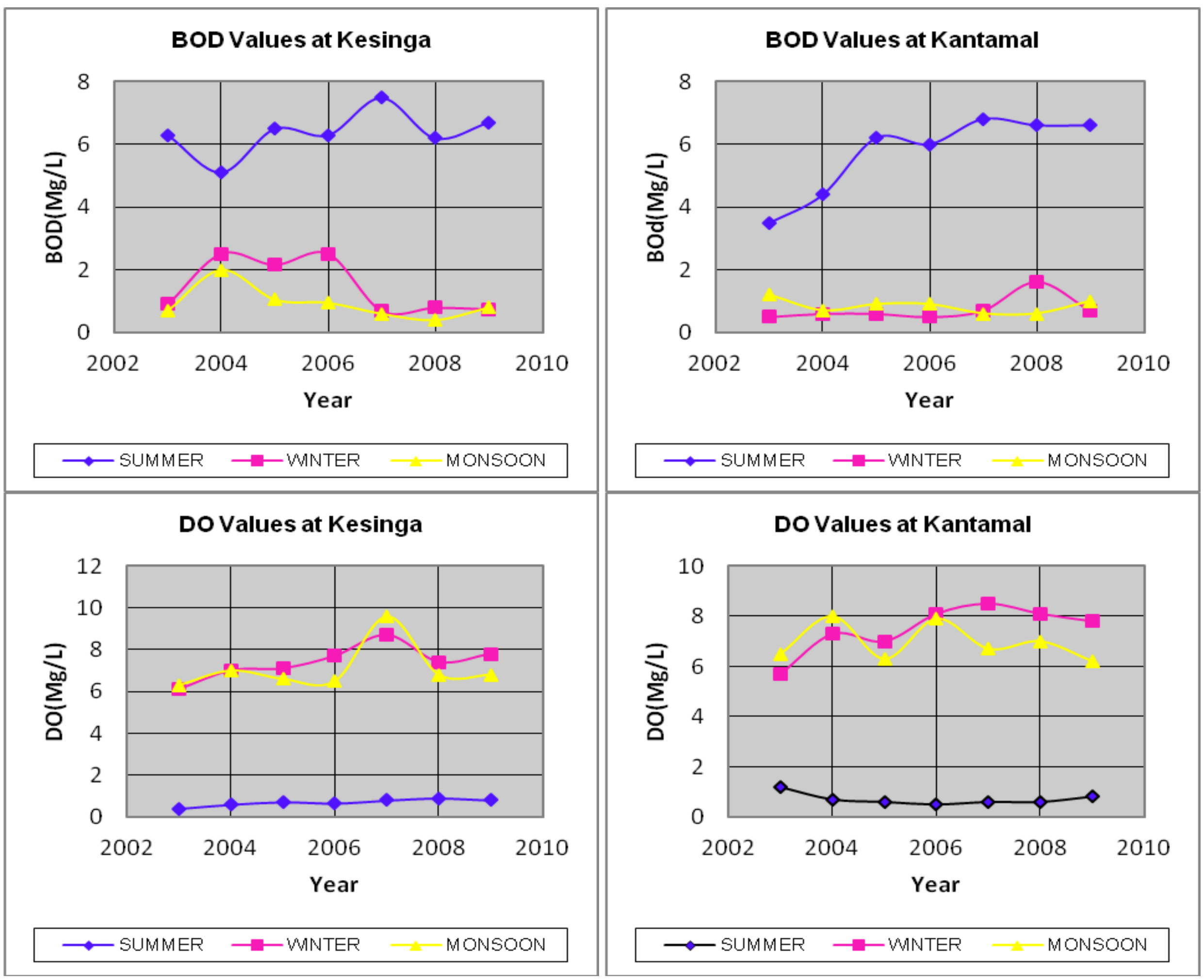


Figure 3.4 (a): BOD and DO values in Mahanadi basin lying in Odisha (source: CWC)

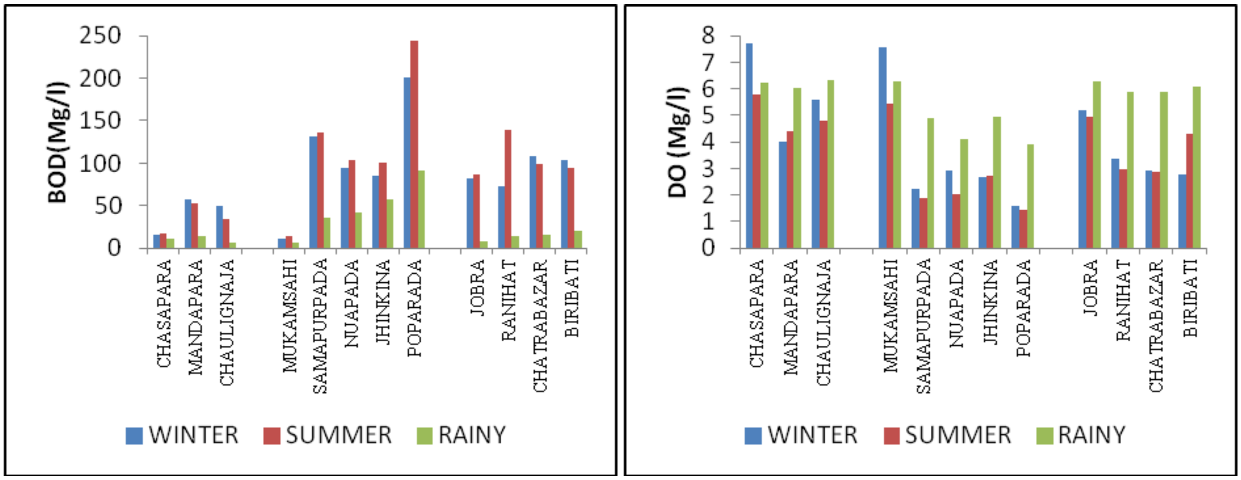
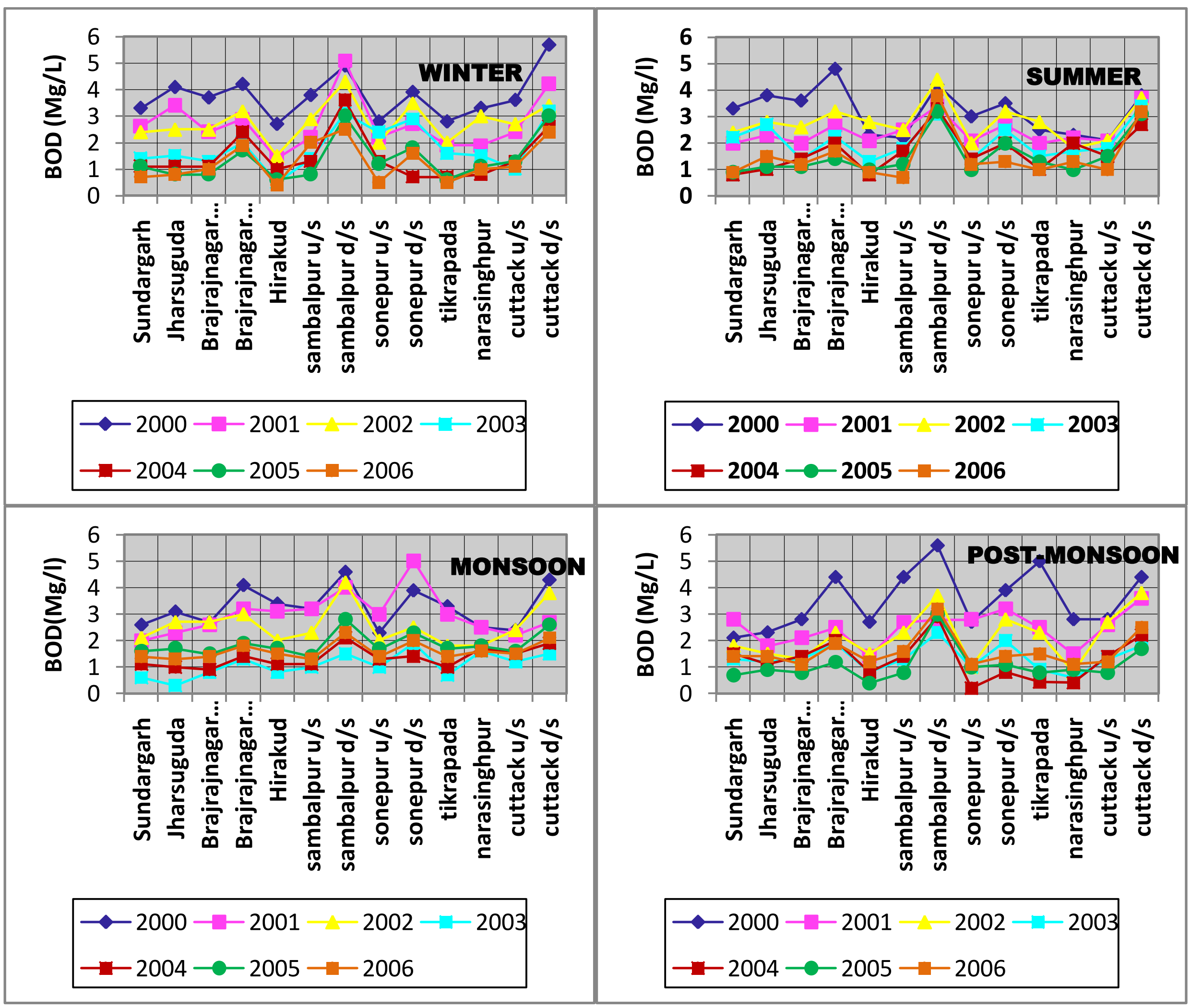


Figure 3.4(b): BOD and DO values in Mahanadi basin lying in Odisha

(source:Das and Acharya, 2003)



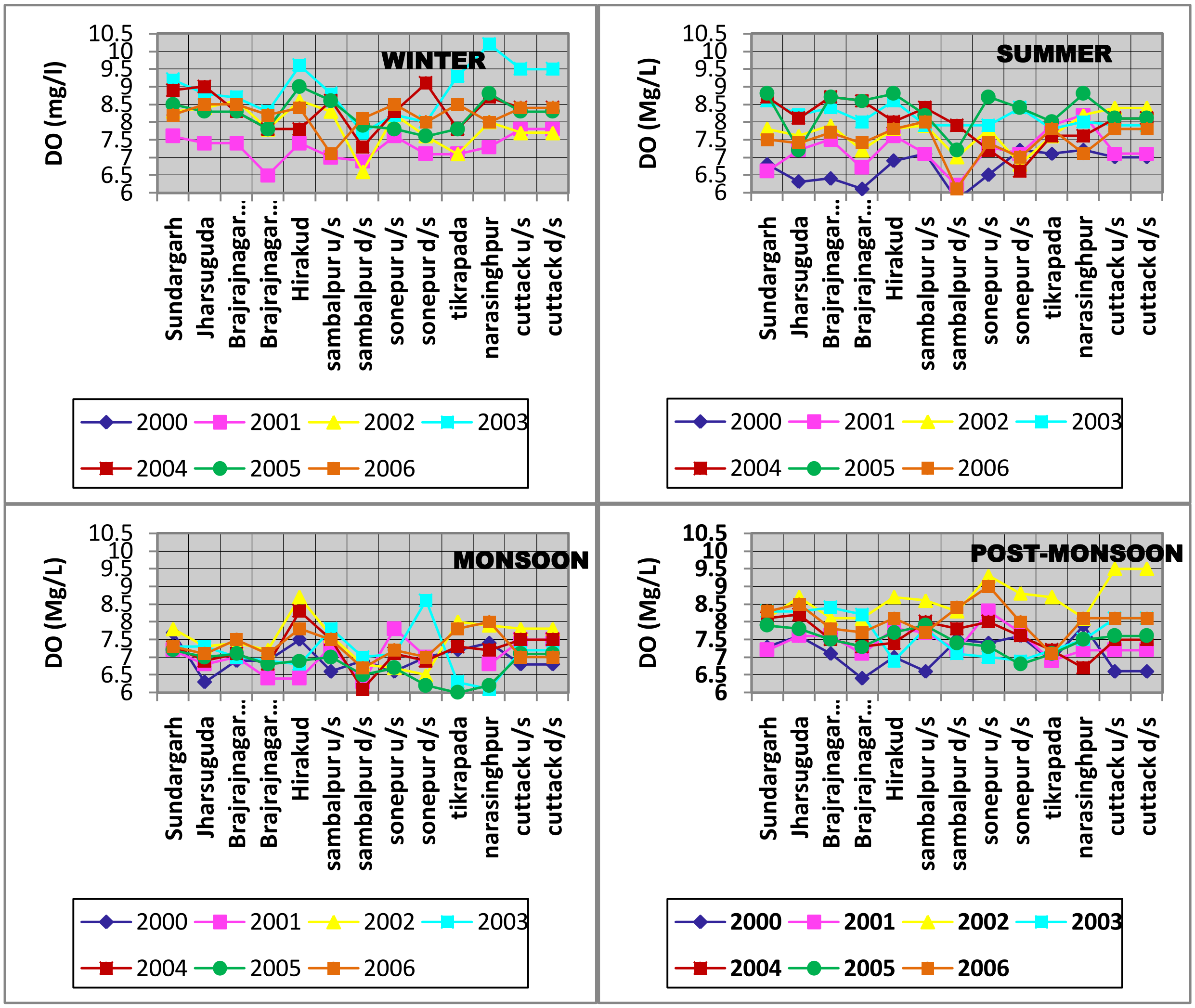


Figure 3.4(c): BOD and DO values in Mahanadi basin lying in Odisha (source:OSPCB)

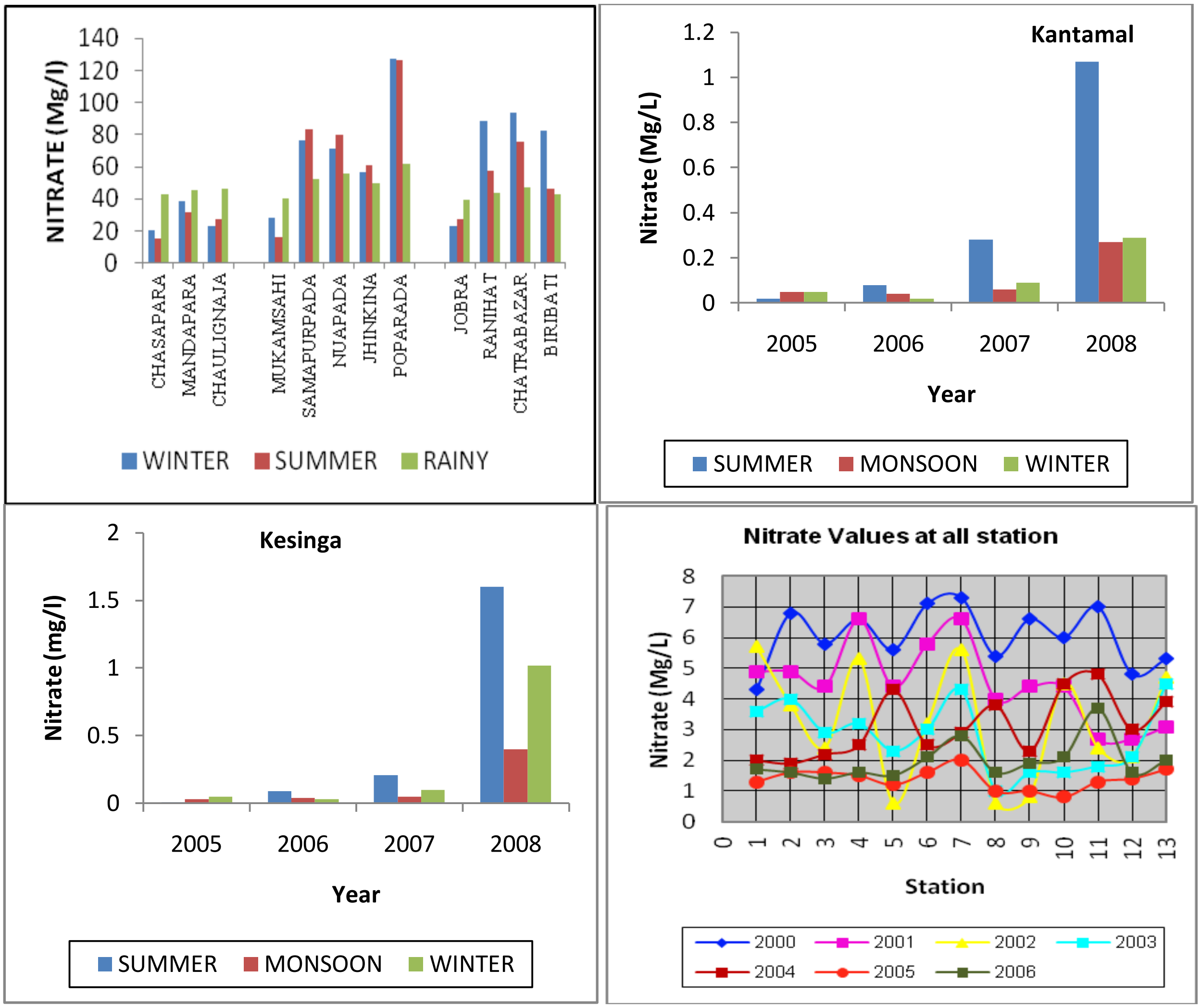


Figure 3.5: Nitrate values in Mahanadi basin lying in Odisha

(source: Das and Acharya, 2003, CWC, OSPCB,)

Chapter 4
METHODOLOGY

For the pollution survey of the river, various sets of data were collected from various sources during different period. Several approaches have been used to simulate point and non-point source pollution in River Mahanadi lying in Odisha.

4.1 Time Series Analysis

Time series is an important method for description of the pollution load in the river system by graphical representation of data, which shows the trend of change of concentration of water quality parameters and load of heavy with respect to time/distance in a river system. In the present study, the following analysis has been carried out: (a) Primary validation of the data by time series plots and the removal of outliers, (b) secondary validation of the data by checking flow and water quality variations with upstream/downstream data and development of cross-correlation between stations, (c) Filling of missing data and modify data for outlier by normal ratio method, (d) development of relationship between different water quality variables using multiple linear regression analysis, and (e) computations of basic statistics to know the data structure and characteristics by estimating mean, median, mode, kurtosis, skewness, range, etc.

The missing data has been filled using the Normal Ratio Method as given below:

$$P_X = \frac{1}{m}\sum_{i=1}^{m}\left[\frac{N_X}{N_i}\right]P_i \qquad (4.1)$$

Where, P_x = Estimate for the ungauged station; P_i = Rainfall values of rain gauges used for estimation; N_x = Normal annual precipitation of X station; N_i = Normal annual precipitation of surrounding stations; m = No. of surrounding stations

4.2 BOD-DO Modeling for Point source pollution simulation using Oxygen Sag Curve

Water quality modeling in a river has progressed from the revolutionary Streeter and Phelps (1925), proposed different water quality modeling in a river and developed a relationship between biochemical oxygen demand (BOD) and dissolved oxygen (DO) that mainly affect the organic decomposition of the river and producing a convectional model namely, the "oxygen sag model".

