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SURFACE WATER QUALITY ASSESSMENT OF RIVER KALI, U.P., WITH SPECIAL EMPHASIS TO NON-POINT SOURCE POLLUTION

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Preface

The growing quantum of pollutant loads through point and non-point sources in streams/rivers have led to the degradation of the water quality of rivers throughout the world. Many rivers in India as well as abroad are receiving threats to their aquatic life. It is important and timely that a rigorous approach to the water quality modelling of such streams be undertaken. Recent years have witnessed lot of advancement in the data procurement using remote sensing and data processing using geographical information system (GIS). Thus, it is equally important to explore these modern tools in addition to laying emphasis on representation of certain important water quality parameters. The present study is undertaken to get an insight into existing water quality models and attempts have been made to come out with modified / improved models for non-point source pollution. For developing and testing the models, the data of River Kali in India, which passes very close to the place of study, have been utilized. Due to this proximity of the site, it has also been possible to generate a large amount of field data including the data from remote sensing and local interaction with the farmers and authorities.

The report has been prepared by Sh. Ramakar Jha, Scientist 'C' and Dr. K.K.S. Bhatia, Scientist ' F' and Technical Co-ordinator, Environmental Hydrology Division. The technical assistance has been provided by the staff of the Water Quality Laboratory. The technical input and laboratory support was also provided by Dr. C. K. Jain, Head, Environmental Hydrology Division and Scientist-in-charge of Water Quality Lab of the Institute.

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

Abstract

Non-point source pollution continues to be an important environmental and water quality management problem. Numerous studies aimed at understanding the processes controlling non-point source pollutant (NPS) concentration, fluxes in the river systems and the quantification of the annual NPS loads to the rivers and streams have been accomplished in the past. However, in India, very little work has been done to estimate the non-point source pollution in streams.

In the present study, an extensive water quality survey has been employed to estimate the inflow of nutrients (nitrate as NO_3 and phosphate as o-PO_4) from non-point sources and point sources for one annual cycle in different reaches of River Kali, western Uttar Pradesh, India. A criteria has been evolved to compute the NPS load from each sub-basins lying in different reaches of River Kali. The governing equation developed is based on the conservation of mass and reaction kinetics phenomena. Field surveys have been accomplished in the study area to collect the water samples, to obtain field information from the farmers and State Govt. departments. Water samples have been collected from sixteen river reaches on monthly basis for one annual cycle to analyze to NO_3 and o-PO_4 inflow to the River Kali from external sources. The computed loads at any section obtained from the predictive equation have been compared with the values observed in the field. The performance of developed equation has been evaluated using percentage error estimation and correlation statistics.

Remote sensing (RS) and geographical information system (GIS) has also been used to develop correlation between basin characteristics and non-point source loads.

Chapter 1

INTRODUCTION

Estimation of non-point source (NPS) pollution is a topic of research that resulted in the development of numerous models and modeling techniques in the last few decades. Agricultural activities are an acknowledged non-point source (NPS) of pollution of surface and ground water. The primary agricultural non-point source pollutants are nutrients, sediment, animal wastes, salts, and pesticides. It cause surface and ground water quality problems (USEPA, 1989a). Among other sources of pollutant, assessment of nutrients is of utmost importance. The nutrients are applied to agricultural land in several different forms and come from various sources, including;

(i) Commercial fertilizer in a dry or fluid form, containing nitrogen (N), phosphorus (P), potassium (K), secondary nutrients, and micro-nutrients;

(ii) Manure from animal production facilities including bedding and other wastes added to the manure, containing N,P,K, secondary nutrients, micro-nutrients, salts, some metals, and organics;

(iii) Municipal and industrial treatment plant sludge, containing N,P,K, secondary nutrients, micro-nutrients, salts, metals, and organic solids;

(iv) Municipal and industrial treatment plant effluent, containing N,P,K, secondary nutrients, micro-nutrients, salts, metals, and organics;

(v) Legumes and crop residues containing N, P, K, secondary nutrients, and micro-nutrients;

(vi) Irrigation water; and

(vii) Atmospheric deposition of nutrients such as nitrogen and sulphur.

Nitrogen (N) and phosphorus (P) are the two major nutrients from agricultural land that degrade water quality. The role of nitrogen (N) and phosphorus (P) as key nutrients determining the status of water bodies has been described below.

1.1 Nitrogen

All forms of transported nitrogen are potential contributors to water quality problems. Dissolved ammonia at concentrations above 0.2 mg/L may be toxic to fish. Nitrates in drinking water are potentially dangerous, especially to newborn infants. Nitrate is converted to nitrite in the digestive tract, which reduces the oxygen-carrying capacity of the blood (methemoglobinemia), resulting in brain damage or even death. The U.S. Environmental Protection Agency has set a limit of 10 mg/L nitrate-nitrogen in water used for human consumption (USEPA, 1989a).

Nitrogen is naturally present in soils but must be added to increase crop production. Nitrogen is added to the soil primarily by applying commercial fertilizers and manure, but also by growing legumes (biological nitrogen fixation) and incorporating crop residues. Not all nitrogen that is present in or on the soil is available for plant use at any one time. Organic nitrogen normally constitutes the majority of the soil nitrogen. It is slowly converted (2 to 3 percent per year) to the more readily plant-available inorganic ammonium or nitrate.

The chemical form of nitrogen affects its impact on water quality. The most biologically important inorganic forms of nitrogen are ammonium (NH_4-N), nitrate (NO_3-N), and nitrite (NO_2-N). Organic nitrogen occurs as particulate matter, in living organisms, and as detritus. It occurs in dissolved form in compounds such as amino acids, amines, purines, and urea.

Nitrate-nitrogen is highly mobile and can move readily below the crop root zone, especially in sandy soils. It can also be transported with surface runoff, but not usually in large quantities. Ammonium, on the other hand, becomes adsorbed to the soil and is lost primarily with eroding sediment. Even if nitrogen is not in a readily available form as it leaves the field, it can be converted to an available form either during transport or after delivery to water bodies.

1.2 Phosphorus

Manure and fertilizers increase the level of available phosphorus in the soil to promote plant growth, but many soils now contain higher phosphorus levels than plants need (Killorn, 1980; Novais and Kamprath, 1978). Phosphorus can be found in the soil in dissolved, colloidal, or particulate forms. Runoff and erosion can carry some of the applied phosphorus to nearby water bodies. Dissolved inorganic phosphorus (orthophosphate phosphorus) is probably the only form directly available to algae. Particulate and organic phosphorus delivered to water bodies may later be released and made available to algae when the bottom sediment of a stream becomes anaerobic, causing water quality problems.

The influence of non-point sources of nutrient loading in the streams is well-established (Jain, 1998). A number of studies and models have been accomplished in the past and many catchment have fairly predicted nutrient- discharge relationships (Hoare, 1982; Hagebro et al., 1983; Munn and Prepas, 1986,). These studies indicate that the nutrient load in streams due to non-point sources play a significant role in addition to the point sources. The magnitude of non-point sources of nutrients is often estimated as the difference between total export from a watershed and identifiable point source discharges (Novotny and Olem, 1994) in the chemical mass balance approach (CMBA). The difficulty in modelling NPS is the problem of identifying sources and quantifying the loads. In contrast to a point source, where a known volume of contaminant is discharged from a single identifiable source, diffuse pollution is an aggregate of small contaminant inputs distributed through a watershed.

In the present study, the chemical mass balance approach has been modified for computing the non-point source pollutants, such as nitrate (as NO_3) and phosphate (as o-PO_4) entering to the River Kali from the external sources (catchment area). The nitrate (NO_3) and phosphate (o-PO_4) are transported from the agriculture land by being dissolved in runoff water, by being adsorbed on the eroded soil particles or by being dissolved in sub-surface flow as non-point source pollution (Jain, 2000). Remote sensing and GIS has been used to determine input parameters required for the modeling approach. The main objectives of the present study are

(i) To test and validate present model by computing non-point source load at any point within a river reach of River Kali.

(ii) **To estimate NPS loads of NO_3 and o-PO_4 from 9 sub-basins in the Kali basin using the approach using mass conservation and reaction kinetics.**

(iii) **To explore the possibility remote sensing and GIS techniques for estimating NPS loads from Kai basin.**

Chapter 2

THE STUDY AREA AND DATA COLLECTION

2.1 The River Kali

River Kali is an important left bank tributary of River Hindon originating near Saharanpur district in western Uttar Pradesh, India. The river traverses a course of 122.10 km before meeting the river Hindon with a total basin area of 925.21 sq. km (Figure 1). The study area is a part of Yamuna basin in the Indo-gangetic plains, composed of pleistocene and sub-recent alluvium, and lies between $29^{0}13'$ to $30^{0}\ 0'$ N latitude and $77^{0}35'$ to $77^{0}45'$ E longitude. The mean rainfall over the basin is 1000 mm which occurs mainly during monsoon period (June to September). The basin area lies between the elevations from 229 m to 274 m above mean sea level with agriculture as the major land use. The soils of the area are loam to silt loam and are normally free from carbonates. The river has a significant socio-economic value to nearby areas.