4.2.1 BOD Model

The amount of oxygen consumption by microorganisms, living in the water, generally affects the oxygen content of water by decompose biodegradable organic matter, which is directly/indirectly harm o the aquatic ecosystem. In the models biodegradable organic matter is taken into consideration by a parameter termed "Biochemical oxygen demand, BOD" and is defined as the amount of oxygen consumed by microorganisms from a unit volume of water, while they decompose organic matter, during a specified period of time. The BOD is measured by determining the oxygen demand from a sample in an airtight container and kept in controlled environment for a pre-selected period of time. In the standard test, 300 ml BOD bottles are used and the sample is incubated at 20 degree centigrade for 5 days. Thus BOD_5 is the five day biochemical oxygen demand that is the amount of oxygen that was used up by micro- organisms in a unit volume of water during five days "incubation" time in the respective laboratory experiment. Thus the unit is mass per unit volume. The chemical used for the determination of BOD are phosphate buffer solution to adjust the pH and magnesium sulphate, calcium chloride and ferric chloride solution as microbial nutrients.

The BOD only represents the oxygen consumed in 5 days. The rate at which organics are utilized by micro-organisms is assumed to be that given by a first-order reaction and articulated as the BOD decay model (termed here L) in function of the time (which is the time of travel along the stream t =x/v). It can be represented as:

$$\frac{dL}{dt} = -k_1 L \qquad (4.2)$$

Where L (mg/l) is the oxygen equivalent of the organics at time t, and k_1 (d^{-1}) is the reaction constant. Equation (4.2) can be rearranged and integrated as follows to obtain the solution:

$$\frac{dL}{L} = -k_1 dt \tag{4.3}$$

$$\int_{L_0}^{L} \frac{dL}{L} = -k_1 \int_0^t dt \tag{4.4}$$

$$ln \frac{L}{L_0} = -k_1 t \tag{4.5}$$

$$L = L_0 e^{-k_1 t} \tag{4.6}$$

Here, L_0 denotes the first stage BOD of the reach (mg/l). BOD at the downstream location of a river reach for known BOD in the upstream location, travel time and reaction constant values can be anticipated by using the above equation (Eq. 4.6).

The deoxygenation rate coefficient, k_1 (per day) used in equation (4.6) can be obtained from the BOD_5 values and estimated travel time between stream reaches. In this approach, the BOD obtained for different reaches are plotted on y axis and the travel time is plotted on x axis. The optimum value of k_1 for present model has been obtained and error estimate has been done to evaluate the performance of the BOD model with k_1 values (Texas Water Development Board 1971). Further, for the estimation of the value of $k_{1,}$ the Table of Fair (Ref. Jolánkai, 1979) is also used for known values of reaeration coefficient, k_2 (Table 4.1) and the ratio k_2/k_1.

Table 4.1: Ratio f=k_2/k_1 for different hydraulic conditions of the stream

Description of the water body	**range of 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

The deoxygenation rate coefficient k_1 depends on the ambient (water) temperature. Hence, the temperature correction formula is given by

$$k_{1(T)} = k_{1(20^0 c)} 1.047^{(T-20)} \quad (4.7)$$

Where, $k_{1(\mathrm{T})}$ - is rate coefficient k_1 at water temperature T °C, $k_{1(20°\mathrm{C})}$ -is the value of rate coefficient k_1 at water temperature T=20 °C.

4.2.2 DO Modeling

The aquatic ecosystem life is generally, required dissolved oxygen for their metabolism process. (i.e. breathing). The dissolved oxygen model describes the fate, the "sag", (Figure 4.1) of the dissolved oxygen in the river as prejudiced by organic matter decay and the reaeration process (across the water surface). The dissolved oxygen of water sample can be measured by titration of the preserved water sample with the addition of manganus sulphate solution and alkali-iodide-azide reagents. Sodium thiosulphate solution is used as titrant dissolved oxygen. The standard values for DO is 5 mg/l for freshwater, if it below than standard values than the quality of water becomes very poor and that affects the aquatic life such as certain insects and fish.

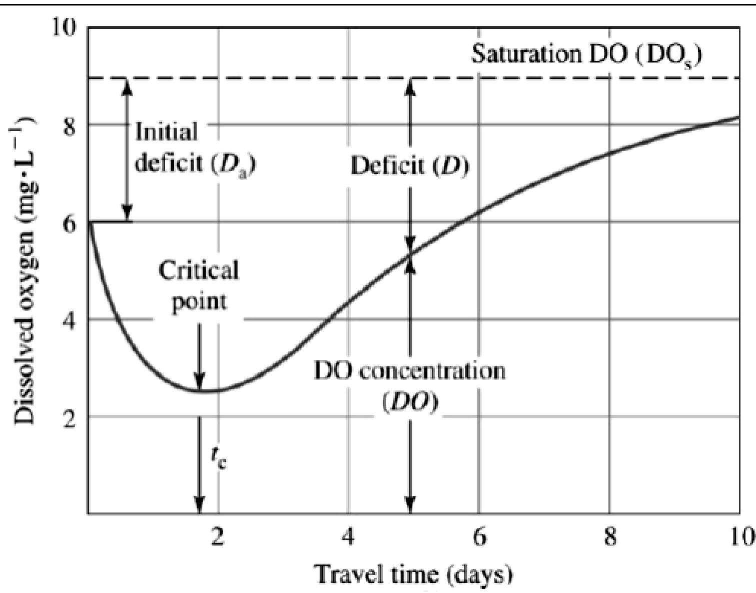


Figure 4.1: Oxygen sag Curve

The analysis of streams assimilative capacity for organic pollution has been based principally on the classical theory of Streeter and Phelps (1925). The equation can be expressed as:

$$\frac{dD}{dt} = k_1 L_t - k_2 D \qquad (4.8)$$

In which D is the DO deficit, mg/l = (Saturated dissolved oxygen- Dissolved oxygen in water), and k_2 is the reaeration rate coefficient, per day. By multiplying $e^{k_2 t}$ both the sides of equation (4.8), it becomes

$$\frac{dDe^{k_2 t}}{dt} + k_2 De^{k_2 t} = k_1 Le^{k_2 t} \qquad (4.9)$$

By substituting $L = L_0 e^{-k_1 t}$ in equation (4.9), it becomes

$$\frac{dDe^{k_2 t}}{dt} + k_2 De^{k_2 t} = k_1 L_0 e^{(k_2 - k_1)t} \qquad (4.10)$$

It can be seen that $\frac{dDe^{k_2 t}}{dt} + k_2 De^{k_2 t}$ is obtained by differentiating $\frac{dDe^{k_2 t}}{dt}$ term. With this modification, the equation (4.10) can be expressed as

$$\frac{dDe^{k_2 t}}{dt} = k_1 L_0 e^{(k_2 - k_1)t} \qquad (4.11)$$

By integrating on both sides, the equation (4.11) becomes,

$$\int dDe^{k_2 t} = k_1 L_0 \int e^{(k_2 - k_1)t} dt \qquad (4.12)$$

Or

$$De^{k_2 t} = \frac{k_1 L_0}{k_2 - k_1}\left(e^{(k_2 - k_1)t}\right) + C \qquad (4.13)$$

The constant of integration C can be determined from known boundary conditions, that is, $D=D_0$ at t= 0. Therefore

$$D_0 = \frac{k_1 L_0}{k_2 - k_1} + C \quad \text{And} \quad C = D_0 - \frac{k_1 L_0}{k_2 - k_1} \qquad (4.14)$$

and the final solution becomes

$$D = \frac{K_1 L_0}{(K_2 - K_1)}(e^{-k_1 t} - e^{k_2 t}) + D_O e^{-k_2 t} \quad (4.15)$$

One of the important water quality parameter, reaeration coefficient, k_2 (per day) used for DO modelling in equation (4.15) has been computed based on mean flow, friction velocity, bed slope, flow depth and Froude number after the classical work of Streeter and Phelps (1925). Some of the most popular formulae and equations have been given in Table 4.2 in chronological order. These equations were used in the present work and the most suitable equations were obtained for their applicability for estimating k_2 values.

Table 4.2: Equations used for computing Reaeration Rate Coefficient (k_2)

S.No.	Equation	Investigator	Year
1	$k_2 = 3.9\, V^{0.5} H^{-1.5}$	O' Connor and Dobbins	1958
2	$k_2 = 5.010\, V^{0.969} H^{-1.673}$	Churchill et al.	1962
3	$k_2 = 173\, (S\, V)^{0.404} H^{-0.66}$	Krenkel and Orlob	1962
4	$k_2 = 5.35\, V^{0.67} H^{-1.85}$	Owens et al.	1964
5	$k_2 = 5.14\, VH^{-1.33}$	Langbein and Durum	1967
6	$k_2 = 186\, (S\, V)^{0.5} H^{-1}$	Cadwallader and McDonnell	1969
7	$k_2 = 24.9(1 + Fr^{0.5}) VH^{-1}$	Thackston and Krenkel	1972
8	$k_2 = 23\, (1 + 0.17 F_r^2)(SV)^{0.375} H^{-1}$	Parkhurst and Pomerory	1972
9	$k_2 = 31200 SV\ for\ Q > 0.28\, m^3/s$	Tsivoglou and Wallace	
10a	$k_2 = 15200\, SV\ for\ Q > 0.28\, m^3/s$	Smoot	1988

10b	$k_2 = 543\ S^{0.6236}\ \ V^{0.5325}\ H^{-0.7258}$		
11a	$k_2 = 1740\ V^{0.46} S^{0.79} H^{0.74}$ for S>0.00	Moog and Jirka	1998
11b	$k_2 = 5.59\ S^{0.16} H^{-0.73}$ for S> 0.00		
12	$k_2 = 5.792\ V^{0.5} H^{-0.25}$	Jha et al.	2001

Where, V = the velocity of stream water in m/s; H = flow depth in m, S = slope; Q = the discharge in m^3/s and; F_r = Froude number

For temperature correction of DO, equation (4.7) was used. The equation used for estimating saturated dissolved oxygen on river temperature is as given by:

$$DO_{(sat)} = 14.61996 - 0.4042T + 0.00842T^2 - 0.00009T^3 \qquad (4.16)$$

Where $DO_{(sat)}$ is the saturation oxygen concentration of water and T stands for the river temperature.

4.3 Artificial Neural Networks for BOD-DO Modeling

An ANN is a simplified mathematical and computational that inspired by the structural/ functional aspects of biological neural network. The application of ANNs to water resources problems has become very popular due to their power and potential in modeling nonlinear systems. ANN has a number of data processing elements called neurons or nodes. The neurons in the input layer receive the input vector and transmit the values subsequently to the next layer across connections. This process is continued until the output layer is reached. A three-layer feed forward ANN, shown in Figure 4.2, has an input layer, an output layer and a hidden middle layer. The solution to the input problem is emanating from the output nodes. When the interconnection weights are modified, the ANN output changes.

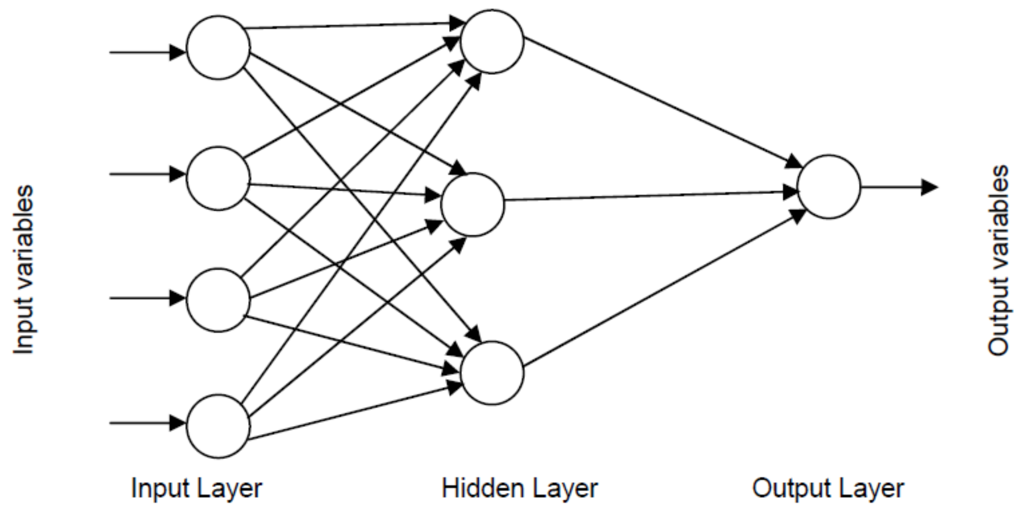


Figure 4.2: A typical three-layer feed forward artificial neural network

4.3.1 Training of an ANN

An ANN stores the knowledge about the problem in terms of weights of interconnections. Generally, training refers as the method of formative ANN weights and it is trained with an input and output training datasets. At the beginning of training, the initial value of weights can be assigned arbitrarily or based on experience and is changed systematically by the learning algorithm. The difference between the ANN computed output and the actual output is small, hence considered ANN is trained. By multiplying each neuron with every input by its inter-connection weight an output will be produce, sums the product, and then passes the sum through a transfer function having S-shaped curve which is increasing steadily, called a sigmoid function. This function is continuous, differentiable everywhere, and is monotonically increasing. The input to the function can vary between $\pm\infty$ and the output is always bounded between 0 and 1.

A popular algorithm to adjust the inter-connection weights during training and is based upon the generalized delta rule popularized by Rumelhart *et al.* (1986) is the back-propagation (BP) algorithm error. The actual result is subtracted from the target result to find the output-layer errors and is "back-propagated" through the network and is used to adjust weights. Sometimes the training will take a long time due to high number of nodes in the hidden layer and the network may sometimes over fit the data (Karunanithi *et al.*, 1994). An over fit network typically has very small error for the training data set, but large error for the validation data set. After training is complete, the weights are frozen and the ANN's performance is to be validated and the performance measures for training data sets are better than for validation data sets. However, if the performance of an ANN on the validation or test data set is poor, it shows that either the ANN has not been able to successfully learn the underlying behavior of the process, or there might be a discontinuity between the training and validation data sets. In many books such as Vemuri (1992) and Yegnanarayana (1999), theory of ANN has been described properly.

In the present study, the available data are divided into two parts. The first part is used to calibrate the model and the second to validate it and the optimal length of calibration data depends upon the number of estimated parameters. The general practice is to use about two-thirds of the data for calibration and the remainder for validation. Out of the data sets, two-thirds of the data sets were randomly selected and used for training. Remaining data were used for testing and validating the ANN model functions developed during calibration. Upstream BOD values have been used to estimate the BOD values of downstream stations. However for DO estimation of downstream station various combinations of BOD and DO values are used. During training, the number of nodes in the hidden layer was systematically changed and the value that gave the best result for a data set was finally adopted. For the hidden layer, a tan-sigmoid transfer function was used and, for the output layer, a linear transfer function was chosen. The multilayer perceptron technique was used to train the ANNs. It requires iterative training, which may be quite slow for large number of hidden units and datasets, but the networks are quite compact, execute quickly once trained, and in most problems yield better results than the other types of networks. The ANN training epoch consisted of 1000 cycles.

4.4. Delineation of Maps for Assessment of Non-point Source Pollution using Remote Sensing and GIS approach

New tools have been provided successfully for the advanced ecosystem management by the application of remote sensing and GIS. The synoptic analysis of function patterning of earth's system was facilitated by collecting the remotely sensed data. To delineate the basin boundary, drainage pattern, land use, slope, aspect, flow direction, accumulation and digital elevation maps for the Mahanadi river basin, Geographical information systems (GIS) techniques has been used. Arc-GIS software has been extensively used with various tool and 3D analyst and spatial analyst to obtain various maps and overlay maps over each other for estimating non-point source pollution. In principle, a DEM describe the elevation in a digital format of an area and contains information of drainage, crests and breaks of slope. After the DEM map, filtering is executed to arrive at a slope map, aspect map and a flow path map. Slope, which can be deliberate in degrees from horizontal (0-90) or percent slope is the incline, or steepness. From a continuous elevation surfaces an aspect can be generated and the slope of an aspect have very significant effects on its local climate. Also, the slope and aspect of an elevation surface identifies terrain steepness and orientation. Flow direction and flow accumulation identifies the amount of water pour from different sources along with point and non-point sources of pollution. Mainly, natural and socio-economic factors and their utilization by man in time and space affect the land use/land cover pattern of a region and these describe the information about the features type found on the earth's surface.

4.5 Non-Point Source Pollution Modeling

The pollution that enters the receiving surface water diffusely at intermittent intervals is termed as Non-Point Source (NPS) pollution, Infiltration and storage characteristics of the basin, the permeability of soils and other hydrological parameters play an important role as driving forces of diffused contamination. To evaluate the continuous entry of NPS of pollutants into River Mahanadi lying in Odisha state, during the non-monsoon period, an existing modeling approach has been applied as shown in Figure 4.3. Data sets of two important water quality variables nitrate (NO_3) and ortho-phosphate (o-PO_4), along with discharge observed at different locations of River Mahanadi for one annual cycle were used for the analysis.

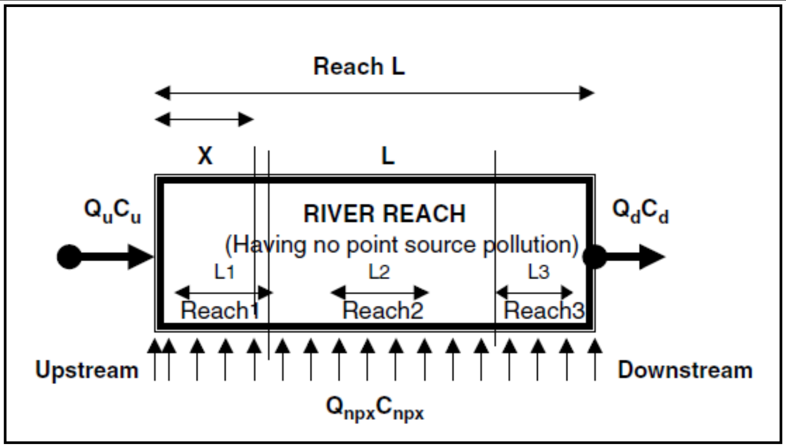


Figure 4.3: Sketch showing the inflow of NPS at different reaches of River Mahanadi

To obtain a solution for estimating non-point source pollutant concentration within a river reach receiving non point source pollution, it is assumed that the non-point source pollutants entering the river reach either from the banks or coming from the bed are uniformly distributed over the river reach. Thomman and Muller (1987) made the similar assumption to estimate the respiration, photosynthesis, sediment oxygen demand and biochemical oxygen demand (BOD) for estimating non-point source loads in DO-BOD modeling.