In some of the reaches, disposal of waste in River Kali pollutes the water and causes problems to the fish life, aquatic biota, human health and the environment. Due to urbanization, inception of industries, use of chemicals and pesticides for agriculture, and increase in population, disposal of wastewater effluent to the River Kali has resulted in deterioration of river water quality. The main point sources, which contribute to pollution in the river, include municipal waste and sugar mill waste of Deoband town and municipal, industrial and sugar mill wastes of Muzaffarnagar town. The river is being used for the disposal of industrial wastes (Verma et al., 1974). Agriculture waste is another important input contributing non-point source pollution to the river water. It has been found that at certain locations of the river anaerobic conditions exist. Hence, the river attains all possible water quality problems and found to be an ideal case for application of different strategies based on various water quality models.

To collect water quality samples for laboratory analysis and for field measurements, twenty-three sampling stations at different locations in a stretch of 122.60 km of River Kali have been selected (Figure 2). These locations are well suited to distinguish the location and non-point source pollutant entry in River Kali. Some of the

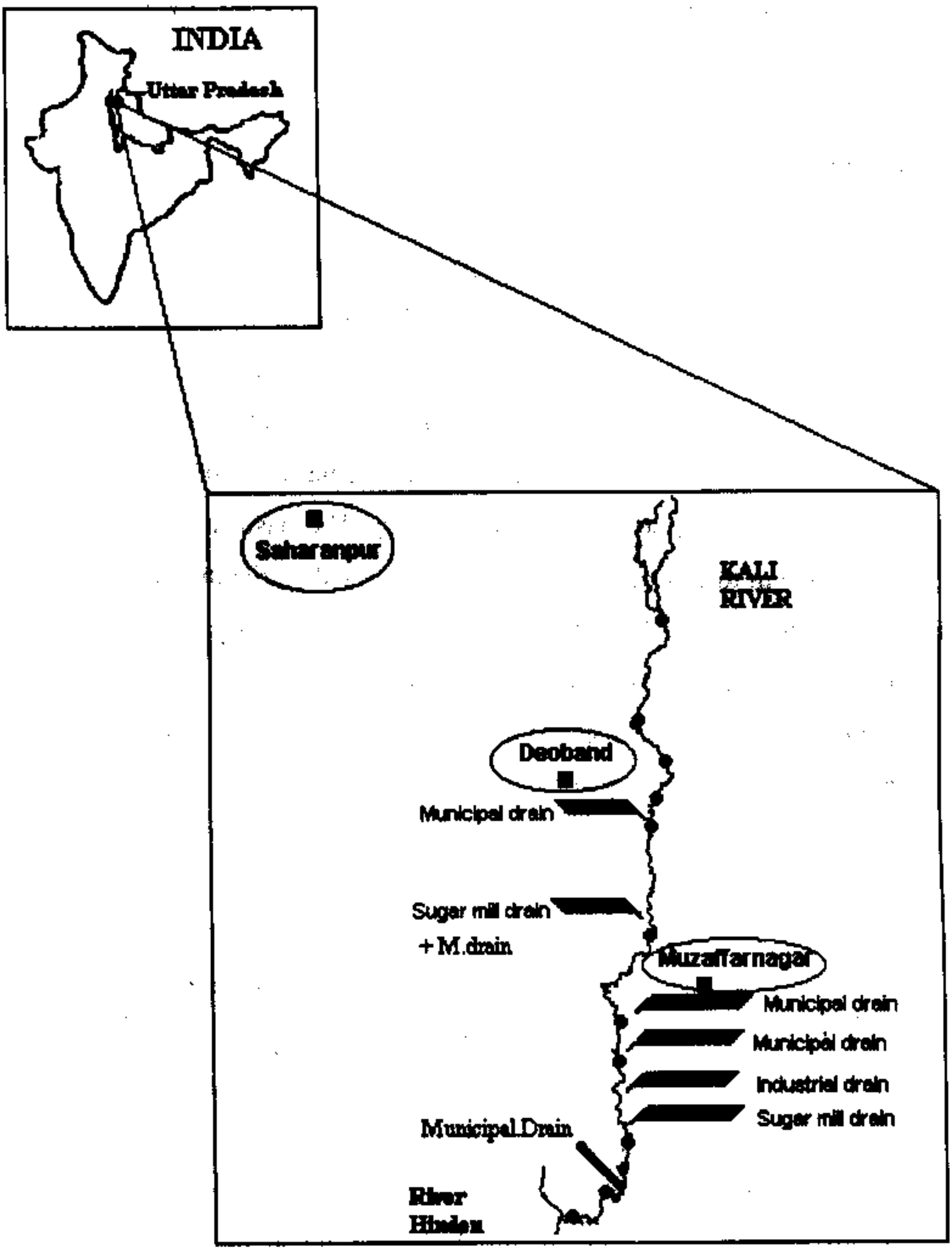

Fig. 1 : Location of River Kali in India

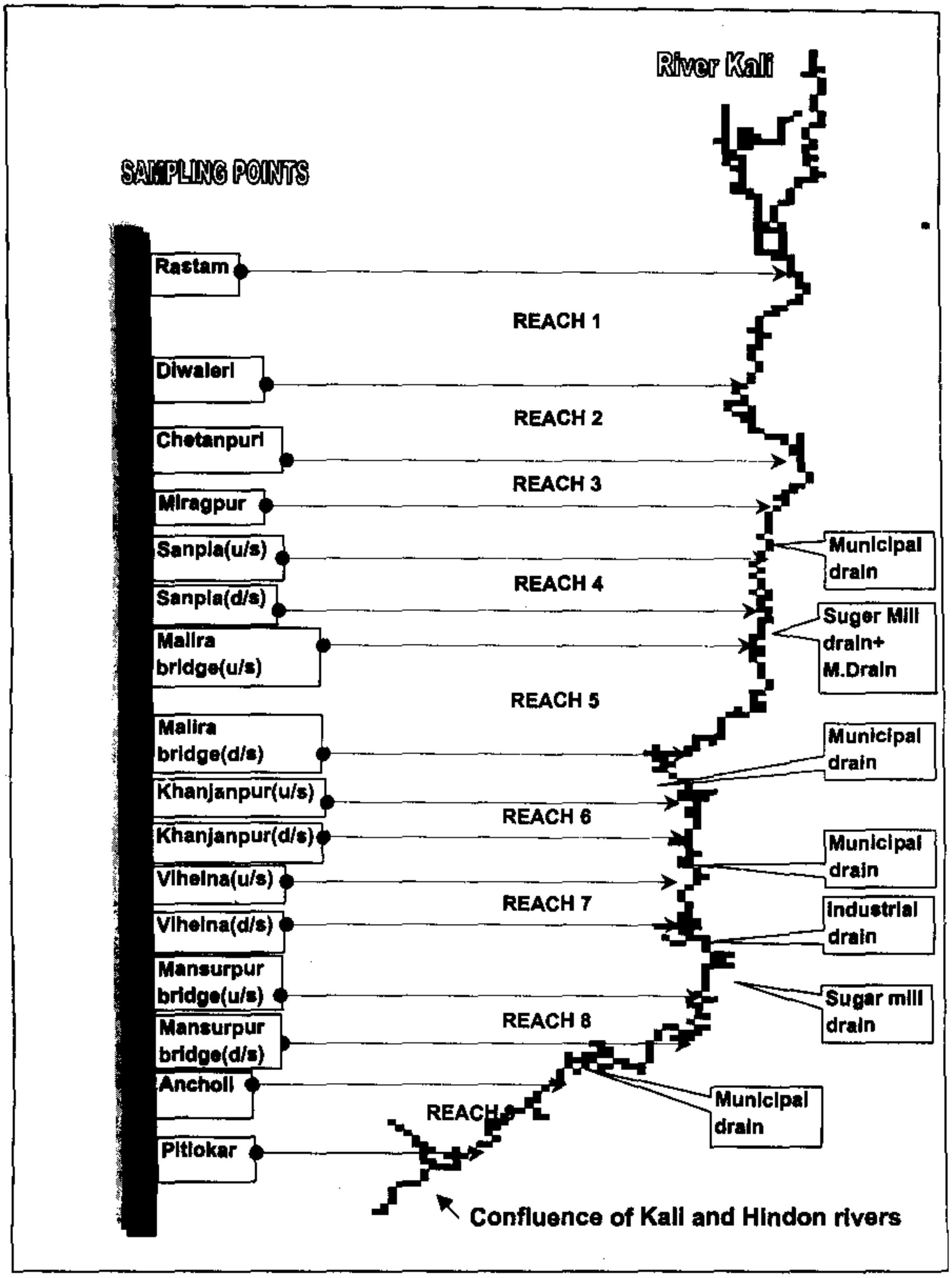

Fig.2: General plan of the sampling points in River Kali

important water quality variables reactive in nature (DO, BOD, NO_3 and o-PO_4) and hydraulic variables (water depth, velocity, cross-sectional area etc.) were also monitored at all the sampling locations simultaneously. The description of sampling locations is as follows:

- Rastam is the 1st sampling location at about 20 km. downstream of the origin of the River Kali. The pollution at this location is mainly due to diffused or non-point sources.
- Diwaleri is the 2nd sampling location 4 km. downstream of 1st location. The pollution at this location is mainly due to diffused or non-point sources.
- Chetanpuri is the 3rd sampling location 4.15 km. downstream of the 2nd location. The pollution at this location is mainly due to diffused or non-point sources.
- Miragpur is the 4th sampling location 2.2 km. downstream of the 3rd location. The pollution at this location is due to diffused or non-point sources.
- Deoband drain confluence with the river is the 5th sampling location 4.0 km. downstream of 4th location. It is the main source of pollution that carries municipal waste.
- Sanpla (u/s) is the 6th sampling location 1.1 km. downstream of the 5th location. The pollution at this location is mainly due to main drain of Deoband town.
- Sanpla (d/s) is the 7th sampling location 20 km. downstream of the 6th location. The pollution at this location is mainly due to diffused or non-point sources.
- Rohana sugar mill and Sila Khala confluence with river is the 8th sampling location 0.10 km downstream of 7th location. The pollution at this location is mainly due to disposal of sugar mill effluent and Sila Khala into the River Kali.
- Malira Bridge (u/s) is the 9th sampling location 0.65 km. downstream of the 8th location. The pollution at this location is mainly due to discharge from Rohana sugar mill and Sila Khala and some distributed sources of pollution
- Malira Bridge (d/s) is the 10th sampling location 12.65 km. downstream of the 9th location. The pollution at this location is mainly due to diffused or non-point sources.
- Niyajupura municipal drain and Imli nala confluence with the river is the 11th sampling location 0.10 km. downstream of 10th location. It is one of the main sources of pollution that carries municipal waste.

- Khanjanpur Bridge (u/s) is the 12th sampling location 0.45 km. downstream of 11th location. The pollution at this location is mainly due to Niyajupura municipal drain and Imli nala.
- Khanjanpur Bridge (d/s) is the 13th sampling location 0.7 km. downstream of 12th location. The pollution at this location is mainly due to diffused or non-point sources.
- Muzaffarnagar drain confluence with the river is the 14th sampling location 0.3 km. downstream of 13th location. It is the main municipal drain that carries municipal waste.
- Vihelna (u/s) is the 15th sampling location 0.3 km. downstream of 14th location. The pollution at this location is mainly due to Muzaffarnagar municipal drain.
- Vihelna (d/s) is the 16th sampling location 8.50 km. downstream of 15th location. The pollution at this location is mainly due to diffused or non-point sources.
- Begharajpur Industrial drain confluence with the river is the 17th sampling location 8.75 km. downstream of 16th location. It is the main Industrial drain which carries mixed waste from variety of industries (such as steel, rubber, ceramic, chemical, plastic, dairy, pulp and paper, and laundries) and municipal areas.
- Mansurpur sugar mill confluence with the river is the 18th sampling location 0.50 km downstream of the 17th location. It is the main sugar mill drain that carries sugar mill wastes with it.
- Mansurpur Bridge (u/s) is the 19th sampling location 0.75 km. downstream of 18th location. The pollution at this location is mainly due to industrial and sugar mill drains and some distributed sources of pollution.
- Mansurpur Bridge (d/s) is the 20th sampling location 1.50 km. downstream of 19th location. The pollution at this location is mainly due to diffused or non-point sources.
- Municipal drain is the 21st sampling location 20 km downstream of 20th location. The pollution at this location is mainly due to Pina drain.
- Ancholi is the 22nd sampling location 2.0 km downstream of 21st location. The pollution at this location is mainly due to Pina drain pollution.
- Pitlokar is the 23rd sampling location 9.9 km downstream of 22nd location. The pollution at this location is mainly due to diffused or non-point sources.

It can be seen that while proceeding towards downstream from sampling station 1, the width and depth of the river is increasing. The quality of water and temperature also differs significantly. The details of data collected and its variation is described in the following section.

2.2 Data Collection

The monitoring and analysis of water quality data and hydraulic parameters in field were conducted during March 1999 to February 2000. Some of the important variables monitored and analysed in the field are categorised as:

1. Hydraulic parameters: depth of flow, flow velocity, and cross-sectional area at each sampling location.
2. Physical parameters: pH and temperature.
3. Nutrients: phosphate (o-PO_4) and Nitrate (NO_3).

In River Kali, the water sampling, field measurements and chemical analysis of water samples collected from twenty-three sampling stations has been done every month. The water samples from a sampling station are collected at a time when the same water that was collected in the previous location reaches at this sampling stations (on the basis of mean travel time of flowing water within a river reach). The reason was to study the variations in the water quality variables during the travel between two sampling locations. At each sampling location, samples were collected three times, i.e. in the morning, in the afternoon and in the evening, during each sampling day and a total of 732 data sets were collected after field measurements and laboratory analysis. All the samples were collected at about 15-cm. depth from three locations across the river (1/3, 1/2, and 2/3), and stored in pre-cleaned polythene bottles. The effluent samples from six out falls were collected from the middle of the drains.

The depth of flow across any section of the River Kali was measured by the measuring-rod and velocity was measured using current meter (WTW, Germany). Figures 3 and 4 illustrate the distribution of flow depth and velocity in the combined data set of River Kali from origin to the confluence with the River Hindon. It has been found that the mean velocity in the river varies between 0.2 to 0.5 m sec^{-1} and the mean flow