For a river reach of length l receiving diffused sources of pollution from the bed or banks of river at any section of river that is having reach length x from the entry point, the contribution of non-point discharge (Q_{npx}) can be estimated as

$$Q_{npx} = \frac{(Q_d - Q_u)}{l} x \tag{4.17}$$

The travel time (t_{npx}) required for a water quality constituent at any small distance x to reach at the outlet of the cell is

$$t_{npx} = t\left(1 - \frac{x}{l}\right) \tag{4.18}$$

Thus, the non-point source load at small distance x becomes,

$$C_{npx} Q_{npx} = C_{npx} \left[\frac{(Q_d - Q_u)}{l} x\right] e^{-kt_{npx}} \tag{4.19}$$

Here C_{npx} is the non-point source pollutant concentration (mg /l unit per length). Now, the NPSL reaching at the outlet of river reach having length l can be expressed as,

$$NPSL = C_{npx} \left[\frac{(Q_d - Q_u)}{l} x\right] e^{-kt_{npx}} \tag{4.20}$$

The equation (4.20) can be integrated from zero to length l to estimate the total non-point source load from the river reach having length l. It can be written as

$$NPSL = \int_0^l C_{npx} \left[\frac{(Q_d - Q_u)}{l} x\right] e^{-kt_{npx}}\, dx \tag{4.21}$$

By substituting Q_{npx} and t_{npx} , equation (4.21) becomes,

$$NPSL = C_{np} \left[\int_0^l \left(\frac{(Q_d - Q_u)}{l} x\right)\right] e^{-kt\left(1-\frac{x}{l}\right)} dx \tag{4.22}$$

$$= \frac{C_{np}\,(Q_d - Q_u) e^{-kt}}{l} \left[x \int_0^l e^{\frac{ktx}{l}}\, dx - \int_0^l \frac{d}{dx}(x) \left(\int_x^l e^{\frac{ktx}{l}}\, dx\right) dx\right] + A \tag{4.23}$$

Where A is the constant of integration. By solving equation (4.23), one gets,

$$NPSL = \frac{C_{np}\,(Q_d - Q_u) e^{-kt}}{l} \int_0^l \left[\frac{x e^{\frac{ktx}{l}}}{\left(\frac{kt}{l}\right)} - \frac{e^{\frac{ktx}{l}}}{\left(\frac{kt}{l}\right)^2}\right] + A \tag{4.24}$$

$$= \frac{C_{np}\, l(Q_d - Q_u)}{kt} \left(1 - \frac{1}{kt} + \frac{e^{-kt}}{kt}\right) + A \tag{4.25}$$

For t=0, A becomes zero. By substituting A=0 in equation (4.25), we get

$$NPSL = \frac{C_{np}\, l(Q_d - Q_u)}{kt} \left(1 - \frac{1}{kt} + \frac{e^{-kt}}{kt}\right) \tag{4.26}$$

Equation (4.26) implies the non-point source load of a river reach. For any river reach having length l, the NPSL can also be estimated by using the following equation:

$$NPSL = Q_d C_d - Q_u C_u e^{-kt} \tag{4.27}$$

By substituting NPSL from equation (4.26) in equation (4.27), the rearranged equation can be written as:

$$C_{np} = \frac{Q_d C_d - Q_u C_u e^{-kt}}{\left[\frac{l(Q_d - Q_u)}{kt}\left(1 - \frac{1}{kt} + \frac{e^{-kt}}{kt}\right)\right]} \tag{4.28}$$

From the equation (4.28) the concentration of pollutant per unit length of the river reach has been computed for different reaches of Mahanadi river basin.

4.6 Performance Evaluation

A large number of statistical criteria are available to compare the goodness/adequacy of a given model. The frequently used performance evaluation statistics are the root mean square error (*RMSE*) and mean multiplicative errors (*MME*). The *RMSE* is computed using the following equation:

$$RMSE = \left(\sum_{i=1}^{N} \frac{(K_P - K_M)^2}{N}\right)^{1/2} \tag{4.29}$$

Where K_P and K_M are predicted and measured values of reaeration coefficient and N is the number of data points. If the model is good, the predicted and measured values will be close and this will result in a small value of *RMSE*.

The *MME* was considered by Moog & Jirka (1998) as another measure to represent the inaccuracies in predicting the reaeration coefficient. It is defined as:

$$MME = exp\left[\frac{\sum_{i=1}^{n}\left|LN\left(\frac{K_c}{K_0}\right)i\right|}{N}\right] \tag{4.30}$$

Where N is the number of values and K_c and K_0 are the computed and observed values.

Results of ANN models have been compared with the measured data on the basis of following correlation coefficient (R), as given below.

$$R = \frac{\sum(Q_0 - M_0)(Q_P - M_P)}{\sqrt{\sum(Q_0 - M_0)^2 \sum(Q_P - M_P)^2}} \qquad (4.31)$$

Where Q_0 and Q_P are the observed and estimated concentrations at the time step, M_0 and M_P are the mean of the observed and estimated concentrations respectively, and N is the total number of observations of the data set.

Chapter 5
RESULTS AND DISCUSSION

In the present study, water quality data have been collected in the river Mahanadi lying in Odisha and simulated for BOD, and DO through point source pollution modeling and NO_3 and o-PO_4 through non-point source modeling approaches.

5.1 Time series analysis along River Mahanadi lying in Odisha

The DO concentration in different reaches of river Mahanadi lying in Odisha ranged from 1.5 to 7.60 mg L^{-1} and maximum during rainy season due to dilution and less amount of domestic deposition. It has been observed that there is a sudden depletion of DO during summer at several sampling stations due to the addition of high organic contents released from sewage disposal lead. Further, a minimum of 11 to a maximum of 250 mg/l of BOD values were observed. Sudden increase in the BOD values were observed particularly during summer season indicating that the river water is largely polluted by organic matter released from sewage disposal and also the metabolic activities of various aerobic and anaerobic micro-organisms are being accelerated with increase in water temperature. As can be seen from the Figure 5.1, the Kathajodi River is found to be the most polluted followed by Mahanadi River and Taladanda canal. Due to high BOD values in river Kathajodi, a self-purification system has been inhibited. BOD values at all sampling locations of Mahanadi river system lying in Odisha are found to be lying in Class B category classified by Central Pollution Control Board (means suitable for bathing).

The nitrate concentration varied from14 to 120 mg/l. The NO_3 ion is usually derived from sources like agricultural fields, domestic sewage and other waste effluents containing nitrogenous compounds. In all station of Mahanadi River and upstream sewage discharge site of Kathajodi River and Taladanda Canal, concentration of nitrate is maximum during rainy season because the sites are related to runoff of large catchment area. However, in Mahanadi river system, the river water quality is very low in nitrate concentrations.

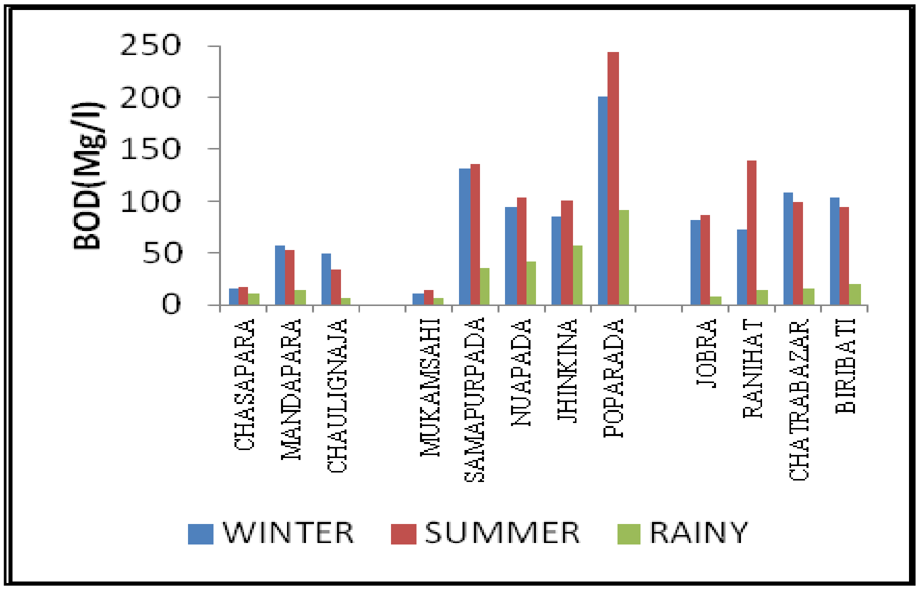


Figure 5.1: Data showing highest pollution in Kathjodi River (a distributary of Mahanadi river system lying in Odisha)

From the water quality data and incidence deliberations, it may be sensible to conclude that the water quality at all stations except Sambalpur D/s and Cuttack D/s can be classified as Class C /D /E (means drinking water source with conventional treatment followed by disinfection/ fish culture and wild life propagation/ irrigation, industrial cooling or controlled waste disposal). In all cases, parameter responsible for downgrading the water quality is TC, besides BOD for Sambalpur D/s, Cuttack D/s. Sambalpur is the major urban area immediately downstream of Hirakud reservoir (about 5 km.). Apart from being a source of water quality supply, Mahanadi at Sambalpur is used for bathing and waste water disposal. Hence the expected deterioration of water quality is found at Sambalpur D/s. From Sambalpur D/s to Sonepur (about 60 km.) the river travels through a region with no major urban settlement or waste water outfall. Sonepur is the confluence point of Mahanadi with two of its important river bank tributaries namely Ong and Tel. thus, the water quality at Sonepur U/s, which is immediately downstream of Ong confluence, is quite satisfactory. Sonepur D/s on Mahanadi is actually the downstream of its confluence with Tel, which has a significant annual average flow with very low pollution load. The 100 km. stretch of the river from Sonepur to Tikrapada does not have any industry or urban settlement on its banks and there is no major wastewater outfall. From Tikarapada to Narasinghpur (about 40 km.) the river flows almost completely undisturbed and it is neither agriculturally nor industrially prosperous, nor human activities on its banks scarce. Hence relatively clean, unpolluted water is expected at Tikrapada and without much change in quality at Narasinghpur. During its course from Narasinghpur to Cuttack (about 50 km.), the river enters into its deltaic region, characterized by high population density and intense agriculture activities. Hence, there is some deterioration in the quality of water entering into Cuttack U/s particularly in respect of TC. Within the city the river receives considerable untreated waste water and the water quality gets further deteriorated at Cuttack D/s. Water quality of this left bank tributary of Mahanadi is monitored at four locations- Sundargarh, Jharsuguda, Brajrajnagar (U/s and D/s). The water quality at Brajrajnagar is a matter of much concern due to discharge of effluent from a large paper mill.

5.2 BOD-DO Modeling for Point source pollution simulation using Oxygen Sag Curve

5.2.1 BOD Model

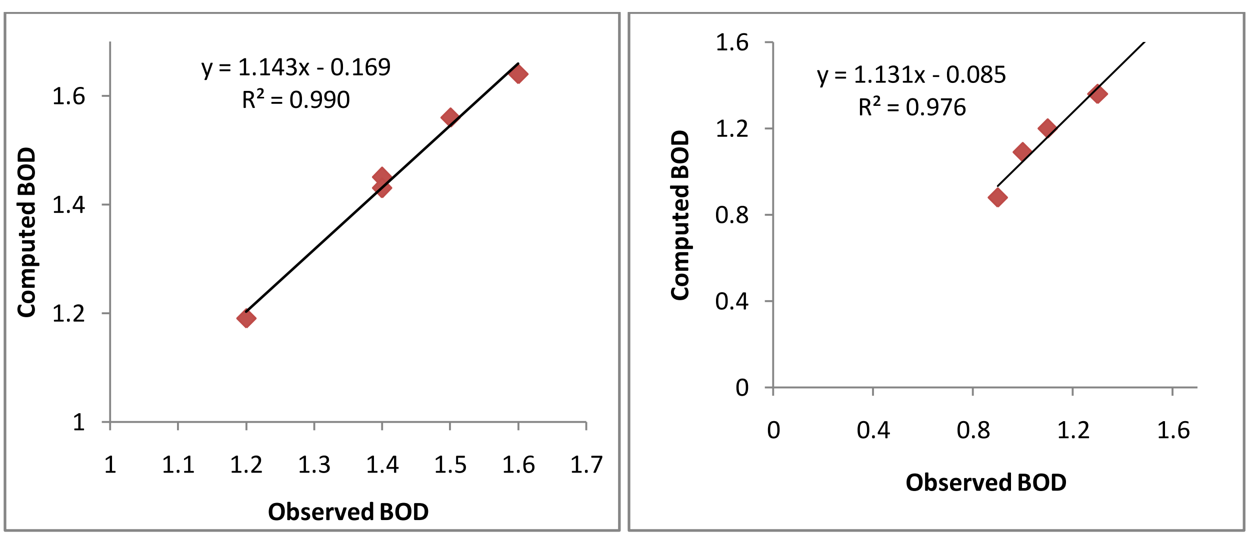
The results have been obtained using equation (4.6) for all the reaches of River Mahanadi lying in Odisha. A total of 28 data sets for seven year collected from Orissa State Pollution Control Board (OSPCB) for thirteen sampling stations were used for calibration and validation of the model and establishment of deoxygenation rate coefficient (k_1) separately.

k_1 Values obtained for different reaches using the method explained in previous chapter are shown in Tables 5.1. It is interesting to note that for reach 1 (Jharsuguda and Brijrajnagar (U/s)), the mean values of k_1 during summer is much smaller than the monsoon. It is observed that the deoxygenation rate is higher in reach 2 (Brijrajnagar (D/s) to Hirakud) and in reach 3 (Sambalpur (D/s) to Sonepur (U/s) due to no/little entry of point source pollution as well as non point source pollution. In some case, we observed negative values of deoxygenation rate coefficients, which indicate the entry of point source pollution or non-point source pollution during monsoon season. In general, the BOD increases during monsoon season due to influx of non-point source pollution without prior treatment. Very low deoxygenation rate coefficient has been observed in reach 4 (Sonepur(D/s)) to Tikarpada) and reach 5 (Narshighpur to Cuttack(U/s)).

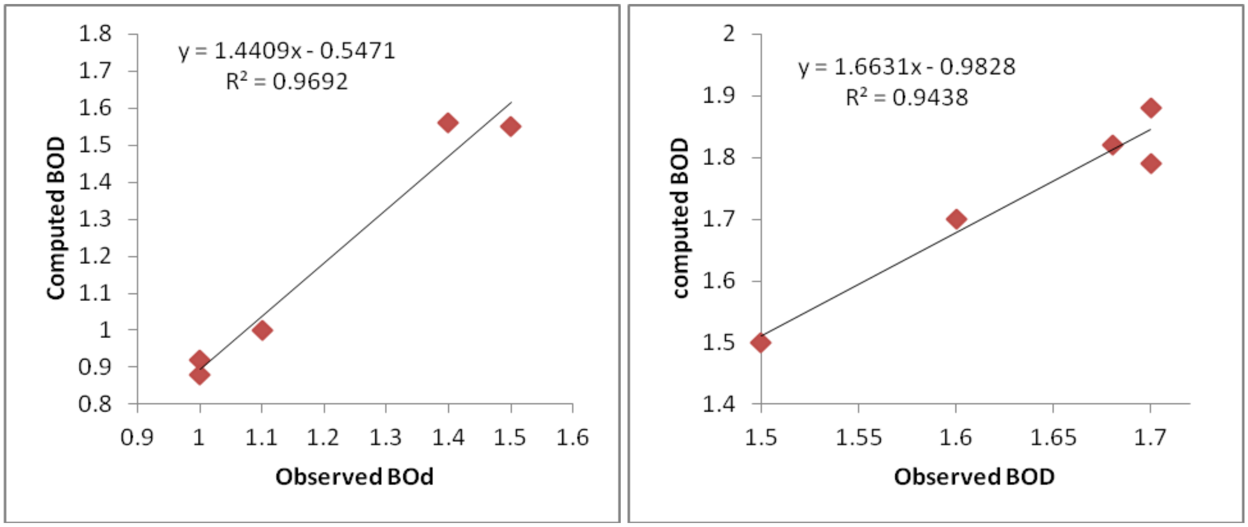
Table 5.1: Deoxygenation rate coefficients for the years 2000-2003 during summer and monsoon

River Reach	Year								Mean k_1 values	
	2000		2001		2002		2003		Summer	Mon-soon
	Summer	Mon-soon	Summer	Mon-soon	Summer	Mon-soon	Summer	Mon-Soon		
1	0.080	0.309	0.208	-0.273	0.110	0.262	0.174	-2.19	0.143	0.285
2	0.525	0.186	0.180	0.032	0.096	0.401	0.392	0.483	0.298	0.301
3	0.198	0.638	0.284	0.266	0.467	0.683	0.472	0.377	0.355	0.397
4	0.022	0.067	0.109	0.206	0.048	0.133	0.186	0.403	0.091	0.101
5	0.040	0.024	0.020	0.078	0.066	-0.173	0.024	0.174	0.015	0.034

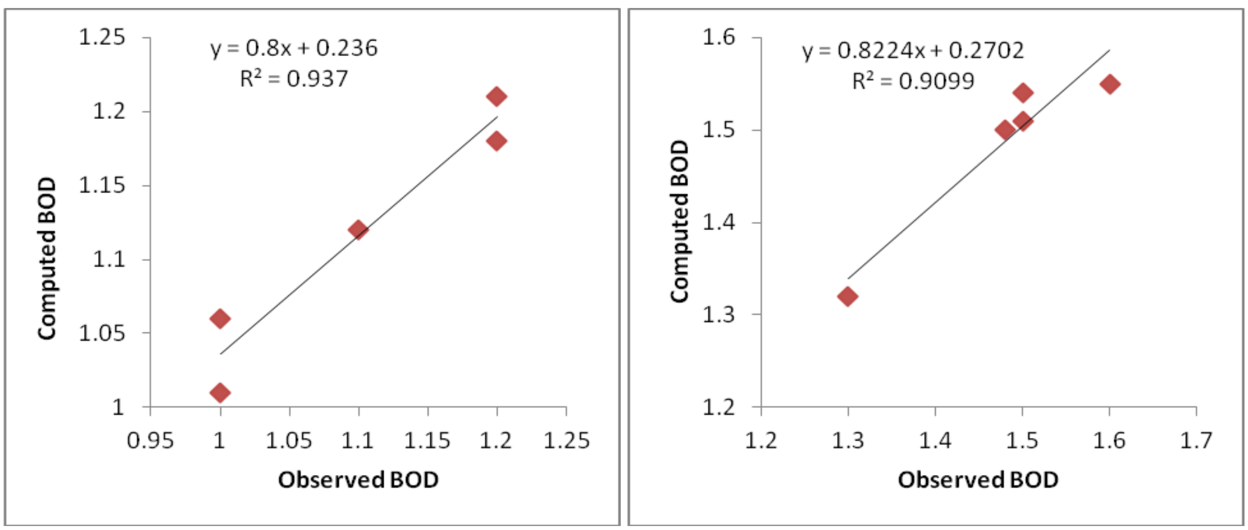
Equation (4.6) was used for validation by using the mean k_1 values given in Table 5.1. For this, data sets of different reaches of river Mahanadi lying in Odisha for the years 2004, 2005 and 2006 tested and validated. It has been found that the k_1 values established for different river reaches can be used successfully for simulating and predicting BOD values. Figure 5.2 shows the results obtained using different values of k_1 for summer and monsoon separately.



(a) Year 2004 (summer and monsoon)



(b) Year 2005(summer and monsoon)



(c) Year 2006(summer and monoson)

Figure 5.2: Computed and Observed BOD in 2004, 2005 & 2006

To test the validity of the model the root mean square error (*RMSE*) and mean multiplicative errors (*MME*) were applied. The results indicate that the values of MME for all the cases lie between 0.972 and 1.025, which are very close to 1 and accurate. A plot of RMSE and MME values for the years 2004, 2005 and 2006 are shown in Figure 5.3.