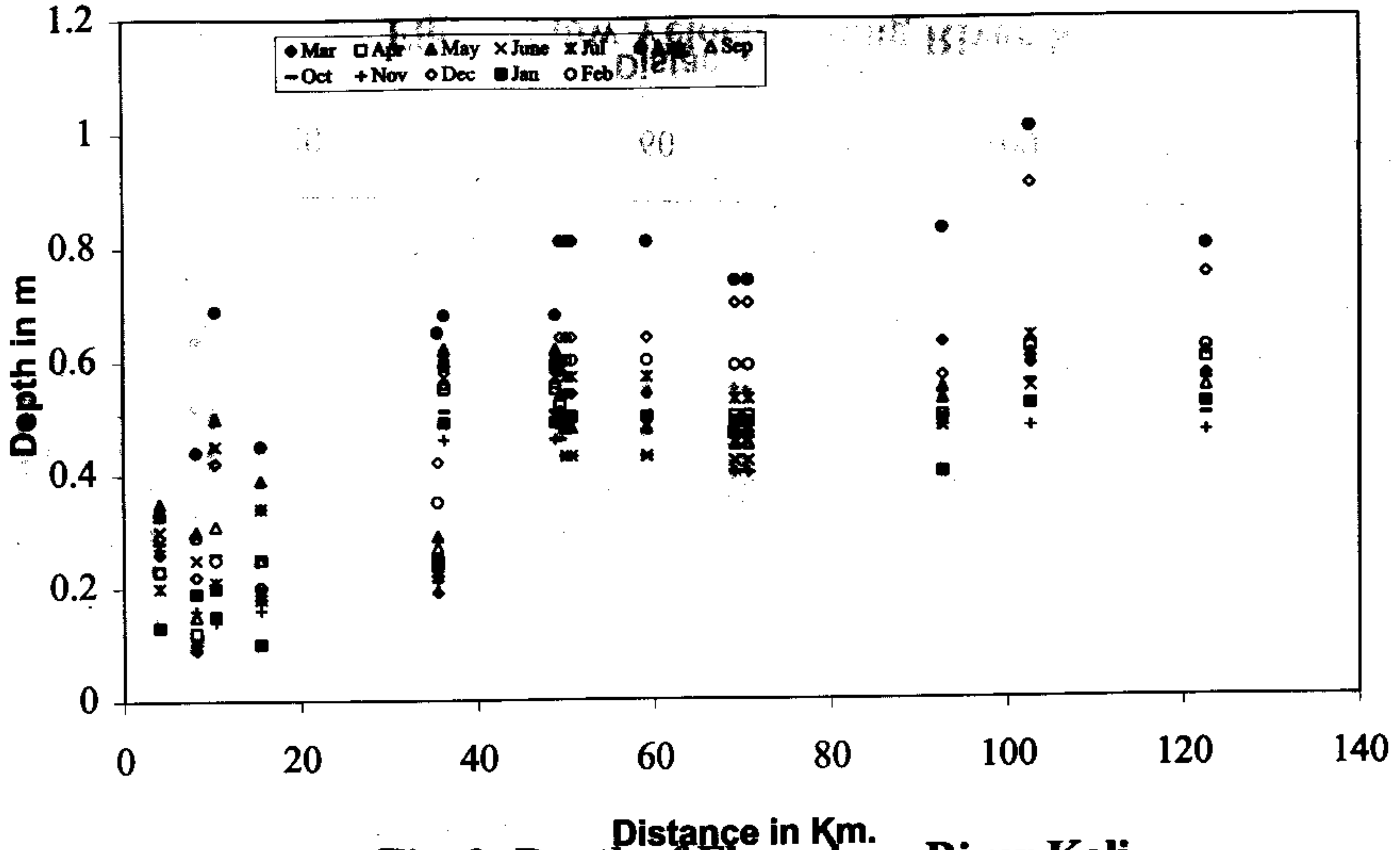

Fig. 3: Depth of Flow along River Kali

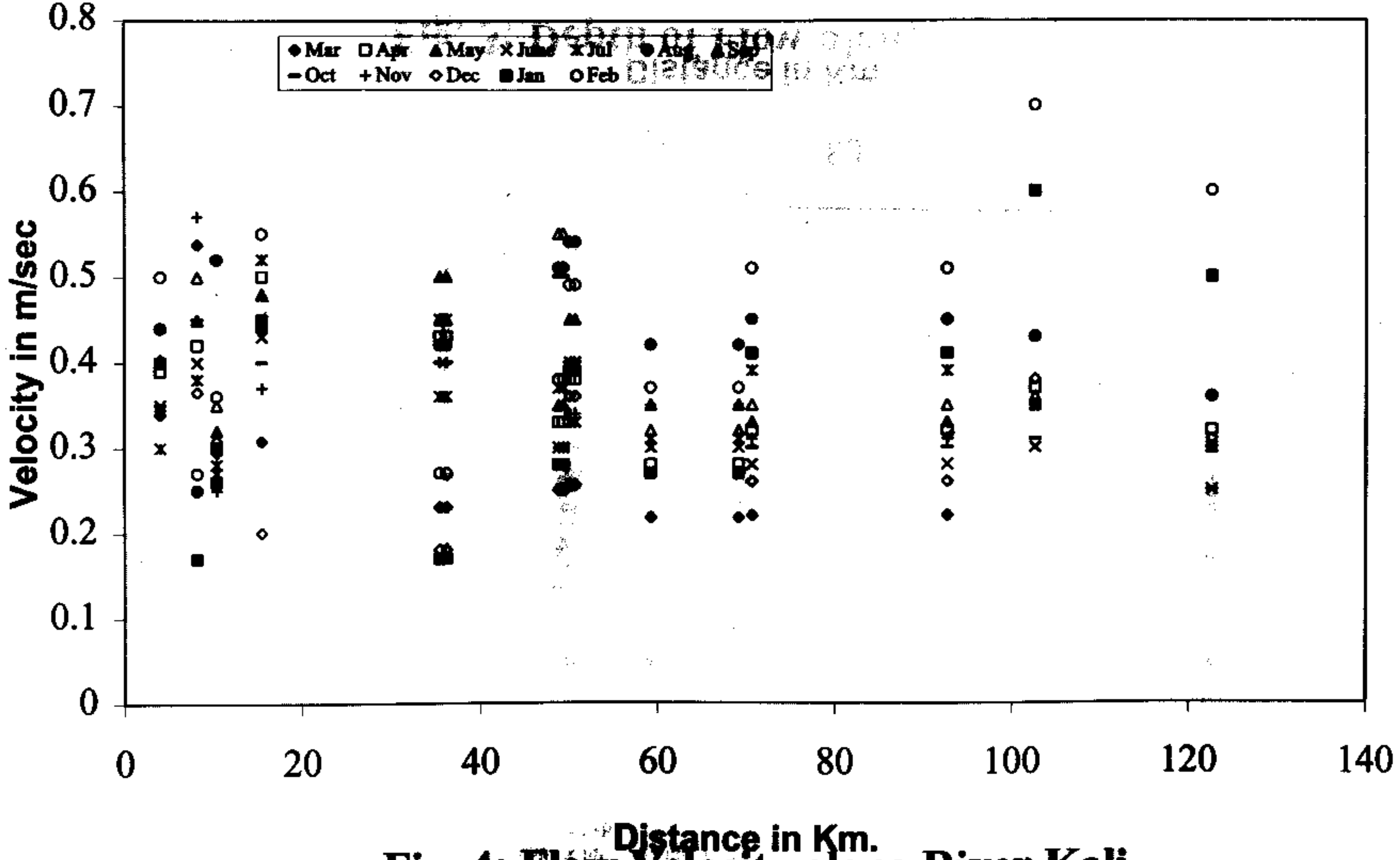

Fig. 4: Flow Velocity along River Kali

depth increases towards downstream from 0.0 to 1.0 meter due to influx of point and non-point sources of discharge into the stream.

The physical parameters, temperature and pH have been measured in the field (in-situ measurement) by means of portable meters. Temperature is an important factor-affecting ion and phase equilibrium, influencing the rates of biochemical processes, which accompany the changes of concentration, and content of organic and mineral substances. In the River Kali, substantial temperature variation has been found. Figure 5 illustrates the spatial and temporal variation in temperature for one annual cycle in River Kali. The pH is found to vary between 7 to 9 along the river, which is within permissible limits.

For nutrients (Nitrate as NO_3 and phosphate as o-PO_4), water samples collected from different river reaches were preserved by adding appropriate reagent (APHA, 1985). The samples so preserved were brought to the laboratory, in sampling kits maintained at 4°C, for detailed chemical analysis. Physio-chemical analyses were conducted following standard methods (APHA, 1985). The longitudinal variation of NO_3 and o-PO_4 for one annual cycle are shown in Figures 6 and 7.

Besides other data, the spatial information and basin characteristics are necessary to determine the total area of the basin, area contributing non-point source pollution at each sampling location, slope of the basin, land use/land cover and cropping pattern in the basin. For the River Kali, digital data of IRS-1C satellite have been obtained from National Remote Sensing Agency (NRSA), Hyderabad and toposheets of the scale 1:50000 were obtained from Survey of India, Dehradun. Figure 8 illustrates the input data obtained from NRSA, Hyderabad. The description for the data procured/collected for the analysis are given in Table 1.