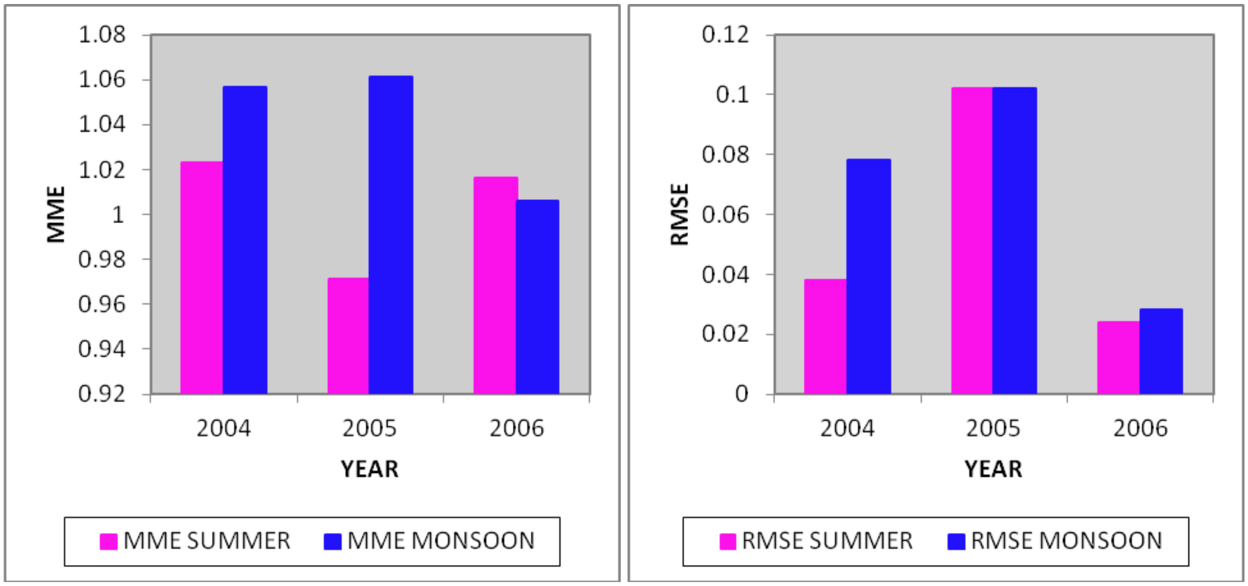


Figure 5.3: MME and RMSE between Observed and Computed BOD (Summer and Monsoon)

5.2.2 DO Model

The results have been obtained using equation (4.15) for all the reaches of River Mahanadi lying in Odisha. Here again, a total of 28 data sets for seven year collected from Orissa State Pollution Control Board (OSPCB) for thirteen sampling stations were used for calibration and validation of the model and establishment of reaeration rate coefficient (k_2).

The values of reaeration rate coefficient (k_2) has been estimated from Equation (Eq.4.15) knowing all other parameters and variables of the equation. DO deficit has been obtain by separating DO values obtained in the field from DO saturated values.

In the literature, it has been found that many reaeration equations, as shown in Table 5.2, are developed using empirical relations mainly with the velocity, depth and slope of the river at any reach. In the present work also, these equations have been used and the most suitable equation has been utilized for computing reaeration rate coefficient (k_2). The suitability of each equation has been verified by the reaeration rate coefficient (k_2) obtained by equation (4.15).

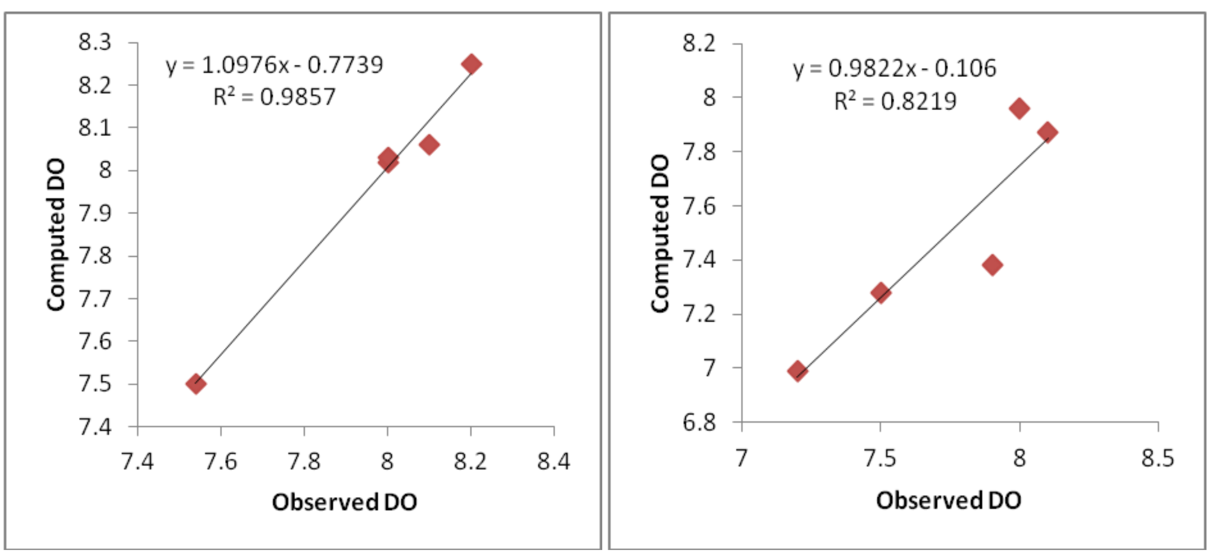
The values of k_2 from the equations given by O' Connor and Dobbins (1958) vary in the range 1.69-6.34 per day for summer and 0.76-4.76 for monsoon per day. The value of k_2 calculated from equation given by Churchill et al. (1962) varies in the range of 1.11-6.33 for summer and 0.52-4.92 for monsoon per day. k_2 Value from the equation given by Owens et al. (1964) varies in the range of 1.77-9.45 for summer and 0.52- 4.92 for monsoon per day. From the equation given by Langbein and Durum (1967), k_2 value varies in the range of 1.13-5.78 for summer and 0.67-4.88 for monsoon per day. From the equation given by Jha et al. (2001), k_2 value varies in the range of 2.83-4.97 and 2.85- 5.45 for monsoon per day.

k_2 values obtained for different reaches using the equation (4.15) are shown in Tables 5.2. It is interesting to note that for every reach the reaeration rate coefficient is more in summer than monsoon due to lowering of water level. In reach 1 (Jharsuguda and Brijrajnagar), the mean values of k_2 during summer is more than the monsoon. It is observed that the reaeration rate is much higher in reach 2 (Brijrajnagar (D/s) to Hirakud) due to more entry of point source pollution as well as non point source pollution. In reach 3 (Sambalpur (D/s) to Sonepur (U/s) also the k_2 value increases due to entry of industrial and municipal sewage. In some case, we observed negative values of reaeration rate coefficients, which indicate the entry of point source pollution or non-point source pollution. Very low reaeration rate coefficient has been observed in reach 4 (Sonepur(D/s)) to Tikarpada) and reach 5 (Narshighpur to Cuttack(U/s)), where sewage effluent is discharge directly into the river resulting in drop of DO concentration.

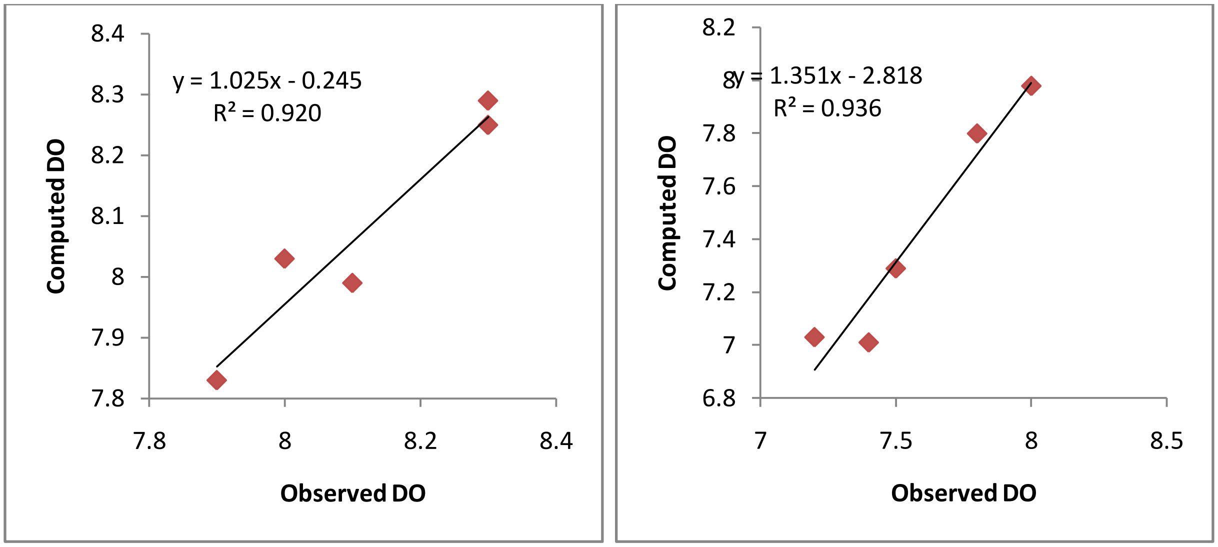
Table 5.2: Reaeration rate coefficients for the years 2000-2003 during summer and monsoon

River Reach	Year								Mean k_2 values	
	2000		2001		2002		2003			
	Summer	Mon-soon	Summer	Mon-soon	Summer	Mon-soon	Summer	Mon-soon	Summer	Mon-soon
1	0.374	0.309	0.915	-0.273	4.098	0.261	-0.164	-2.192	1.816	0.285
2	0.885	0.186	1.331	0.032	8.333	0.401	2.714	0.482	3.316	0.155
3	0.758	0.638	1.004	0.265	2.731	0.682	2.038	0.376	1.633	0.396
4	0.356	0.067	3.403	0.206	0.690	0.132	0.718	0.403	1.292	0.101
5	-0.004	0.024	-0.726	0.078	0.622	-0.173	-0.032	0.174	0.622	0.034

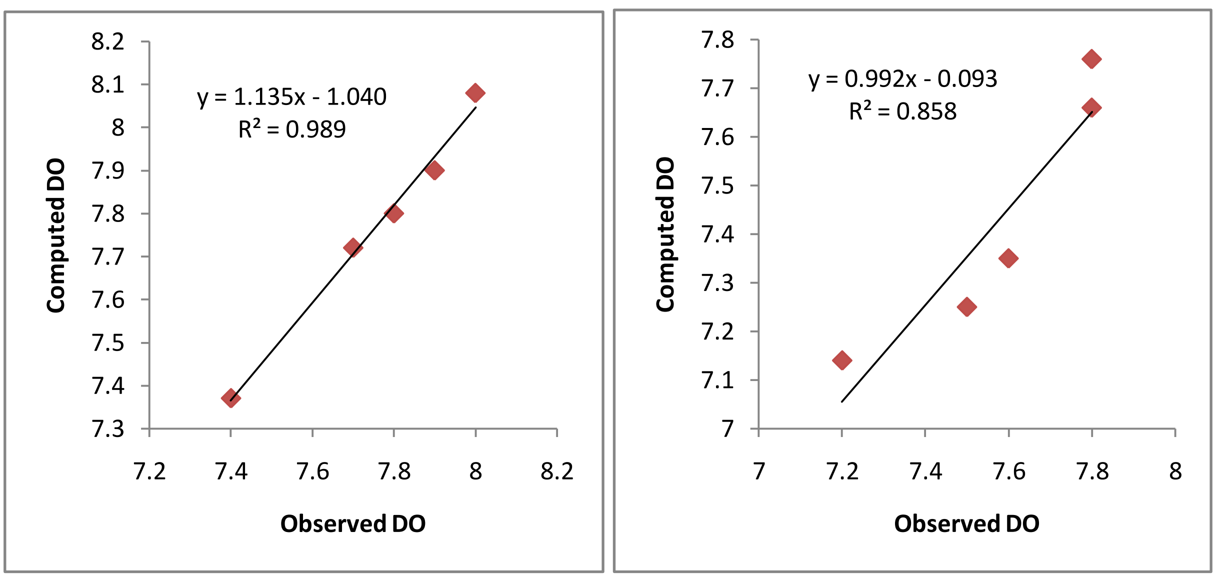
The data sets of different reaches of river Mahanadi lying in Odisha for the years 2004, 2005 and 2006 tested and validated. It has been found that the k_2 values established for different river reaches can be used successfully for simulating and predicting DO values. Figure 5.4 shows the results obtained using different values of k_2 for summer and monsoon separately.



(a) Year 2004 (summer and monsoon)



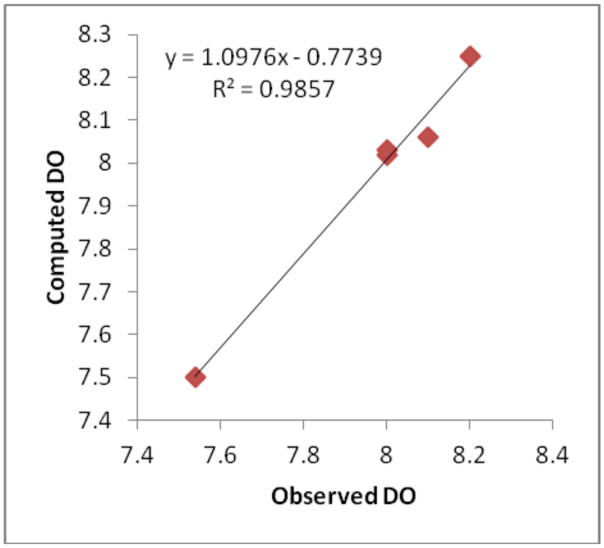
(b) Year 2005(summer and monsoon)



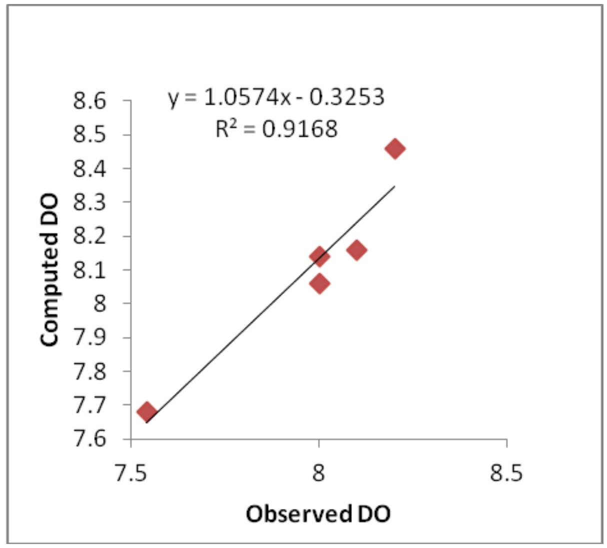
(c) Year 2006(summer and monoson)

Figure 5.4: Computed and Observed DO in 2004, 2005 & 2006

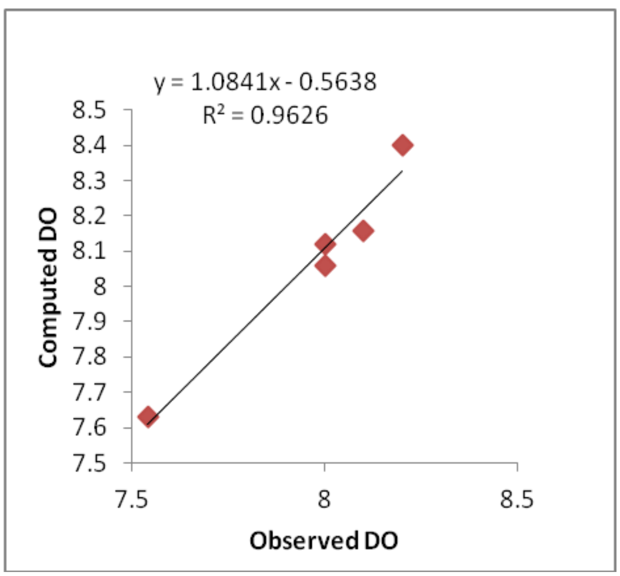
The data for the year 2004, 2005 and 2006 during summer and Monsoon were also used to look for the applicability of reaeration equations as discussed above and the results for the year 2004 is shown in Figures 5.5 and 5.6 respectively. It is interesting to note that, no empirical equation provides better estimate of reaeration rate coefficients during monsoon due to dynamic nature of flow depth and velocity. However, all the empirical equations can be used to estimate the reaeration rate coefficient during summer months.



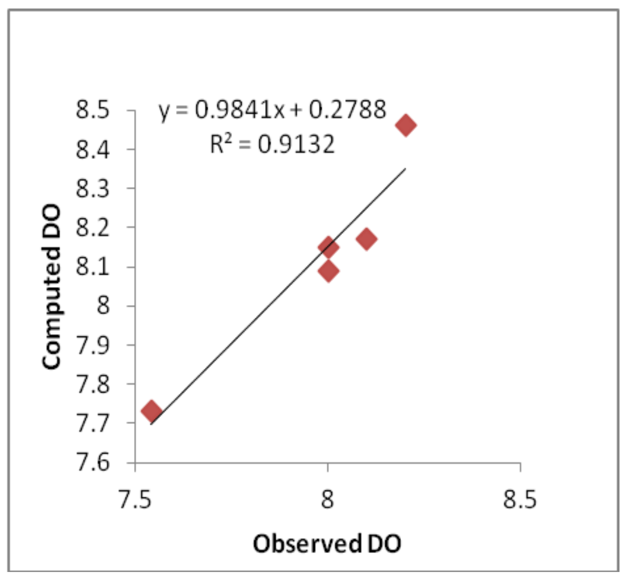
(a) using equation (4.15)



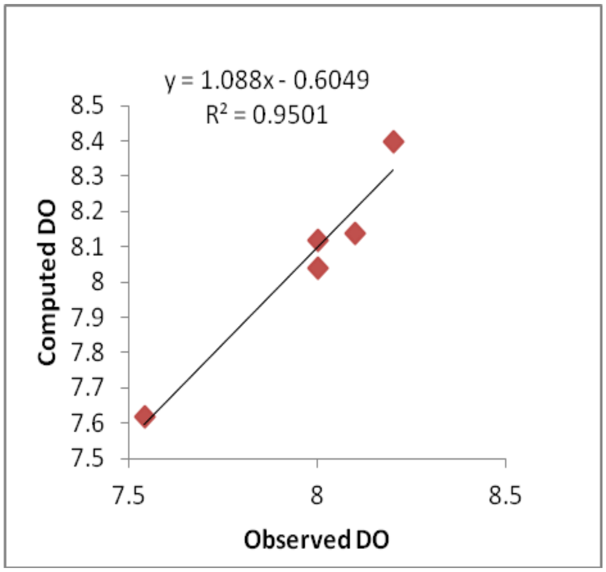
(b) using O’Connor and Dobbins approach

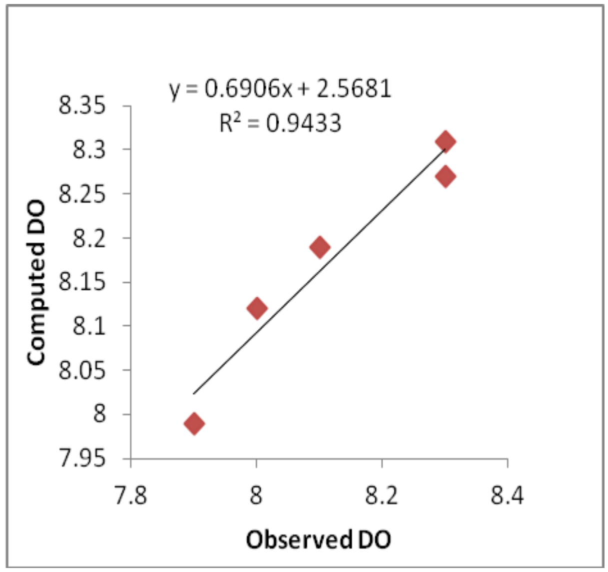


(c) usingChurchill et al. approach



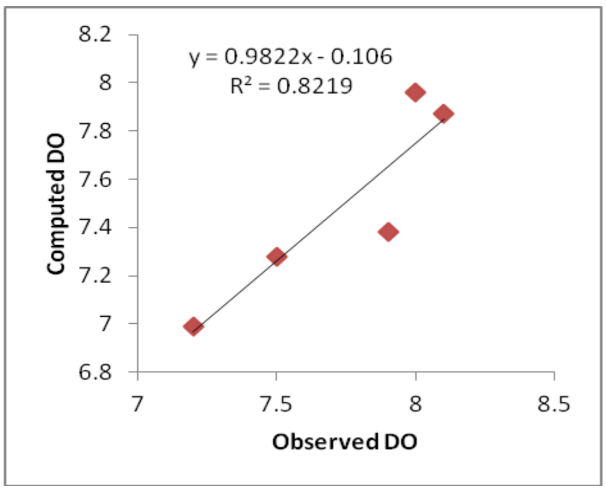
(d) using Owens et al. approach

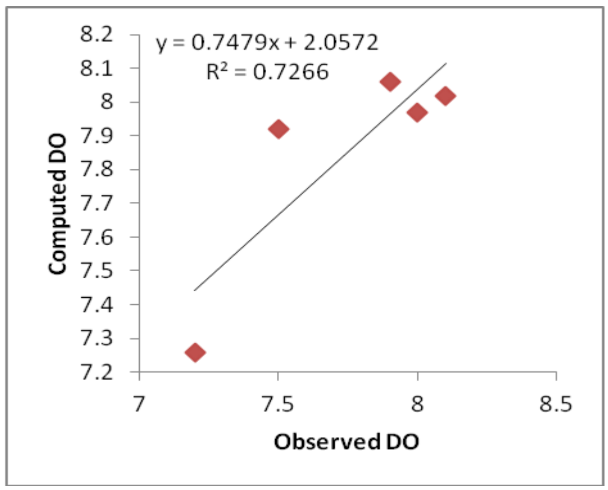




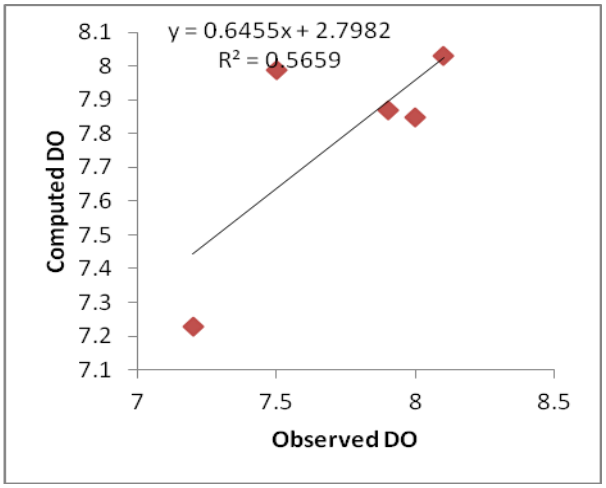
(e) using Langbein and Durum approach **(f) using Jha et al. approach**

Figure 5.5: Representation of Computed and Observed DO using k_2 from Different Equations for year in 2004(summer)

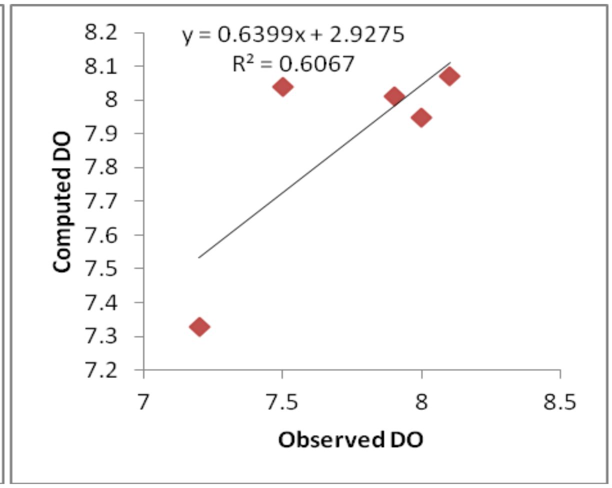




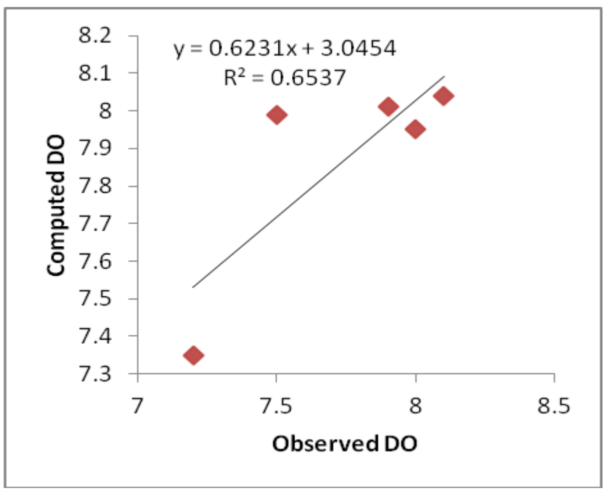
(a) using equation (4.15) **(b) using O'Connor and Dobbins approach**



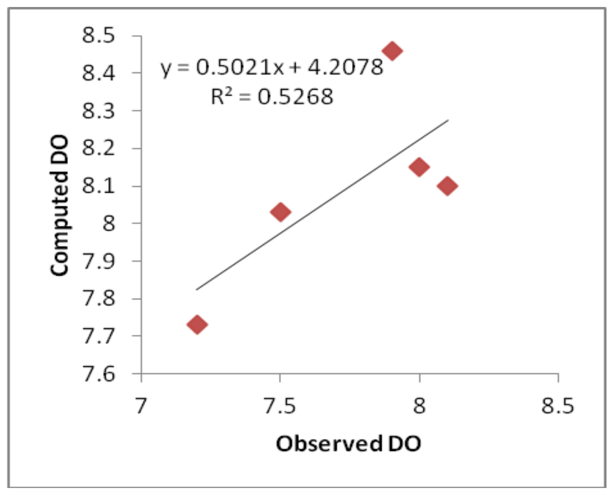
(c) usingChurchill et al. approach



(d) using Owens et al. approach



(e) using Langbein and Durum approach



(f) using Jha et al. approach

Fig 5.6: Representation of Computed and Observed DO using k_2 from Different Equations in 2004(Monsoon)

To test the validity of the model the root mean square error (*RMSE*) and mean multiplicative errors (*MME*) were applied. The results indicate that the values of MME for all the cases lie between 0.97 and 1.04, which are very close to 1 and accurate. A plot of RMSE and MME values for the years 2004, 2005 and 2006 are shown in Figure 5.7.

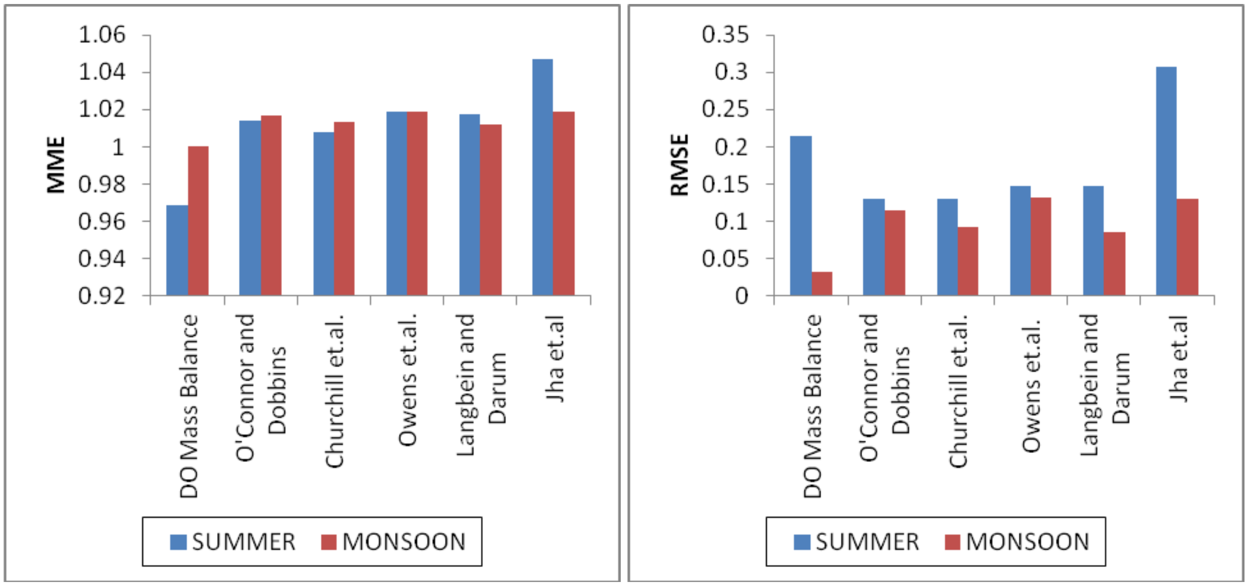
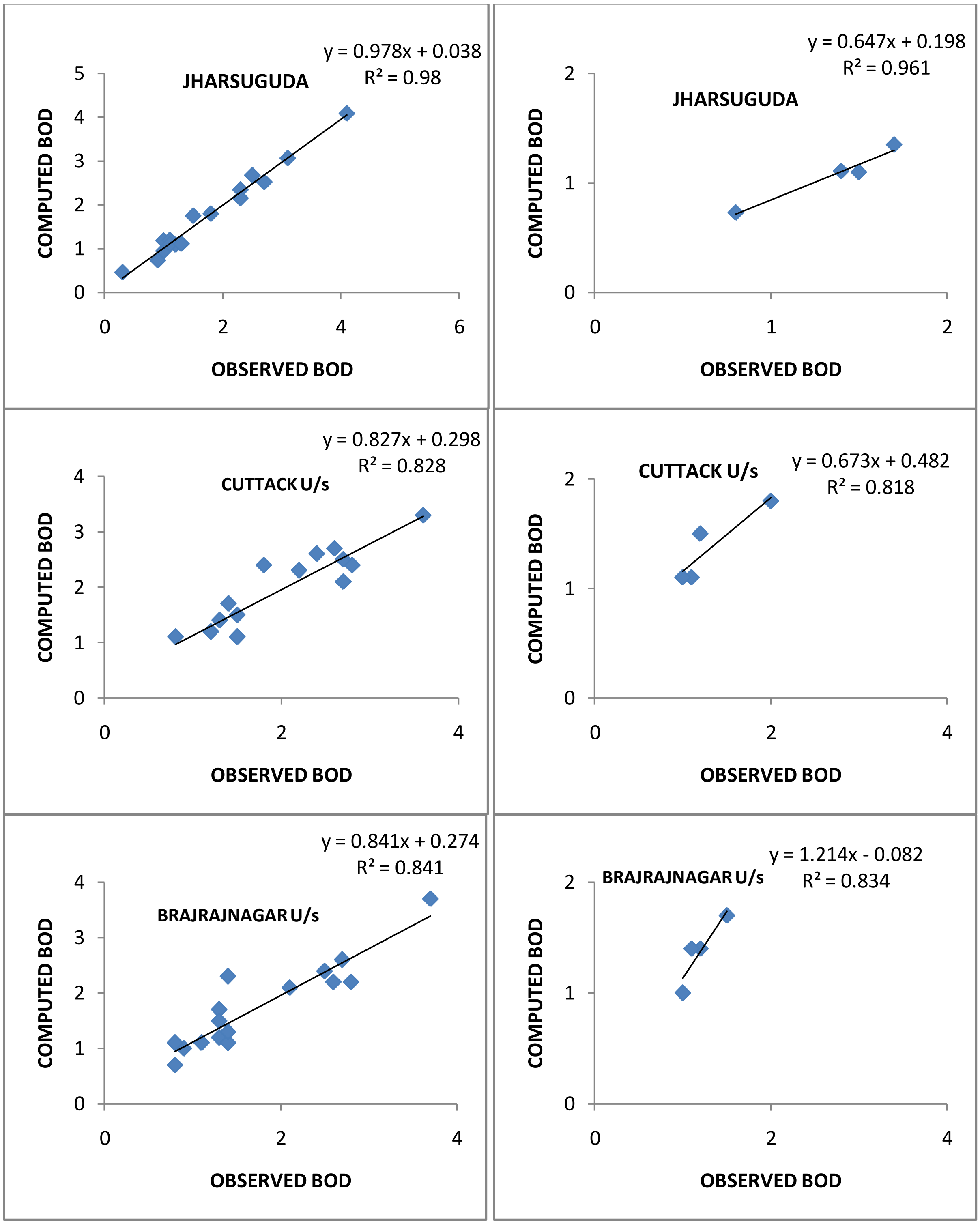


Figure 5.7: Representation of MME and RMSE in 2004

5.3 Artificial Neural Networks Model for BOD-DO simulation

In order to determine the number of nodes in the hidden layer and transfer functions, different ANN models were constructed and tested. Selection of an appropriate number of nodes in the hidden layer is very important aspect as a larger number of these may result in over-fitting, while a smaller number of nodes may not capture the information adequately. Subsequently, two different ANN models were constructed for the computation of DO and BOD in the river water.

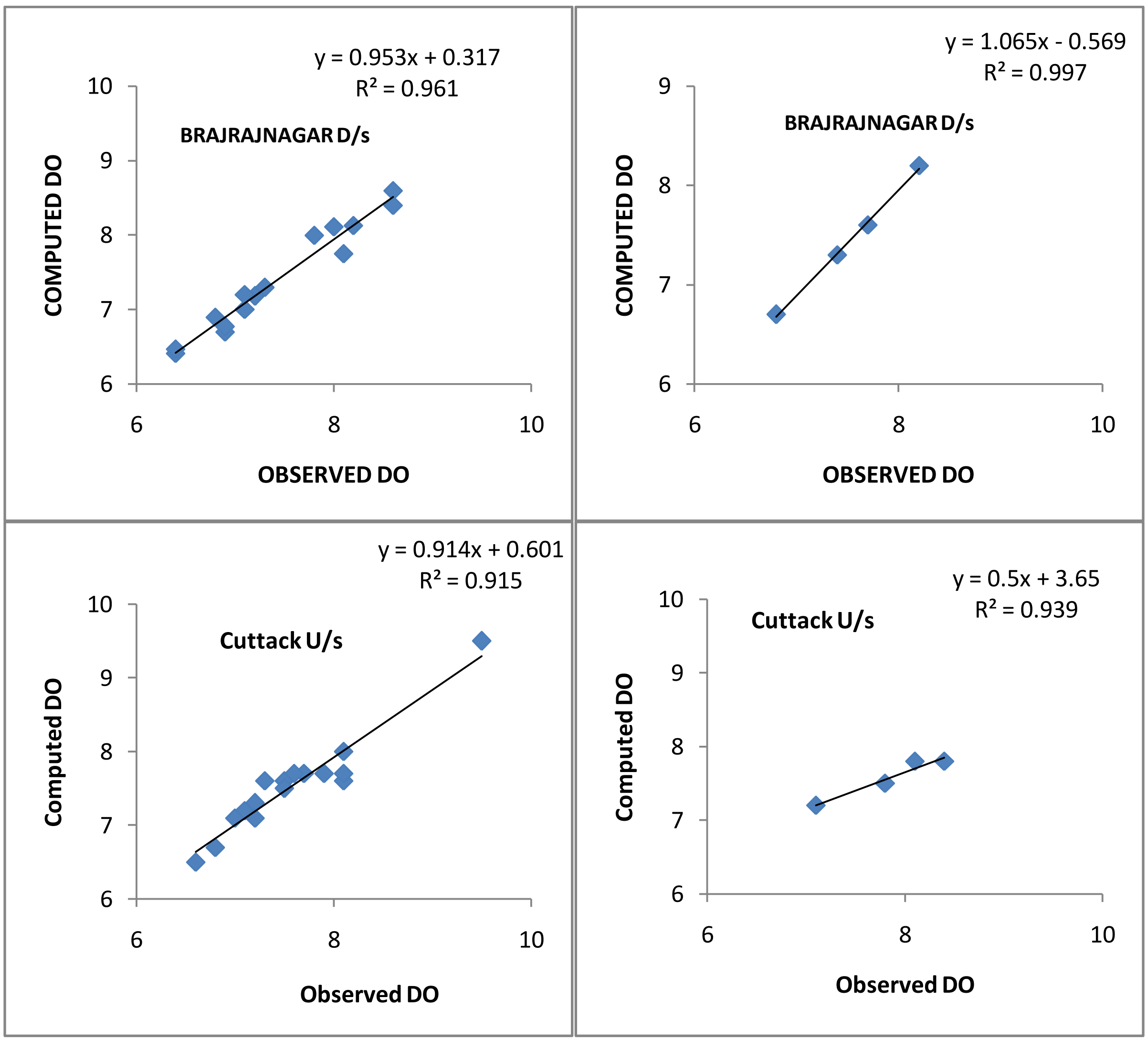
For BOD modeling various combinations of data structures were tried for different reaches and for reaches 1 to 5, data structures showing the highest correlation coefficient were considered during training of the data sets. It has been found that the developed data structures show very good results during validation with very high correlation coefficients ranging between 0.81 to 0.97. Figure 5.8 shows the plots between measured and computed values of BOD for training and validation data sets at different river reaches.



(a) Training data set **(b) Validation data set**

Fig.5.8 Comparison of the model computed and Observed BOD levels in the river water

Similar to BOD modeling, various combination of data structures were tried for different reaches for DO modeling and for reaches 1 to 5, data structures showing the highest correlation coefficient were considered during training of the data sets. It has been found again that the developed data structures show very good results during validation with very high correlation coefficients ranging between 0.98 to 0.99. Figure 5.9 shows the plots between measured and computed values of DO for training and validation data sets at Brijrajnagar D/s and Cuttack U/s sampling station.



(a) Training data set **(b) Validation data set**

Fig.5.9 Comparison of the model computed and Observed DO levels in the river water

The correlation coefficient (R) as computed for the training and validation data sets used for the two models (DO and BOD) are presented in Table 5.3. The results suggest for a good-fit of the BOD and DO models to the data set using proper data structure in ANN. The results indicate the applicability of neural network model to recognize the pattern of the water quality variable and to provide good predictions of the monthly variations of BOD and DO in Mahanadi River lying in Odisha.