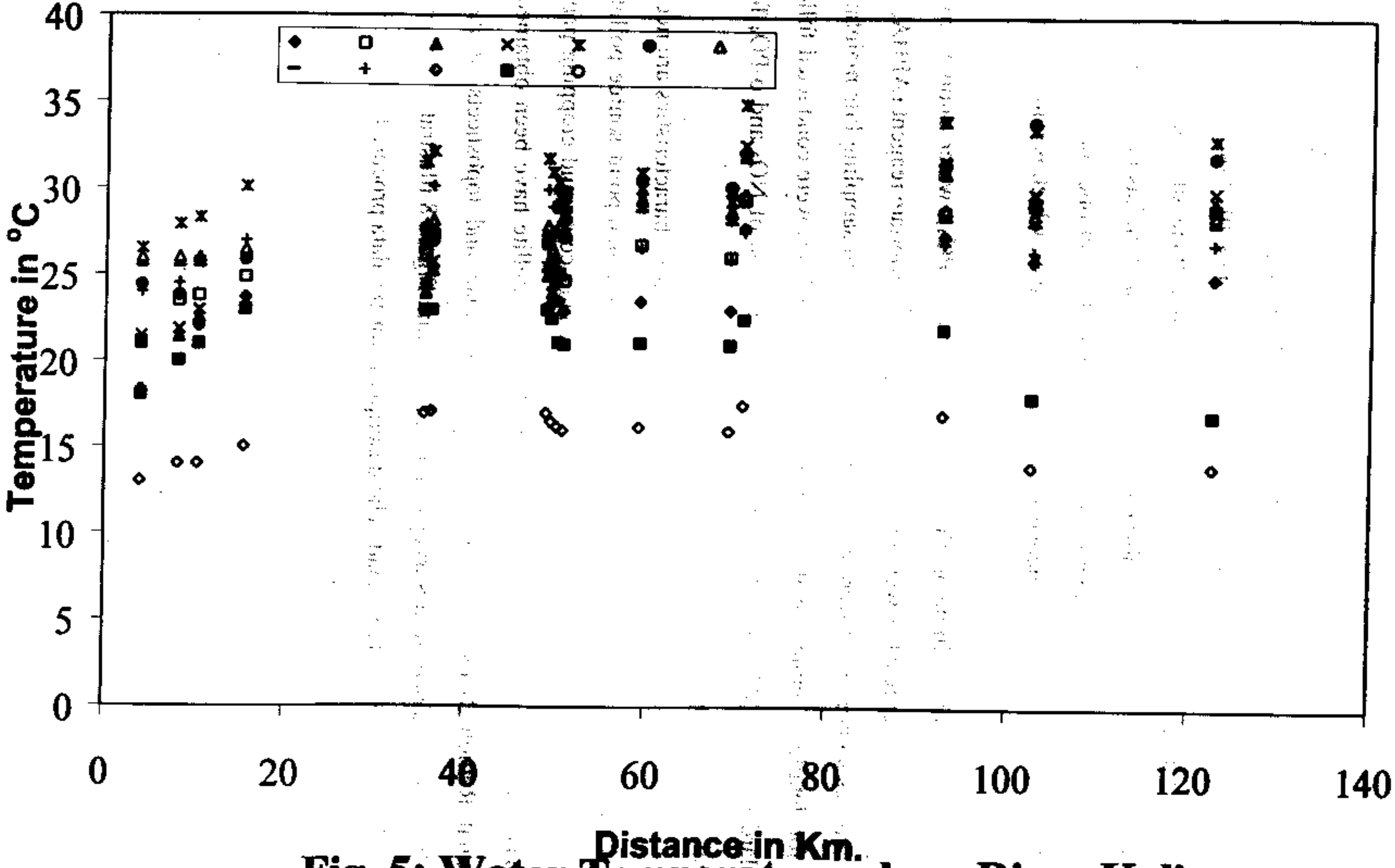

Fig. 5: Water Temperature along River Kali

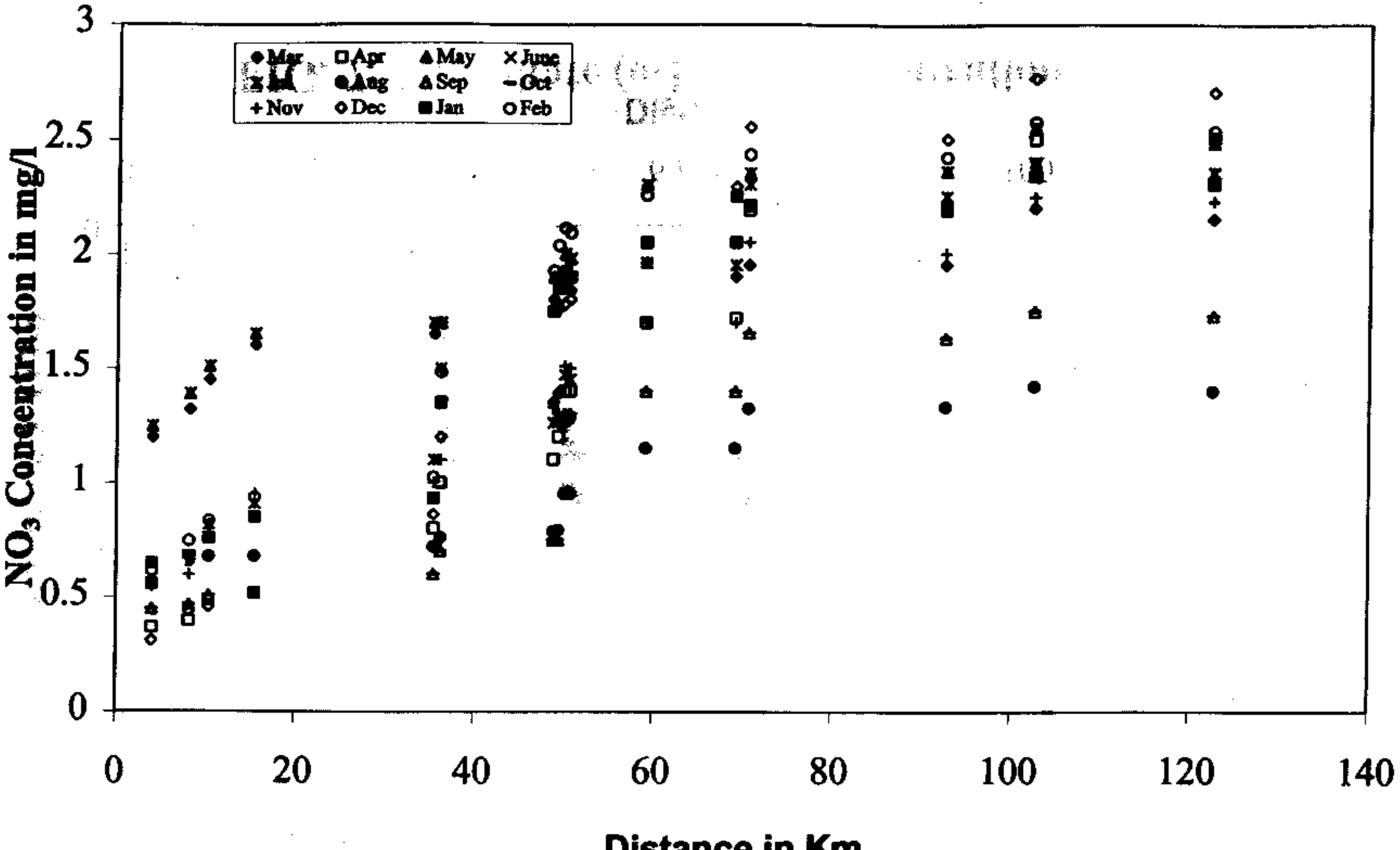

FIG. 6: Nitrate (NO_3) Concentration along River Kali

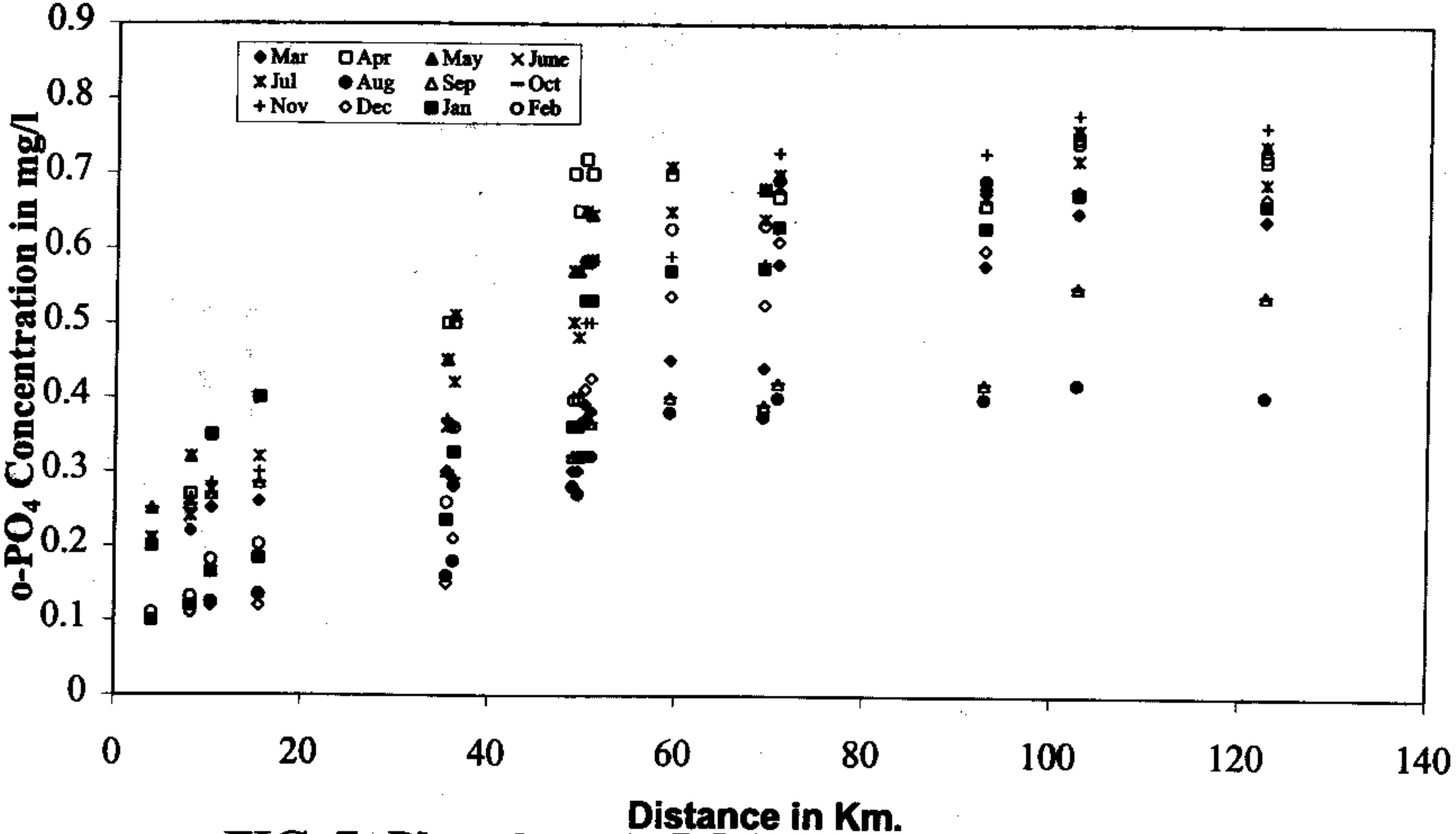

FIG. 7: Phosphate (o-PO$_4$) Concentration along River Kali

Table 1: Description of the spatial data collected for the analysis

Sl. No.	Type of data	Format, Path/row	Date
1.	IRS-IC- LISS III	Digital data, 96/50	11th February, 1997
2.	IRS-IC- LISS III	Digital data, 96/50	28th October, 1998
3.	IRS-IC- LISS III	Digital data, 96/50	8th April, 2000
4.	IRS-IC- PAN	Digital data, 96/50	7th May, 2000
5.	Toposheets	53 G/9, 53 G/10, 53 G/11, 53 G/12, 53 G/13, 53 G/14,	-

Chapter 3

METHODOLOGY

River Kali in western Uttar Pradesh, India, having a significant socio-economic value for nearby areas, receives many point and non-point sources of pollution (Ghosh, 1993; Jain, 1996; Jha et al. 2001). In view of this continuous entry of non-point sources of pollutants in River Kali, it is found essential to find a suitable approach that requires minimum input data for estimating non-point source loads (NPSL) in a river reach. The methodology adopted for the present study is described below:

3.1 Remote Sensing (RS) and Geographic Information System (GIS) Applications

For River Kali, the basin boundary, drainage pattern, contour maps, point maps of spot heights and built up area maps were digitized from the base map of Survey of India (SOI) and stored in ILWIS – GIS package. The maps were stored as point map, segment map and polygon maps. The spatial data set are required to be transformed into a map showing the distribution of a hydrologic variable, to be used for further analysis, or as input in a distributed model. Interpolation of point data is perhaps the most common operation in a single data plane. These include the interpolation from digitized contours and points to obtain a digital elevation model (DEM), followed by filtering to arrive at a slope map, or a flow path map. A digital elevation model (DEM) is an ordered array of numbers that represent the spatial distribution of elevations above some arbitrary datum in the landscape (Moore et al., 1993). In principal, a DEM describes the elevation of any point in a given area in digital format and contains information of the drainage, crests and breaks of slope.