Table 5.3: Data structure and their error statistics for training and validation data sets

MODEL	ANN- Structure	DATASETS	R
BOD	1-8-1	TRAINING	0.98
		VALIDATION	0.98
	1-18-1	TRAINING	0.9
		VALIDATION	0.88
	1-3-1	TRAINING	0.9
		VALIDATION	0.92
	2-7-1	TRAINING	0.91
		VALIDATION	0.92
DO	6-3-1	TRAINING	0.97
		VALIDATION	0.99
	4-3-1	TRAINING	0.93
		VALIDATION	0.99

The results obtained are comparable with the BOD-DO model used in the previous section. However, no extensive data sets are required to be monitored to simulate the BOD and/or DO values in the downstream sites.

5.4. Delineation of Maps for Assessment of Non-point Source Pollution using Remote Sensing and GIS approach

As discussed in previous chapter, it is essential to estimate the non-point source pollution at different river reaches. For this, different maps are required to be delineated and used as input to estimate non-point source pollution. First topographical maps with drainage pattern are developed to obtain the area contributing over each river reach. Digital elevation model, slope, aspect, flow direction and flow accumulation maps are developed. In the present work GTOPO30, a global digital elevation model (DEM) with a horizontal grid spacing of 30 arc seconds (approximately 1 kilometer), was derived from the URL: (http://edc.usgs.gov/products/elevation/gtopo30/gtopo30.html) and the Shape file was created for delineated the focused area in Arc-GIS. Figure 5.10 shows the Digital Elevation Model developed for the Mahanadi river basin lying in Odisha.

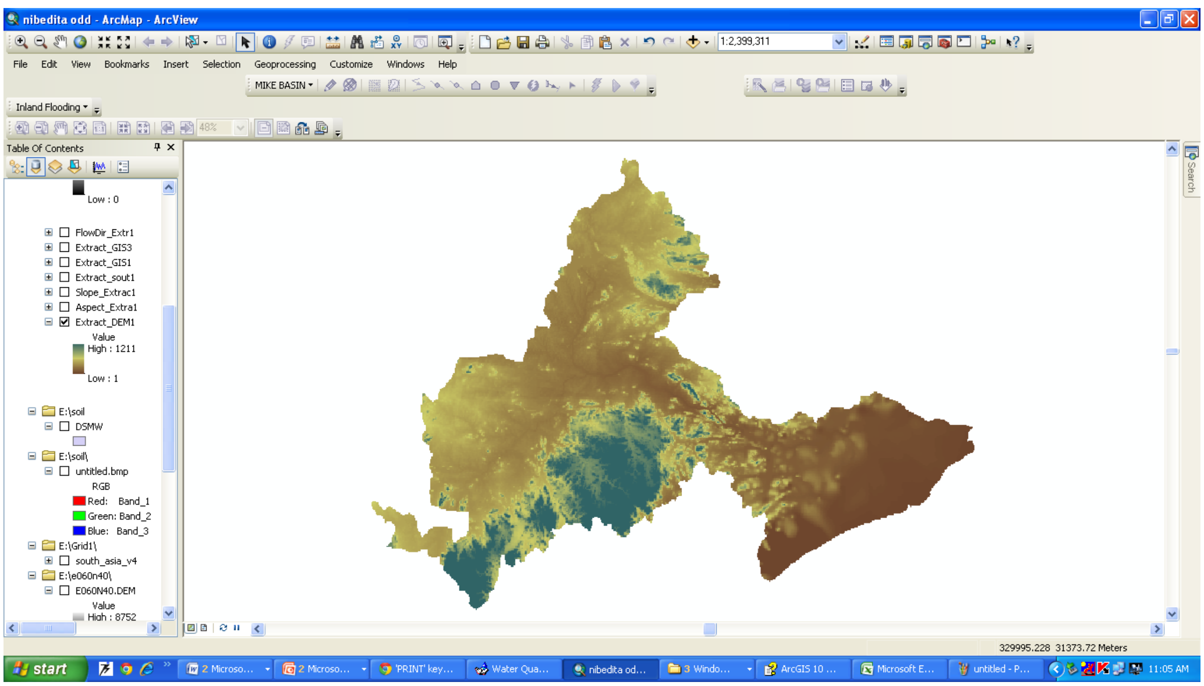


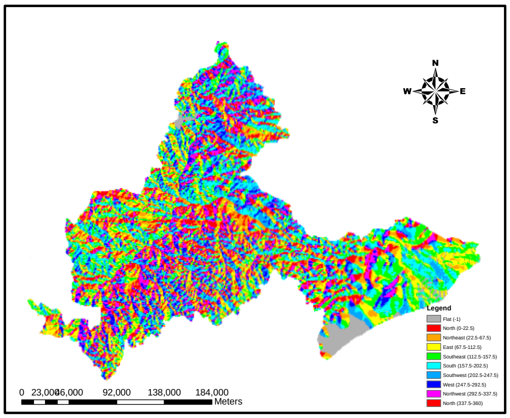
Figure 5.10: GTOPO 30 Digital Elevation Model of Mahanadi basin lying in Odisha

The boundary and drainage characteristics of the river basin were also derived in ArcGIS software. Following operations were performed step by step:

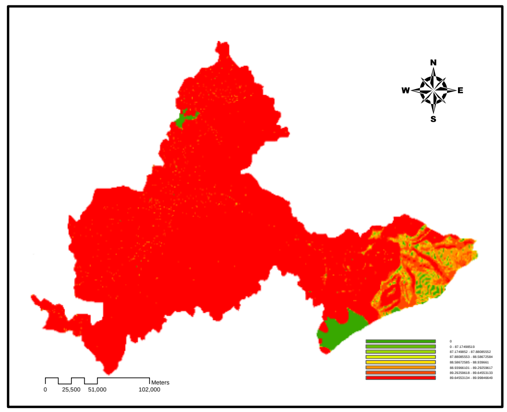
- Development of Aspect map

- Development of Slope map
- Development of Flow direction map
- Development of Flow accumulation map

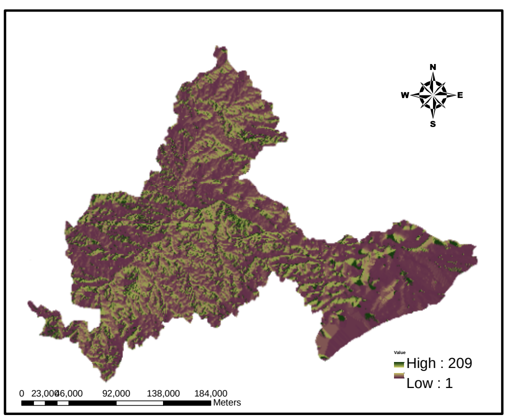
Figure 5.11 indicates all the maps in sequence. With the use of these maps, non-point source pollution has been estimated.



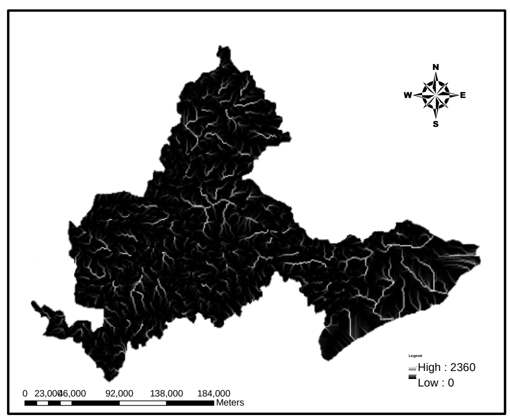
(a) Aspect map



(b) Slope map



(c) Flow Direction map



(d) Flow Accumulation map

Figure 5.11: Development of maps for input to non-point source pollution estimation

Historical and current land cover mapping of the Mahanadi river basin was done to see the changes that have taken place over time. For land cover study, satellite images based on remote sensing being most consistent with synoptic views of large areas. This map is essential to know the agricultural area, urban area, barren land etc. lying in each river each and contributing non-point source pollution. Figure 5.11 shows the land use map of Mahanadi river basin lying in Odisha.

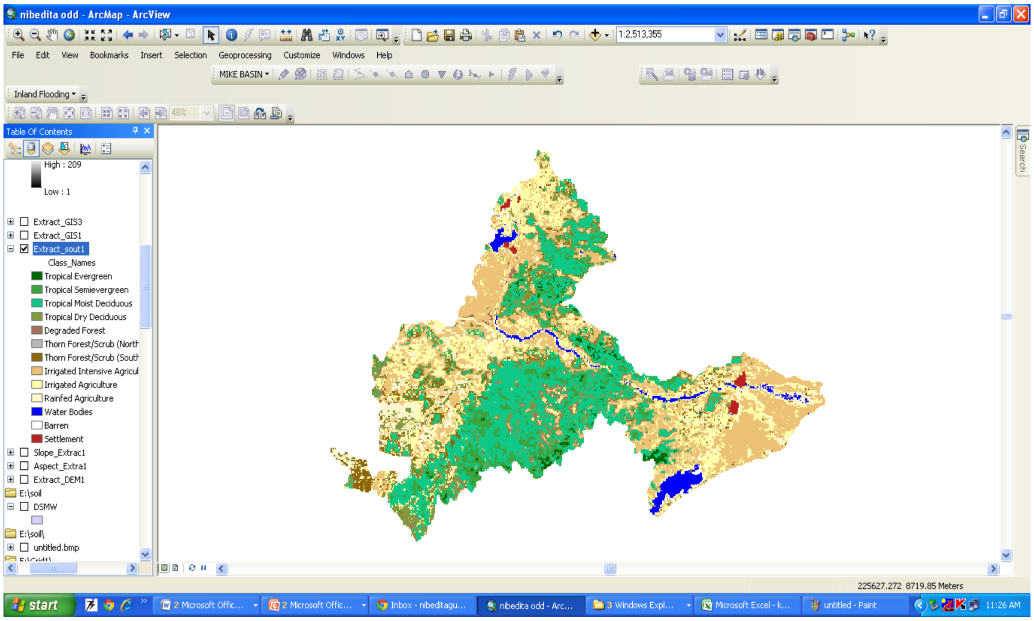


Figure 5.12: Land use/Land cover of Mahanadi basin lying in Odisha (Source: GLC 2000)

5.5 Non-point source modeling

To verify the modeling approach, it is essential to select a river reach, which receives non-point loads from the watershed. For testing the model nitrate is used, which is reactive in nature. The rate of attenuation for nitrate is considered to be 0.10 (Ambrose et al., 1991). Measurements of nitrate at all the sampling points were based on travel time. Figure 5.13 illustrates the nitrate loads along the River Mahanadi during different seasons of different periods and during rainy season, the quantum of nitrate load is more due to intensive rainfall, the chemical applied in the crop land are transported with runoff. However, during non-monsoon period the non-point source pollutants are transported through sub-surface flow and overland flow from areas very close to the banks of the river. Also, the non-point source pollution is calculated using the equation (Eq. 4.28).

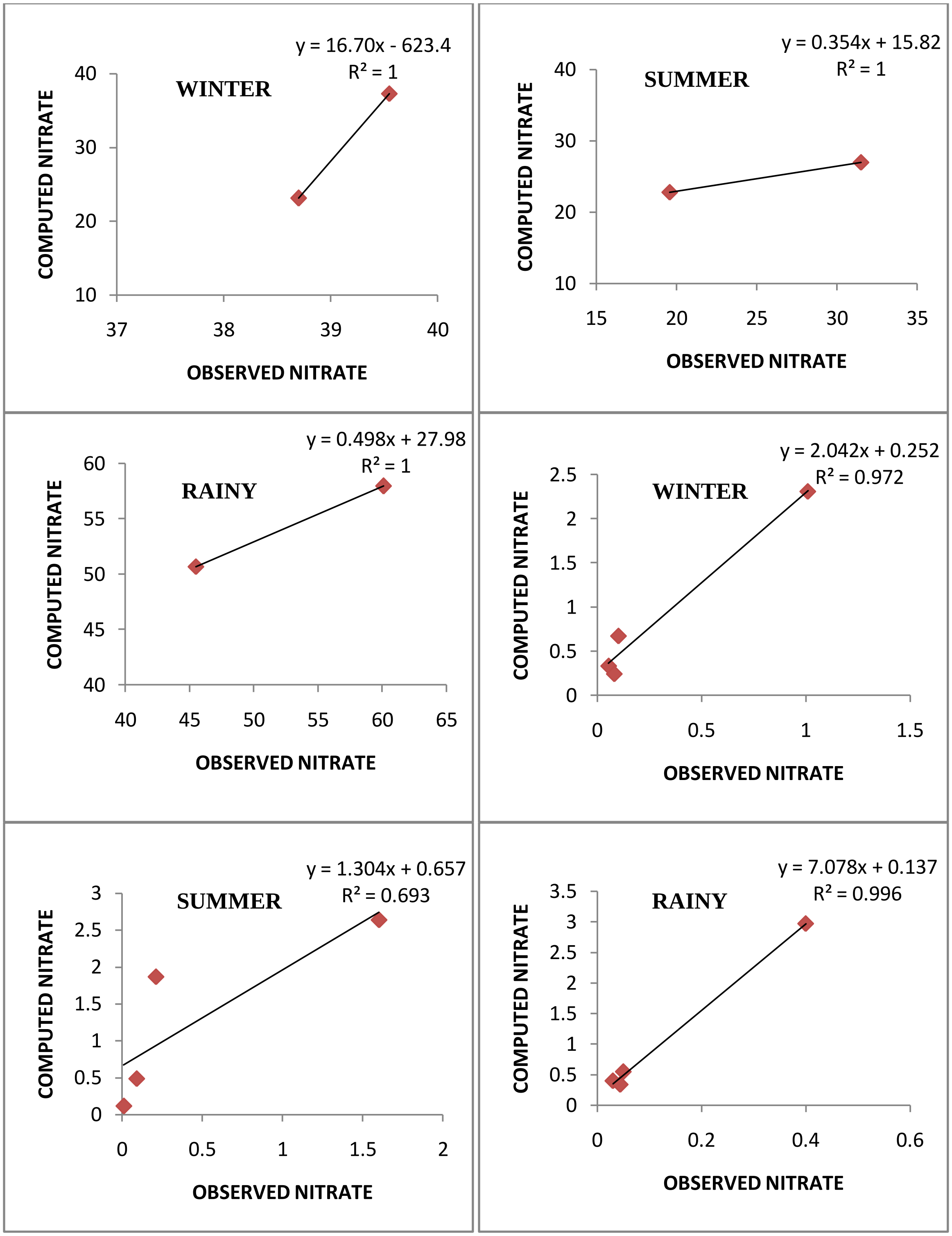


Figure 5.13: Non-point Load (NO_3) in different reaches of Mahanadi basin lying in Odisha (source: Das and Acharya, 2003, CWC)

Chapter 6
SUMMARY AND CONCLUSIONS

In the present work, the water quality modeling efforts have been oriented towards:

(a) Realistic representations of the temporal variation in important water quality parameters including, DO, BOD, NO_3, PO_4 and water temperature in river Mahanadi lying in Odisha.

(b) Different strategies for simulation of DO and BOD profiles within the river using analytical models of different mechanisms of DO and BOD depletion and different expressions for reaeration coefficients and de-oxygenation coefficient.

(c) Simulating DO and BOD at different locations non-linear functions in ANN model.

(d) Application of Remote Sensing and GIS to delineate land use land cover, drainage, contour, DEM, flow direction, flow accumulation and slope maps.

(e) Estimate of non-point source pollution entry from different river reaches.

The following conclusions are drawn during the course of present investigations:

1. It is found essential to carry out time series analysis prior to the application of water quality modeling for assessment of trend, bias, gaps and other related information.

2. The deoxygenation rate coefficient obtained using river data (Texas Water Development Board 1971) provided very good results. MME in relation to observed and computed BOD was found near one and RMSE was very small. The method is highly suitable for model validation.

3. The reaeration rate coefficient values obtained from the equation given by O'Connor and Dobbins (1958) and Mass Balance equation performs much better than those evaluated from

other predictive equations. However, most commonly used predictive equations were used for the analysis.

4. Considering the findings of this study, it is concluded that the BOD-DO modeling in river Mahanadi lying in Odisha performs well by using deoxygenation rate coefficient evaluated by BOD model based on first order kinetics and reoxygenation rate coefficient evaluated by the equation given by O'Connor and Dobbins and Mass balance equation.

5. The prospective of an artificial neural network technique (ANN) was examined by comparing the results of observed and estimated BOD and DO in the Mahanadi River and from above discussion it was found that for prediction of the BOD and DO in the Mahanadi River lying in Odisha an ANN model appears to be a useful tool. The results are comparable and in some cases better.

6. With the help of remote sensing and GIS, a variety of basin characteristics such as land use/land cover, digital elevation model, slope, aspect, map showing flow direction and accumulation have been assessed.

7. Considering that non-point pollutants may also go under a process of attenuation due to a variety of mechanisms including settling, decay due to reaction, modified mass balance equation is used to estimate non-point source pollution. The practice of concentrating the non-point load at the upstream of any reach may not lead to the better description of the distribution of non-point load rather it is assumed that, the uniform distributed load along the reach is found to perform consistently better.

8. To test the validity of these models, performance evaluation was done using various error statistics.

9. Finally, to simulate point and non-point source pollutions in Mahanadi river system, it is proposed to use the present analytical and ANN models as the model parameters have been established and tested. The models may also be applied in other basins with similar conditions.

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APPENDIX

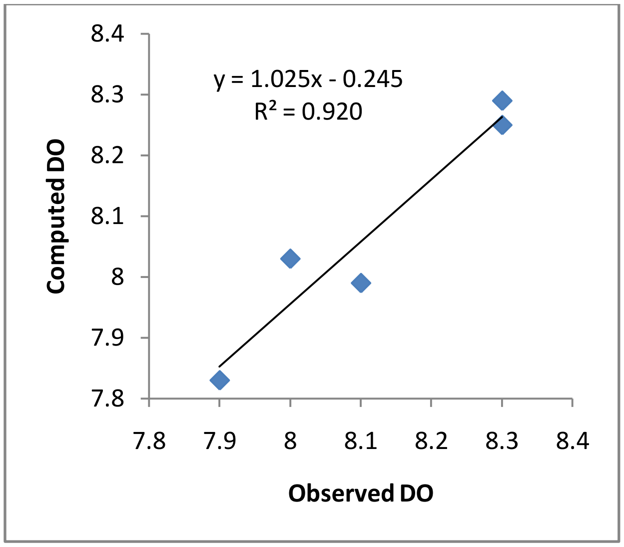
Table 1: Dissolved Oxygen Data (Modified) for Mahanadi River System (Source: OSPCB)

Season	YEAR	Sundargarh	Jharsuguda	Brajrajnagar U/s	Brajrajnagar D/s	Hirakud	Sambalpur U/s	Sambalpur D/s	Sonepur U/s	Sonepur D/s	Tikrapada	Narasinghpur	Cuttack U/s	Cuttack D/s
	2000	8.1	7.3	7.7	7.2	8	7.72	7.23	8.3	7.34	7.5	7.35	7.1	7.16
	2001	7.6	7.4	7.4	6.5	7.4	7	6.9	7.6	7.1	7.1	7.3	7.8	7.8
	2002	8.3	8.4	8.6	7.8	8.6	8.3	6.6	8.2	7.6	7.1	8	7.7	7.7
WINTER	2003	9.2	8.8	8.7	8.3	9.6	8.8	7.7	8.2	8	9.3	10.2	9.5	9.5
	2004	8.9	9	8.3	7.8	7.8	8.6	7.3	8.3	9.1	7.8	8.7	8.4	8.4
	2005	8.5	8.3	8.3	7.8	9	8.6	7.9	7.8	7.6	7.8	8.8	8.3	8.3
	2006	8.2	8.5	8.5	8.2	8.4	7.1	8.1	8.5	8	8.5	8	8.4	8.4
	YEAR	Sundargarh	Jharsuguda	Brajrajnagar U/s	Brajrajnagar D/s	Hirakud	Sambalpur U/s	Sambalpur D/s	Sonepur U/s	Sonepur D/s	Tikrapada	Narasinghpur	Cuttack U/s	Cuttack D/s
	2000	6.8	6.3	6.4	6.1	6.9	7.1	5.8	6.5	7.2	7.1	7.2	7	7
	2001	6.6	7.2	7.5	6.7	7.6	7.1	6.2	7.3	7.1	7.9	8.2	7.1	7.1
	2002	7.8	7.6	7.9	7.2	7.8	7.9	7	7.8	6.8	7.6	8.2	8.4	8.4
SUMMER	2003	8.6	8.2	8.4	8	8.6	7.9	7.9	7.9	8.4	7.8	8	7.9	7.9
	2004	8.7	8.1	8.7	8.6	8	8.4	7.9	7.2	6.6	7.6	7.6	8.1	8.1
	2005	8.8	7.2	8.7	8.6	8.8	8.2	7.2	8.7	8.4	8	8.8	8.1	8.1
	2006	7.5	7.4	7.7	7.4	7.8	8	6.1	7.4	7	7.8	7.1	7.8	7.8
	YEAR	Sundargarh	Jharsuguda	Brajrajnagar U/s	Brajrajnagar D/s	Hirakud	Sambalpur U/s	Sambalpur D/s	Sonepur U/s	Sonepur D/s	Tikrapada	Narasinghpur	Cuttack U/s	Cuttack D/s
	2000	7.7	6.3	6.9	6.9	7.5	6.6	6.9	6.6	7	7.2	7.4	6.8	6.8
	2001	7.2	6.8	7	6.4	6.4	7.3	6.3	7.8	7		6.8	7.5	7.5
	2002	7.8	7.3	7.4	7.2	8.7	7.6	6.8	6.7	6.5	8	7.9	7.8	7.8
MONSOON	2003	7.3	7.3	7	6.9	6.8	7.8	7	7.1	8.6	6.3	6.1	7.2	7.2
	2004	7.3	6.9	7.1	6.8	8.3	7.5	6.1	7.1	6.9	7.3	7.2	7.5	7.5
	2005	7.2	7	7.1	6.8	6.9	7	6.5	6.7	6.2	6	6.2	7.1	7.1
	2006	7.3	7.1	7.5	7.1	7.8	7.5	6.7	7.2	7	7.8	8	7	7
	YEAR	Sundargarh	Jharsuguda	Brajrajnagar U/s	Brajrajnagar D/s	Hirakud	Sambalpur U/s	Sambalpur D/s	Sonepur U/s	Sonepur D/s	Tikrapada	Narasinghpur	Cuttack U/s	Cuttack D/s
	2000	7.3	7.6	7.1	6.4	7	6.6	7.5	7.4	7.6	6.9	7.9	6.6	6.6
	2001	7.2	7.6	7.6	7.1	7.8	7.7	7.2	8.3	7.7	6.9	7.2	7.2	7.2
	2002	8.1	8.7	8.1	8.1	8.7	8.6	8.3	9.3	8.8	8.7	8.1	9.5	9.5
POST-MONSOON	2003	8.3	8.3	8.4	8.2	6.9	7.8	7.1	7	6.9	7.2	7.5	8.1	8.1
	2004	8.1	8.2	7.5	7.3	7.4	8	7.8	8	7.6	7.2	6.7	7.5	7.5
	2005	7.9	7.8	7.5	7.3	7.7	7.9	7.4	7.3	6.8	7.1	7.5	7.6	7.6
	2006	8.3	8.5	7.8	7.7	8.1	7.7	8.4	9	8	7.1	8.1	8.1	8.1

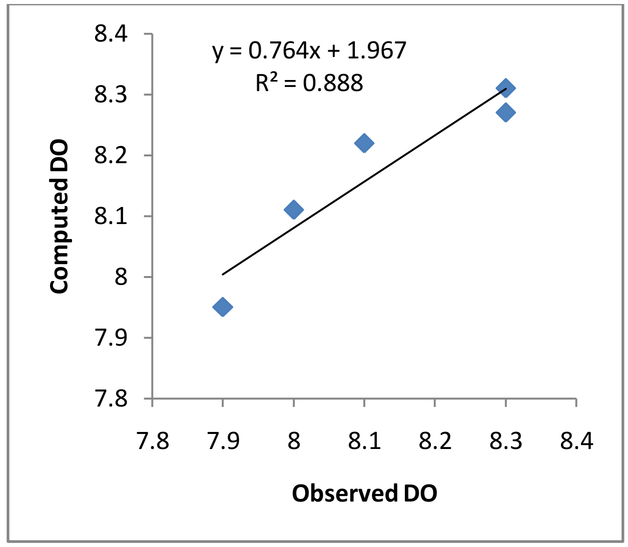
Table 2: Biochemical Oxygen Demand Data (Modified) for Mahanadi River System (Source: OSPCB)

Season	YEAR	Sundargarh	Jharsuguda	Brajrajnagar U/s	Brajrajnagar D/s	Hirakud	Sambalpur U/s	Sambalpur D/s	Sonepur U/s	Sonepur D/s	Tikrapada	Narasinghpur	Cuttack U/s	Cuttack D/s
	2000	3.3	4.1	3.7	4.2	2.7	3.8	4.9	2.8	3.9	2.8	3.3	3.6	5.7
	2001	2.6	3.4	2.4	2.9	1.4	2.2	5.1	2.2	2.7	1.9	1.9	2.4	4.2
	2002	2.4	2.5	2.5	3.2	1.5	2.9	4.3	2	3.5	2	3	2.7	3.4
WINTER	2003	1.4	1.5	1.3	2	0.5	1.4	3.1	2.4	2.9	1.6	1.5	1	3.2
	2004	1.1	1.1	1.1	2.4	1	1.3	3.6	1.3	0.7	0.7	0.8	1.3	2.6
	2005	1.1	0.8	0.8	1.7	0.6	0.8	3	1.2	1.8	0.6	1.1	1.3	3
	2006	0.7	0.8	1	1.9	0.4	2	2.5	0.5	1.6	0.5	1	1.1	2.4
	YEAR	Sundargarh	Jharsuguda	Brajrajnagar U/s	Brajrajnagar D/s	Hirakud	Sambalpur U/s	Sambalpur D/s	Sonepur U/s	Sonepur D/s	Tikrapada	Narasinghpur	Cuttack U/s	Cuttack D/s
	2000	3.3	3.8	3.6	4.8	2.3	2.2	4.2	3	3.5	2.5	2.3	2.1	3.8
	2001	2	2.3	2	2.7	2.1	2.5	3.4	2.1	2.7	2	2.2	2.1	3.7
	2002	2.4	2.8	2.6	3.2	2.8	2.5	4.4	2	3.2	2.8	1.8	2.1	3.7
SUMMER	2003	2.22	2.7	1.4	2.25	1.3	1.8	3.1	1.4	2.5	1.5	1.7	1.8	3.4
	2004	0.8	1	1.4	2	0.8	1.7	3.3	1.4	2	1	2	1.5	2.7
	2005	0.9	1.1	1.1	1.4	1	1.2	3.2	1	2	1.3	1	1.5	3.1
	2006	0.9	1.5	1.2	1.7	0.9	0.7	3.8	1.2	1.3	1	1.3	1	3.2
	YEAR	Sundargarh	Jharsuguda	Brajrajnagar U/s	Brajrajnagar D/s	Hirakud	Sambalpur U/s	Sambalpur D/s	Sonepur U/s	Sonepur D/s	Tikrapada	Narasinghpur	Cuttack U/s	Cuttack D/s
	2000	2.6	3.1	2.7	4.1	3.4	3.2	4.6	2.3	3.9	3.3	2.5	2.4	4.3
	2001	2	2.3	2.6	3.2	3.1	3.2	4	3	5	3	2.5	2.2	2.7
	2002	2.1	2.7	2.7	3	2	2.3	4.2	2	2.5	1.8	1.8	2.4	3.8
MONSOON	2003	0.6	0.3	0.8	1.3	0.8	1	1.5	1	1.9	0.7	1.6	1.2	1.5
	2004	1.1	1	0.9	1.4	1.1	1.1	2.1	1.3	1.4	1	1.7	1.5	1.9
	2005	1.6	1.7	1.5	1.9	1.7	1.4	2.8	1.68	2.3	1.7	1.8	1.6	2.6
	2006	1.4	1.3	1.4	1.8	1.5	1.3	2.3	1.4	2	1.4	1.6	1.5	2.1
	YEAR	Sundargarh	Jharsuguda	Brajrajnagar U/s	Brajrajnagar D/s	Hirakud	Sambalpur U/s	Sambalpur D/s	Sonepur U/s	Sonepur D/s	Tikrapada	Narasinghpur	Cuttack U/s	Cuttack D/s
	2000	2.1	2.3	2.8	4.4	2.7	4.4	5.6	2.7	3.9	5	2.8	2.8	4.4
	2001	2.8	1.8	2.1	2.5	1.4	2.7	2.8	2.8	3.2	2.5	1.5	2.6	3.6
	2002	1.8	1.5	1.3	2.3	1.5	2.3	3.7	1	2.8	2.3	0.8	2.7	3.8
POST-MONSOON	2003	1.3	1.2	1.3	1.9	0.8	1.3	2.3	1	2	0.9	0.6	1.3	1.8
	2004	1.5	1.1	1.4	2	0.8	1.4	2.9	0.2	0.8	0.43	0.4	1.4	2.2
	2005	0.7	0.9	0.8	1.2	0.4	0.8	3	1	1.1	0.8	0.9	0.8	1.7
	2006	1.4	1.4	1.1	1.9	1.2	1.6	3.2	1.1	1.4	1.5	1.1	1.2	2.5

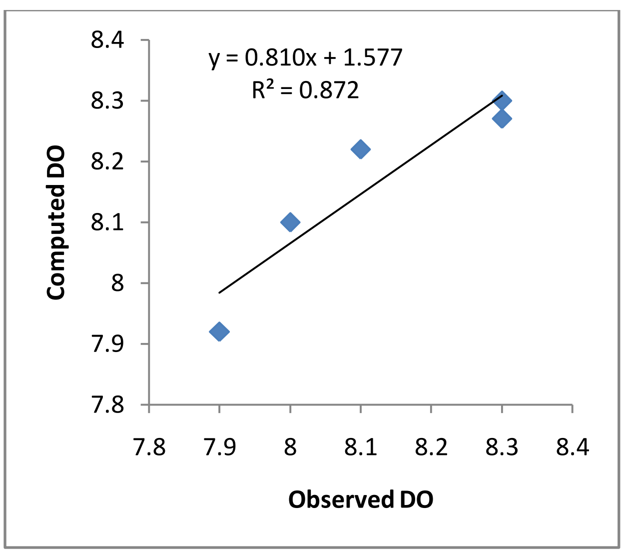
Figure 1: Representation of Computed and Observed DO using k_2 from Different Equations for year in 2005(summer)



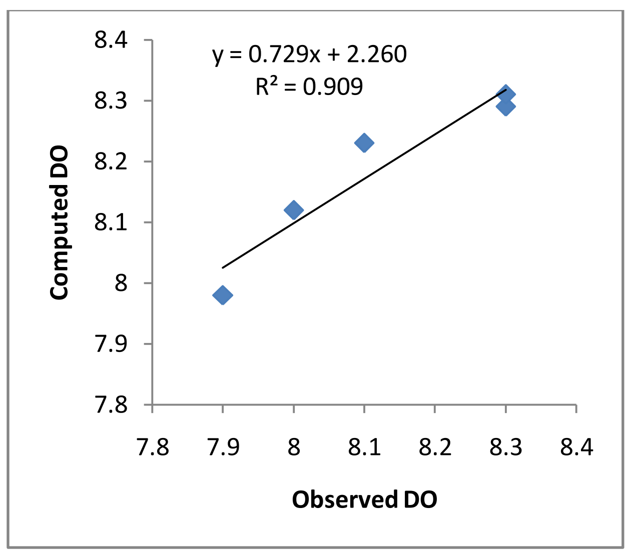
(a) using equation (4.15)



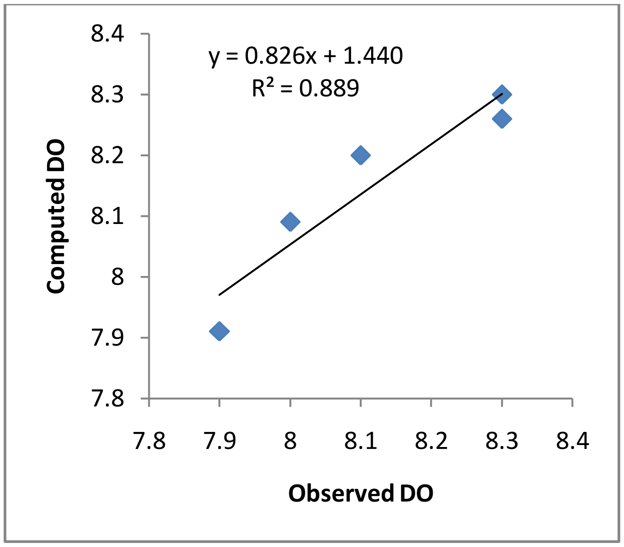
(b) using O'Connor and Dobbins approach



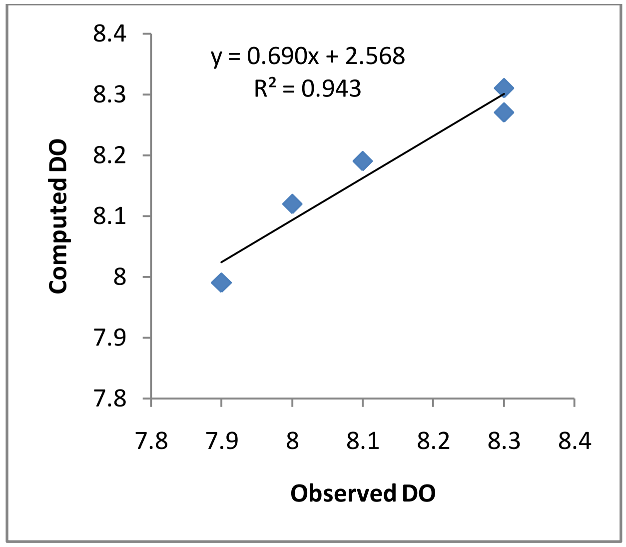
c) usingChurchill et al. approach



(d) using Owens et al. approach

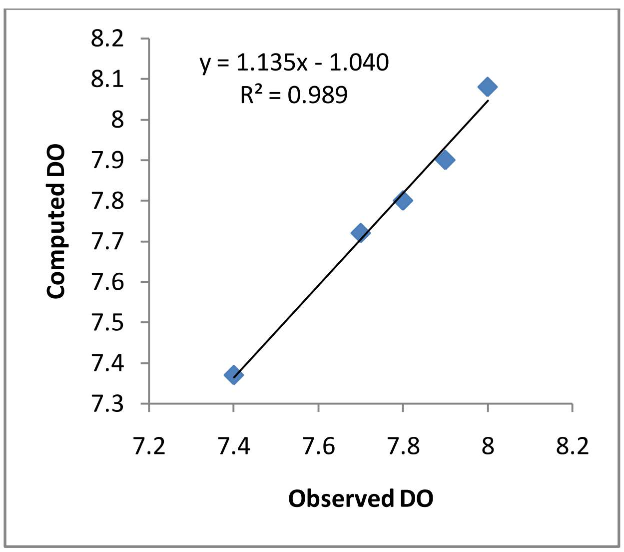


(e) using Langbein and Durum approach

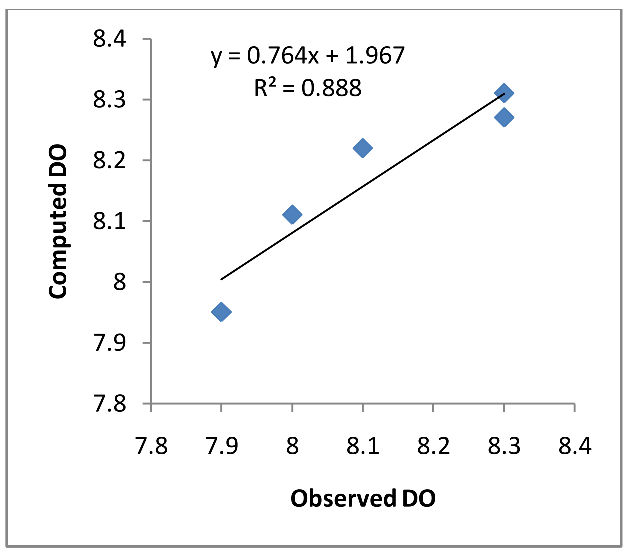


(f) using Jha et al. approach

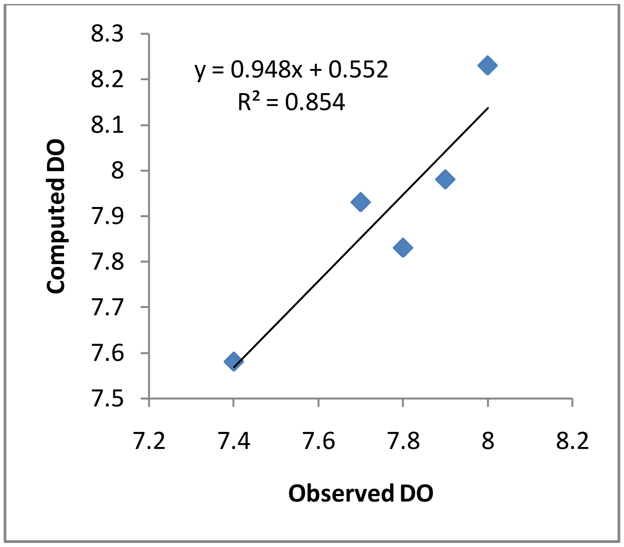
Figure 2: Representation of Computed and Observed DO using k_2 from Different Equations for year in 2006(summer)



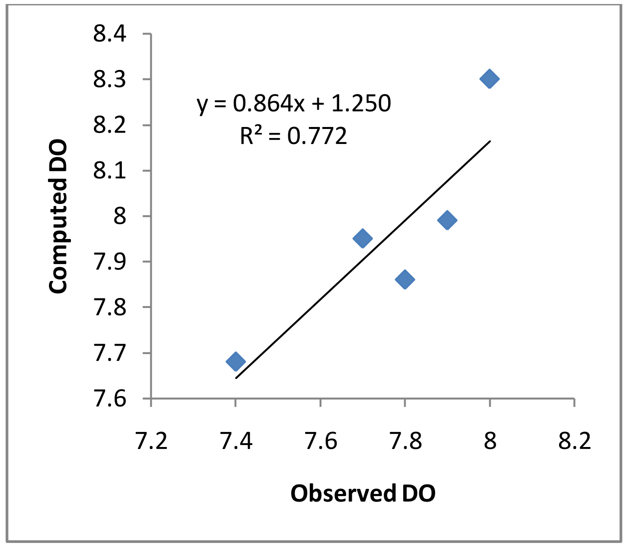
(a) using equation (4.15)