In the present study, the digital elevation model (DEM) is created by digitizing the existing contour lines from topographic maps and using linear interpolation technique. The vector map with the contour lines was converted to raster format before interpolation took place. The linear interpolation is a piecewise first order polynomial, whereby the knots coincide with the reference points. The interpolation formula for the interval [X_i, X_{i+1}] is (Figure 3):

$$f(x) = f_1 - \frac{f_{l+1} - f_1}{x_{l+1} - x_l} x_l + \frac{f_{l+1} - f_1}{x_{l+1} - x_l} x \qquad (1)$$

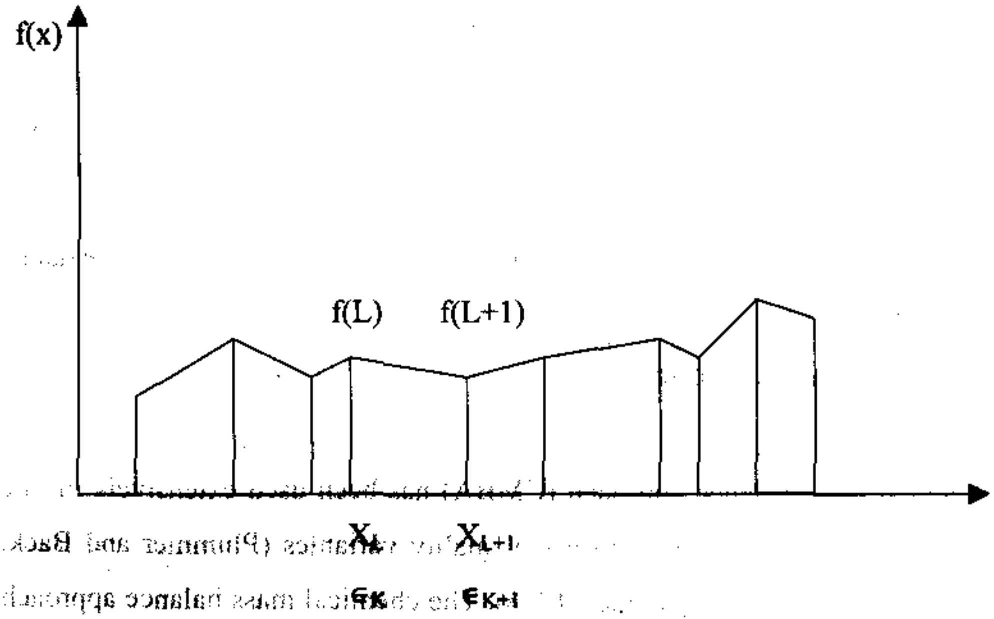

Fig.8: Linear Interpolation- First order piecewise polynomial, Knots coincide with reference points

This interpolation is perhaps the most widely used, because of its simplicity. The method is exact and no attention is given to the behaviour of the variable in between the reference points. If the sampling density is too low according to the sampling theorem, linear interpolation will in general perform better than the higher degree polynomials.

For further analysis, remote sensing data of IRS LISS III multi-spectral imageries for the period Feb.'98, Oct.'99 and May'2000 and IRS-PAN data for the period April'2000 of Kali basin have been used. The slope, flow path, sub-basin areas contributing non-point source pollution at each sampling point, land use/ land cover maps, classification and quantification of different crops, and its temporal variation have been estimated. The application of fertilizers, chemicals, pesticides and manure is influenced by the status of the vegetation and the indicator for the status may be the simple normalized difference vegetation index (NDVI). The multi-spectral data makes it possible to differentiate various cover types.

Vegetation index (VI) in remote sensing are combinations of reflectance of two or more bands, usually in the visible red band and the near infrared band. The most commonly vegetation index is the normalized difference vegetation index;

$$NDVI = \frac{(R_{nir} - R_{red})}{(R_{nir} + R_{red})} \qquad (2)$$

in which R_{nir} and R_{red} are the reflectance in near infra-red and red bands of satellite data.

3.2 The Mathematical Approach

The chemical mass balance approach (CMBA) has been used extensively during recent years for the quantification of each water quality variables (Plummer and Back, 1980; Elder, 1985; Yuretich and Batchelder, 1988). The chemical mass balance approach (CMBA) is a viable alternative over other conventional techniques (Plummer and Back, 1980). The magnitude of non-point sources of nutrients is often estimated as the difference between total export from a watershed and identifiable point source discharges (Novotny and Olem, 1994) in the chemical mass balance approach.

The equation for estimating pollution loads in the river can be written as:

$$Q_d C_d = Q_u C_u + \sum_{i=1}^{n} L_i \qquad (3)$$

where Q_u and Q_d are upstream and downstream flow, C_u and C_d are upstream and downstream concentrations, and $\sum_{i=1}^{n} L_i$ is the sum of individual loading including effect of any loss or generation within the water body.

As can be seen from the Figure 9, that for any contaminant undergoing significant volatilization, degradation, settling, and reaction phenomena, the approach used in equation (3) will not provide an accurate loading summation and the realistic phenomena of pollutants in river.

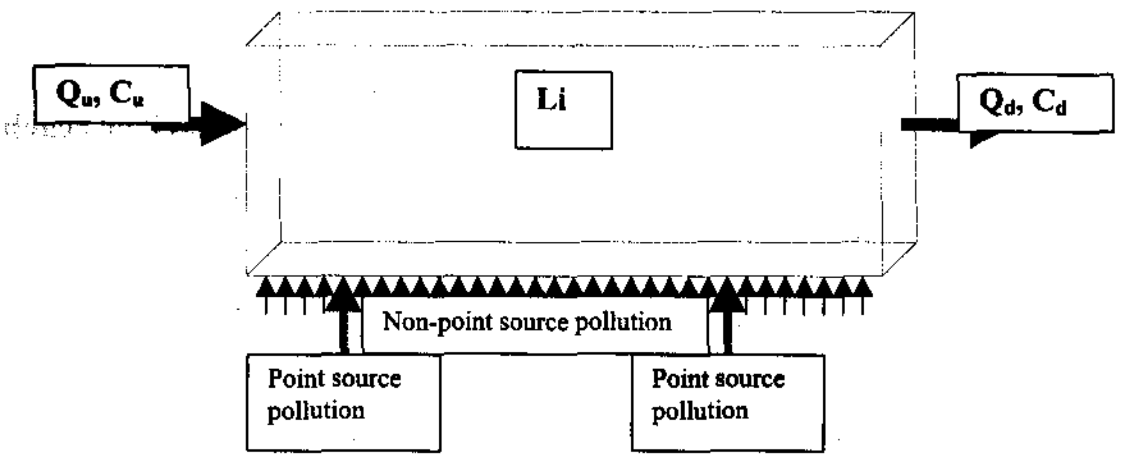

Fig. 9: The chemical mass balance approach for a river reach receiving point and non-point source pollutants

To obtain a generalized solution for estimating non-point source pollutant concentration within a river reach receiving no point source pollution, an modeling approach has been evolved (Figure 10). 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 modelling.

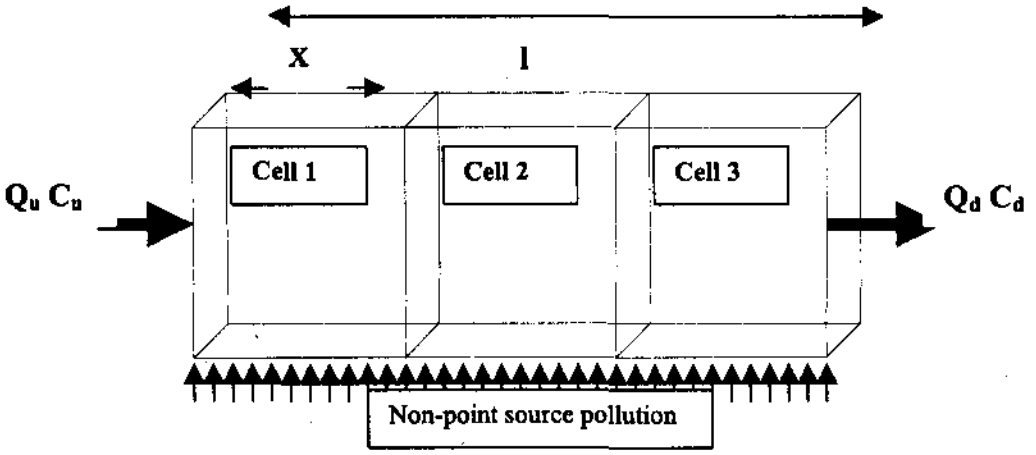

Fig. 10: A generalized distributed modeling approach for a river reach receiving non-point source pollutants from the basin

To evolve the model, consider a river reach of length l receiving diffused source of pollution from the bed or banks of river (Figure 10). Now, at any section of the river that is having reach length x from the entry point, the contribution of non-point discharge (Q_{npx}) can be estimated as

$$Q_{npx} = \frac{(Q_d - Q_u)}{l} x \tag{4}$$

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

$$t_{npx} = t\left(1 - \frac{x}{l}\right) \tag{5}$$

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

$$C_{npx} Q_{npx} = C_{npx}\left[\frac{(Q_d - Q_u)}{l} x\right] \tag{6}$$

Here C_{npx} is the non-point source pollutant concentration (mg l^{-1} unit length^{-1}). Now, the NPSL reaching at the outlet of river reach having length l can be expressed as,

$$NPSL = C_{npx}\left[\frac{(Q_d - Q_u)}{l} x \cdot\right] e^{-kt_{npx}} \tag{7}$$

The equation (7) 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

$$NPSL = \int_0^l C_{npx}\left[\frac{(Q_d - Q_u)}{l}x\right] e^{-kt_{npx}}\,dx \tag{8}$$