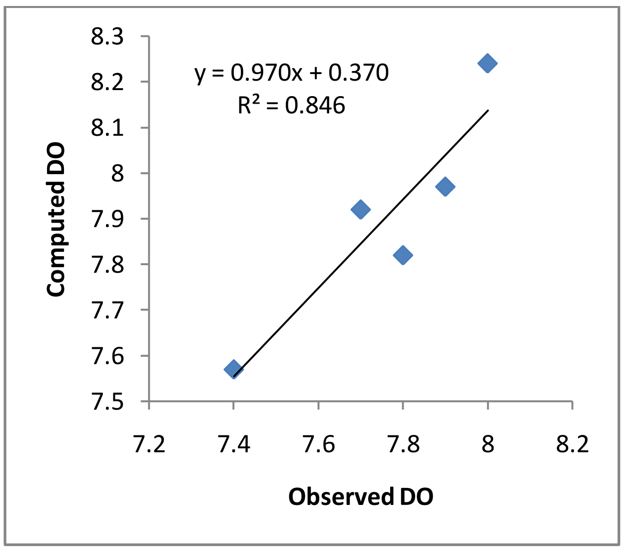
(b) using O'Connor and Dobbins approach



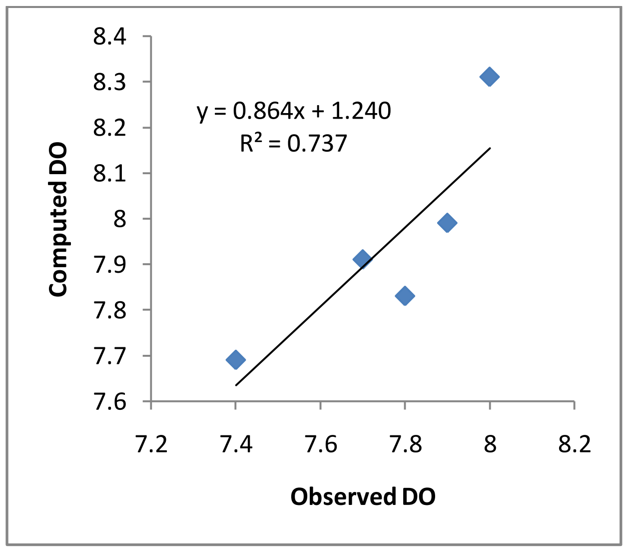
c) usingChurchill et al. approach



(d) using Owens et al. approach

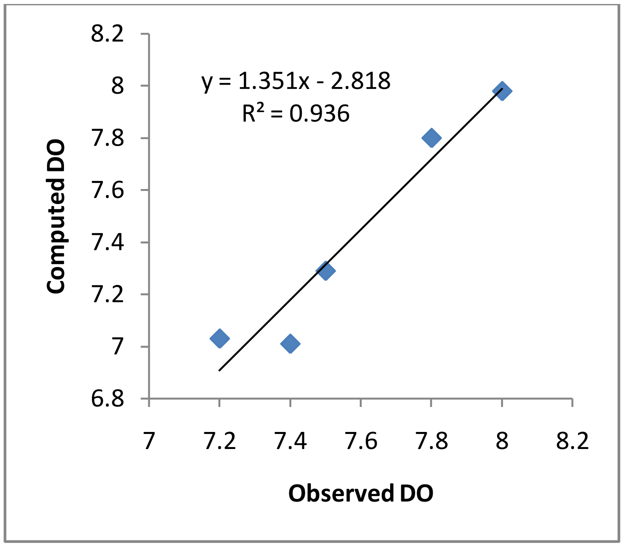


(e) using Langbein and Durum approach

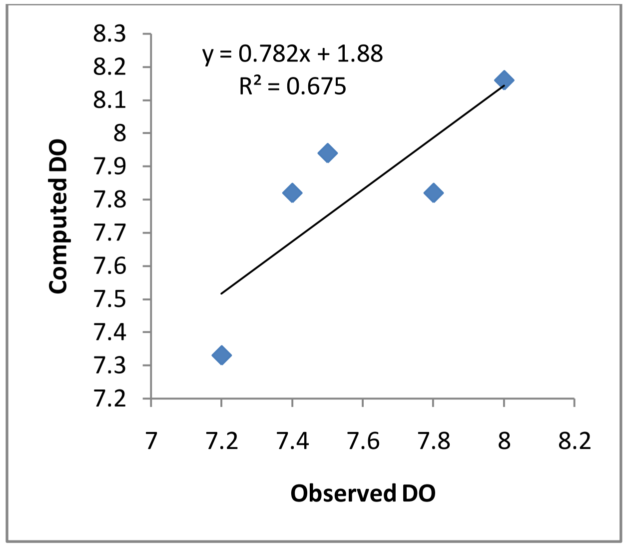


(f) using Jha et al. approach

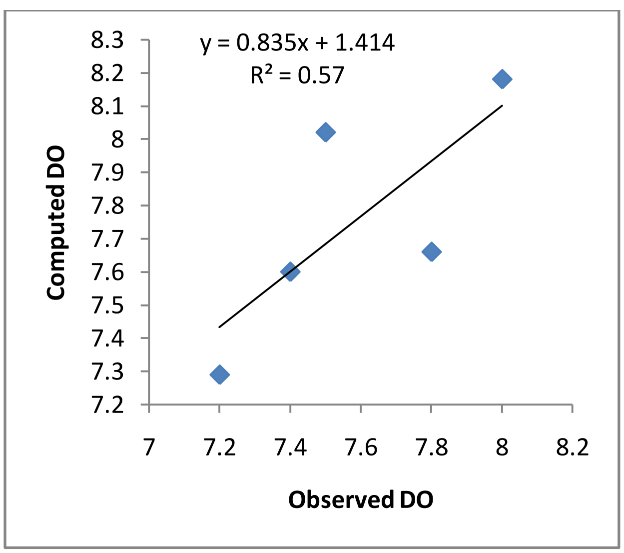
Figure 3: Representation of Computed and Observed DO using k_2 from Different Equations for year in 2005(monsoon)



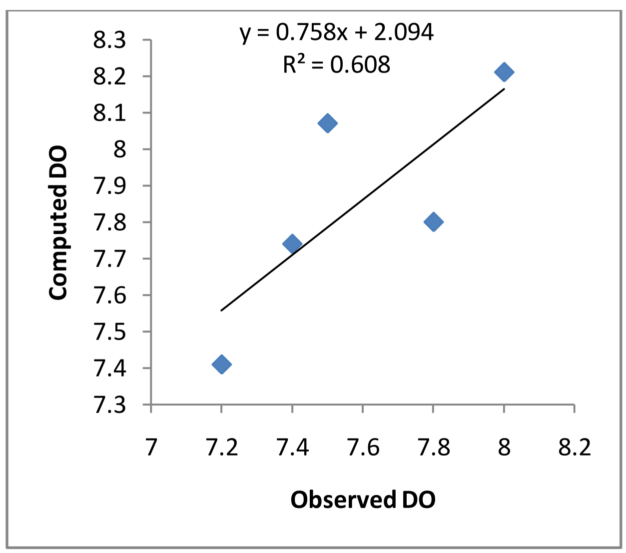
(a) using equation (4.15)



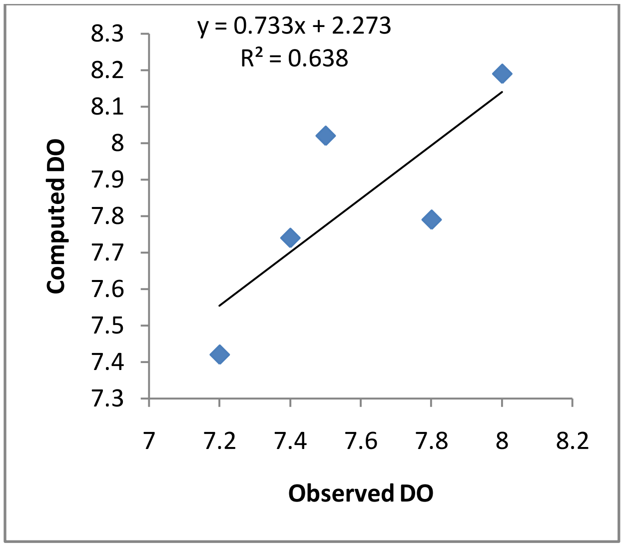
(b) using O'Connor and Dobbins approach

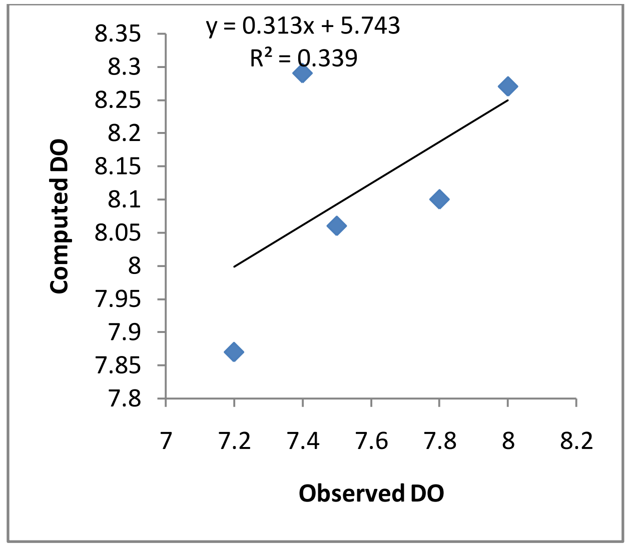


c) usingChurchill et al. approach



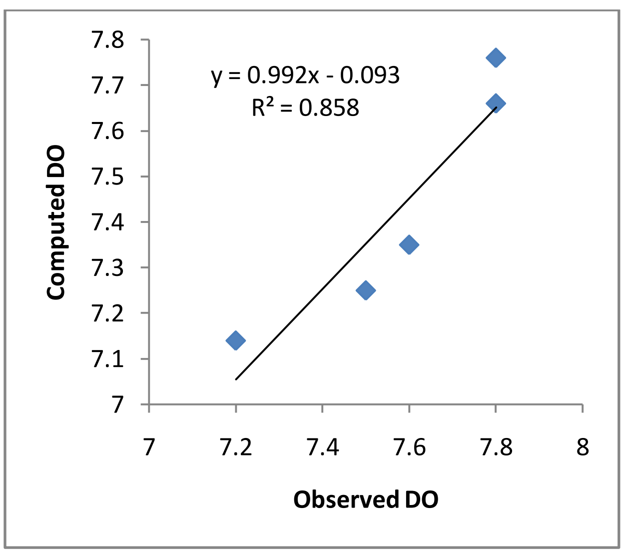
(d) using Owens et al. approach

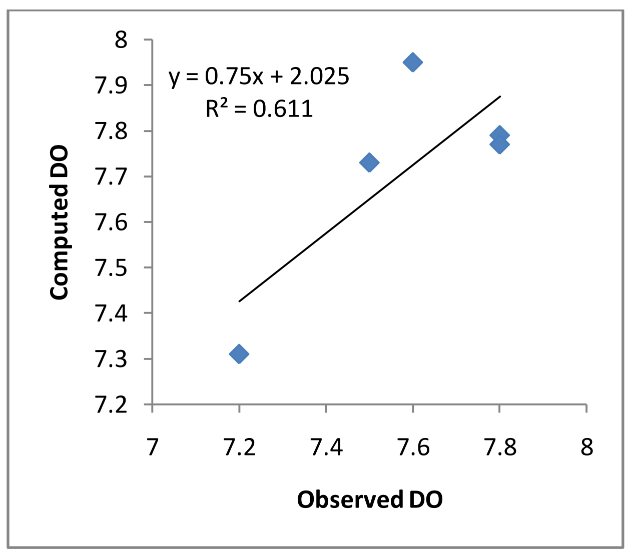




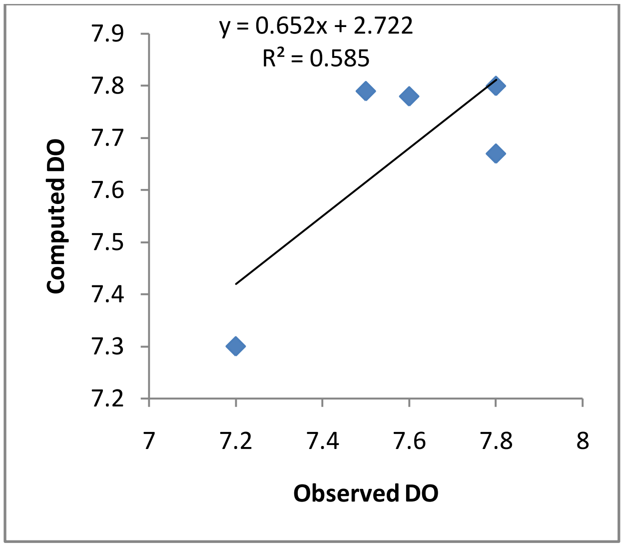
(e) using Langbein and Durum approach **(f) using Jha et al. approach**

Figure 4: Representation of Computed and Observed DO using k_2 from Different Equations for year in 2006(monsoon)

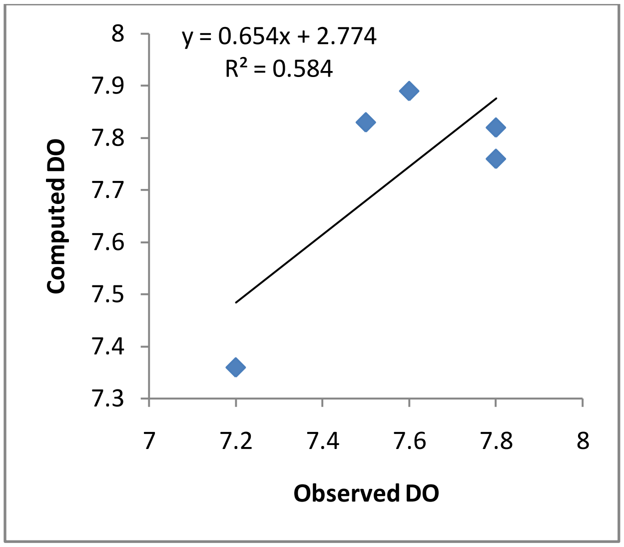




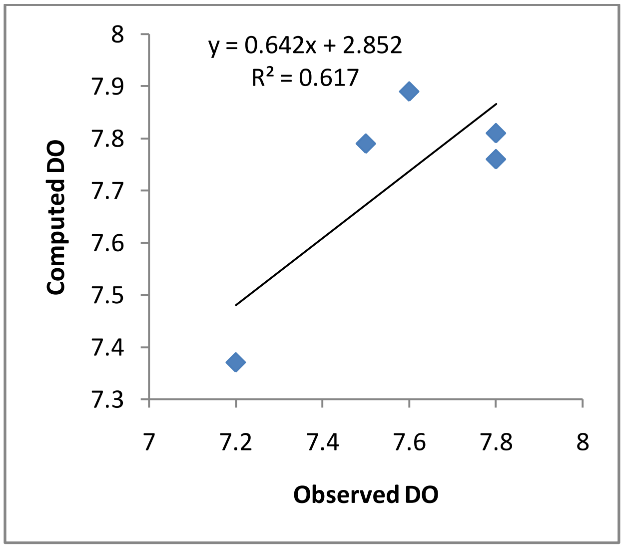
(a) using equation (4.15) **(b) using O'Connor and Dobbins approach**



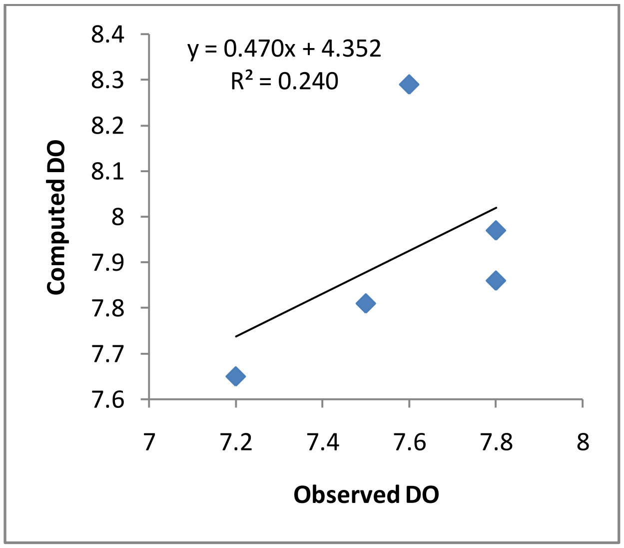
c) usingChurchill et al. approach



(d) using Owens et al. approach



(e) using Langbein and Durum approach



(f) using Jha et al. approach

Figure 5: Representation of MME and RMSE in 2005

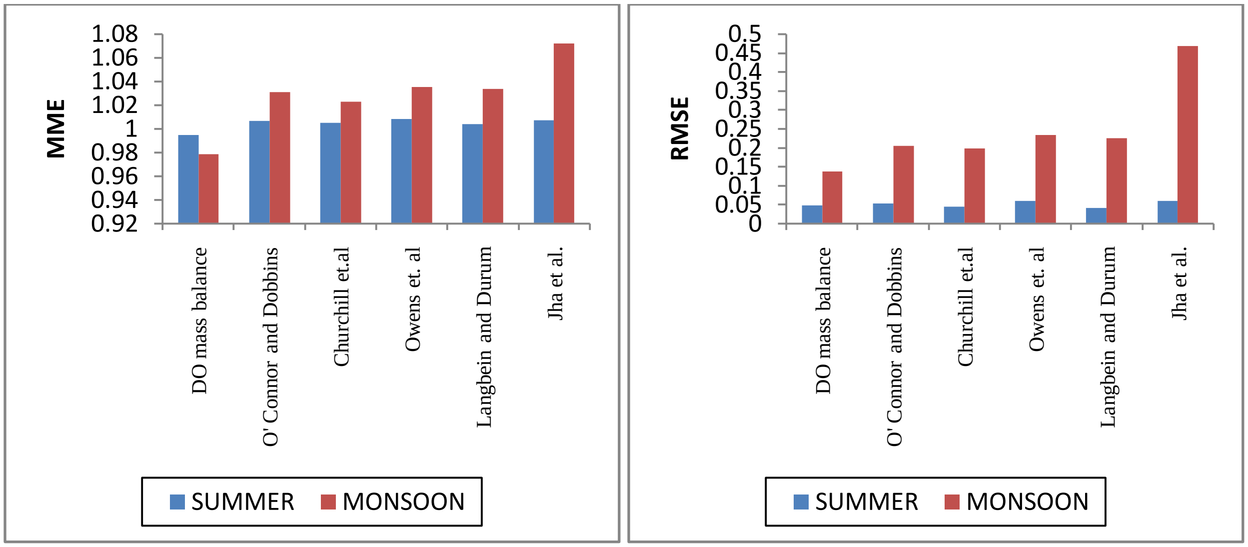


Figure 6: Representation of MME and RMSE in 2006