By substituting Q_{npx} and t_{npx}, equation (8) becomes,

$$NPSL = C_{np}\left[\int_0^l \left(\frac{(Q_d - Q_u)}{l}x\right) e^{-kt\left(1-\frac{x}{l}\right)} dx\right] \tag{9a}$$

$$= C_{np}\frac{(Q_d - Q_u)}{l}\left[\int_0^l x.\, e^{-kt} e^{\frac{ktx}{l}}\, dx\right] \tag{9b}$$

$$= \frac{C_{np}(Q_d - Q_u)e^{-kt}}{l}\left[x\int_0^l e^{\frac{ktx}{l}}\,\mathrm{dx} - \int_0^l \frac{d}{dx}(x)\left(\int_x^l e^{\frac{ktx}{l}}\,\mathrm{dx}\right)\mathrm{dx}\right] + A \tag{9c}$$

where A is the constant of integration. By solving equation (9c), one gets,

$$\text{NPSL}= \frac{C_{np}(Q_d - Q_u)e^{-kt}}{l}\left[\frac{xe^{\frac{ktx}{l}}}{\left(\frac{kt}{l}\right)} - \frac{e^{\frac{ktx}{l}}}{\left(\frac{kt}{l}\right)^2}\right]_0^l + A \tag{10a}$$

$$= \frac{C_{np}(Q_d - Q_u)e^{-kt}}{l}\left[\frac{l^2e^{kt}}{kt} - \frac{l^2e^{kt}}{k^2t^2} + \frac{l^2}{k^2t^2}\right] + A \tag{10b}$$

$$= \frac{C_{np}l(Q_d - Q_u)}{kt}\left(1 - \frac{1}{kt} + \frac{e^{-kt}}{kt}\right) + A \tag{10c}$$

For, t=0, A becomes zero. By substituting A=0 in equation (10c), we get

$$NPSL = \frac{C_{np}l(Q_d - Q_u)}{kt}\left(1 - \frac{1}{kt} + \frac{e^{-kt}}{kt}\right) \tag{11}$$

Equation (11) 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:

$$NPSL = Q_dC_d - Q_uC_ue^{-kt} \tag{12}$$

By substituting NPSL from equation (11) in equation (12), the rearranged equation can be written as:

$$C_{np} = \frac{Q_d C_d - Q_u C_u e^{-kt}}{\left[\frac{l(Q_d - Q_u)}{kt}\left(1 - \frac{1}{kt} + \frac{e^{-kt}}{kt}\right)\right]} \tag{13}$$

From the equation (13) the concentration of pollutant per unit length of the river reach can be computed. Further, this C_{np} can be used to estimate the non-point load of any sub-reach having length y as described next.

3.3 Laboratory Analysis

Monthly water samples were collected from twenty two sampling points starting from the origin of the river to its confluence with the River Hindon over a period from March 1999- December 1999 to estimate nitrate (as NO_3) and Phosphate (as o-PO_4). All the samples were collected at about 15 cm depth to avoid floating material from three points across a location of the river (1/3, 1/2, and 2/3) using Hydro-Bios standard water sampler using the dip/grab sampling method and stored in pre-cleaned polythene bottles.

The effluent samples from six out falls were collected on a monthly basis from the middle of the drains. The cross sectional area, water depth and velocity parameters were monitored at all twenty two sampling sites to compute temporal variation in river discharges over a period of one complete annual cycle. The flow data were obtained in the same period in which water samples were collected for the analysis of NO_3 and o-PO_4 concentrations.

Samples for nitrate determination were preserved by acidifying with ultra pure concentrated sulfuric acid to $pH<2$ and brought to the laboratory in sampling kits maintained at 4°C. For phosphate analysis samples were kept at 4°C until the analysis was made. The analyses of nutrients were carried out following standard method (APHA, 1985). The NO_3 was determined by chromotropic acid method, which is based upon the yellow colour produced by the reaction of nitrate with chromotropic acid (detection limit $= 0.01 \text{ mg l}^{-1}$). The o-PO_4 was determined by molybdophosphoric acid method. In this method orthophosphate reacts with ammonium molybdate to form molybdophosphoric acid, which is transformed by reductants to the intensely blue coloured complex of molybdenum blue (detection limit = 0.01 mg l^{-1}). The rate constants for NO_3 and o-PO_4 were obtained in the laboratory by experiments.

3.4 Error criteria

Two error criteria have been applied to evaluated the performance of results. Towards this, the percentage error between observed and computed NPSL values have been estimated using the equation

$$\textit{Percentage error} = \left[\frac{\textit{Observed value} - \textit{Computed value}}{\textit{Observed value}}\right] * 100 \tag{14}$$

The other criteria is the correlation analysis that can be used to measure the strength and statistical significance of the association between two or more random water quality variables. Presently, the values of this coefficient, r, have been computed by Pearson's Product Moment correlation equation as given below

$$r = \frac{n\sum_{i=1}^{n} K_{p_i} K_{M_i} - \sum_{i=1}^{n} K_{P_i} \sum_{i=1}^{n} K_{M_i}}{\sqrt{[n\sum_{i=1}^{n} K_{P_i}^2 - (\sum_{i=1}^{n} K_{P_i})^2][n\sum_{i=1}^{n} K_{M_i}^2 - (\sum_{i=1}^{n} K_{M_i})^2]}} \tag{15}$$

Chapter 4

ANALYSIS OF RESULTS

4.1 Model Testing and Vaqlidation

To verify the modelling approach, it is essential to select a river reach and its sub-reaches, which receives non-point loads from the watershed. For doing so, River Kali, in western Uttar Pradesh, India has been selected. For model testing and validation two water quality constituents namely, ortho-phosphate (o-PO_4) and nitrate (NO_3), which are reactive in nature, were used. The rate of attenuation for o-PO_4 and NO_3 were considered to be 0.22 and 0.10 (Ambrose et al., 1991). Measurement of ortho-phosphate (o-PO_4) and nitrate (NO_3) at all the sampling points were based on travel time. Figures 11 (a, b) and 12 (a, b) illustrate the o-PO_4 and NO_3 loads along the River Kali during different periods of one annual cycle.

In the River Kali, as shown in Figure 2 (chapter 2) , no point source effluent is discharged into the river between the sampling points 1 to 4 and the river receives only non point source load. This location is found to be most suitable for testing the validity of equations (13). The total length of the reach between sampling points 1 and 4 is 10.35 km. For model testing the total reach was divided into three sub-reaches, such as reach 1 (between sampling point 1 and 2), reach 2 (between sampling point 2 and 3), reach 3 (between sampling point 3 and 4). The length of reach 1, reach 2 and reach 3 were measured to be 4.00 km., 4.15 km. and 2.2 km. respectively. The following procedure has been adopted to test the validity of equation (13):

Step 1: Equation (13) was used to estimate concentration per unit length and loads of non-point source pollutants, namely, ortho-phosphate (o-PO_4) and nitrate (NO_3) at reach 1, reach 2, and reach 3. The results are shown in Table 2.

Step 2: Also, equation (13) was used to estimate concentration per unit length and loads of non-point source pollutants, namely, ortho-phosphate (o-PO_4) and nitrate (NO_3) of the total reach length considering it to be a single cell. In this case, the

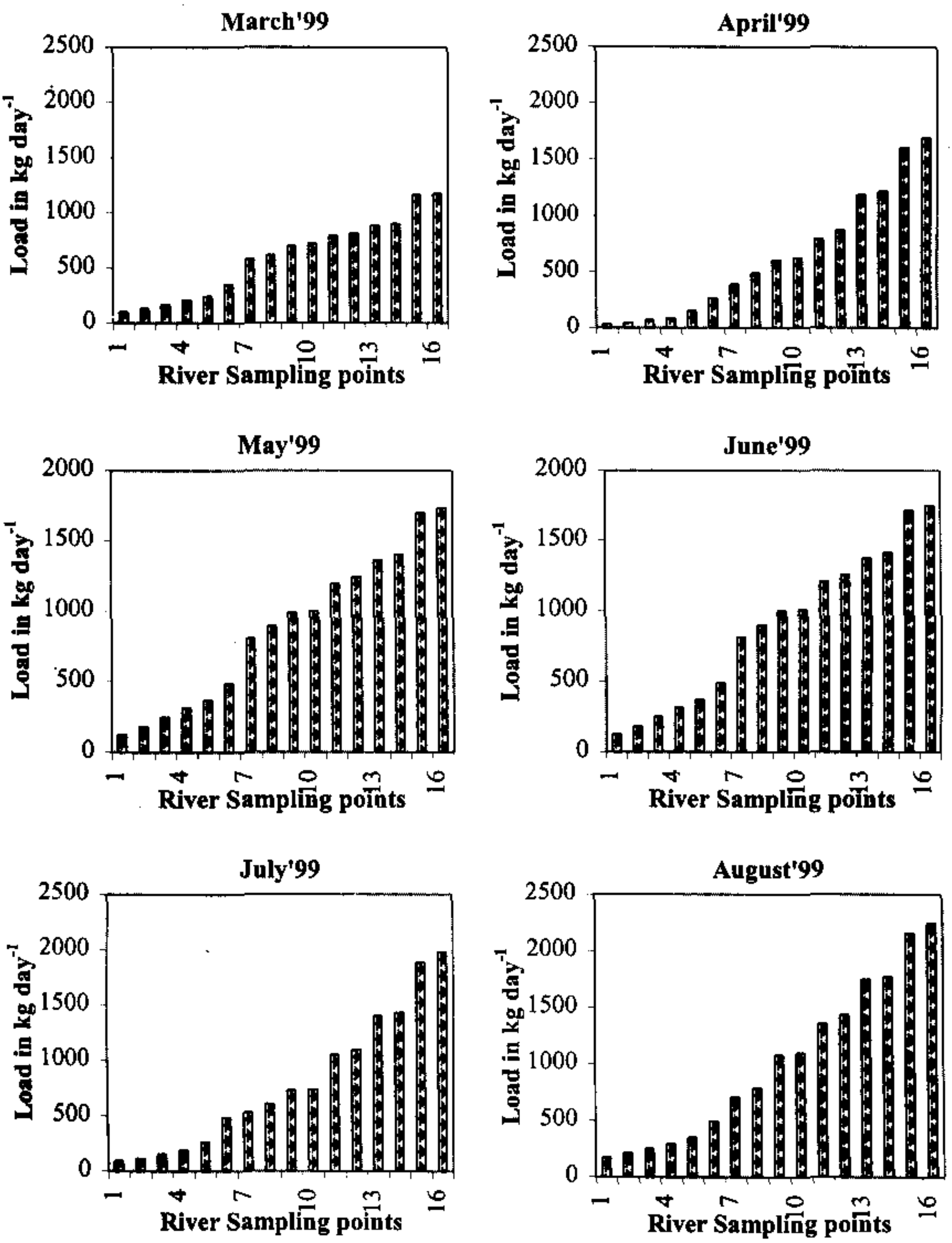

Fig. 11(a): Nitrate (NO_3) load for one annual cycle
(March-August)

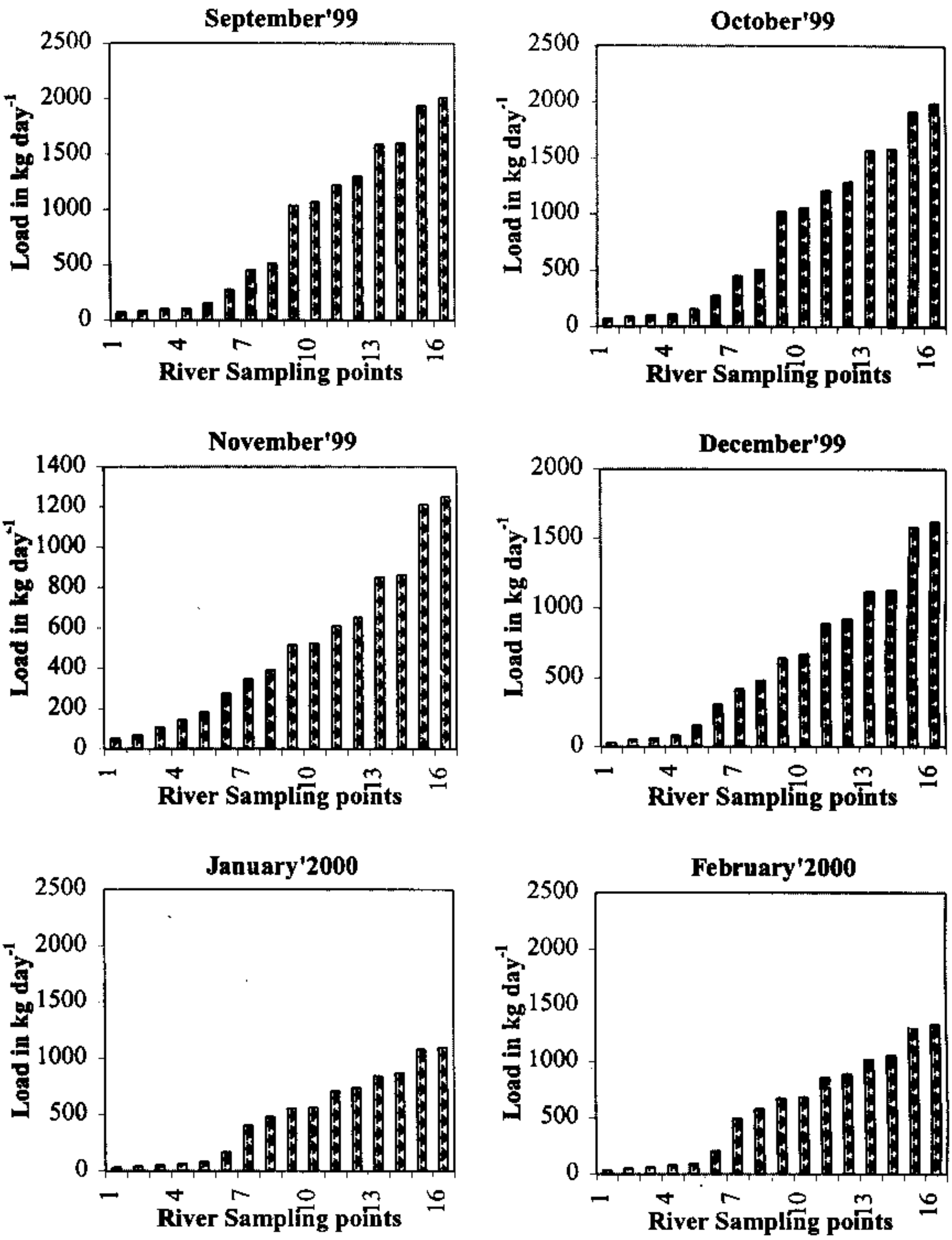

Fig. 11(b): Nitrate (NO_3) load for one annual cycle (September-February)

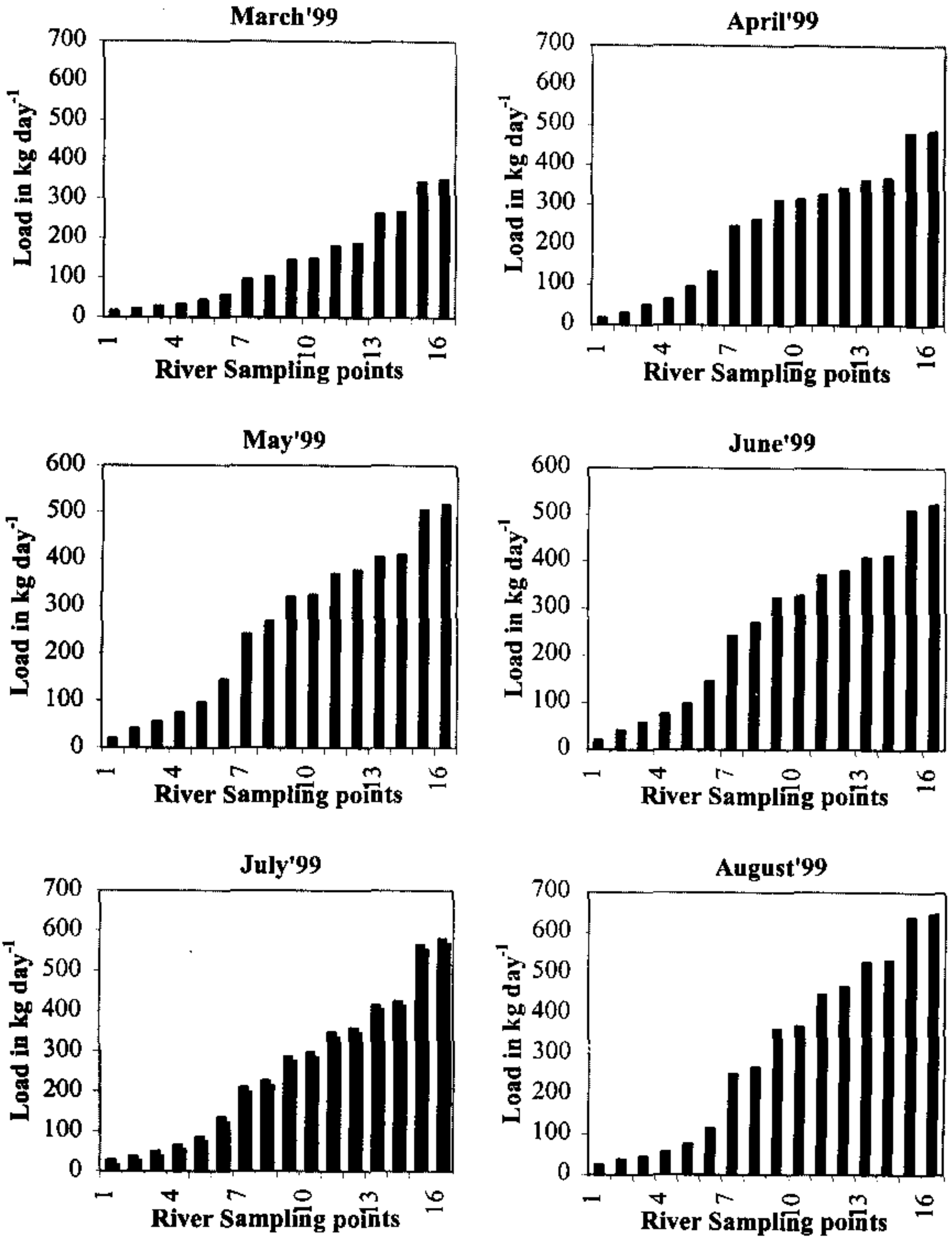

Fig. 12(a): Phosphate (o-PO_4) load for one annual cycle (March-August)

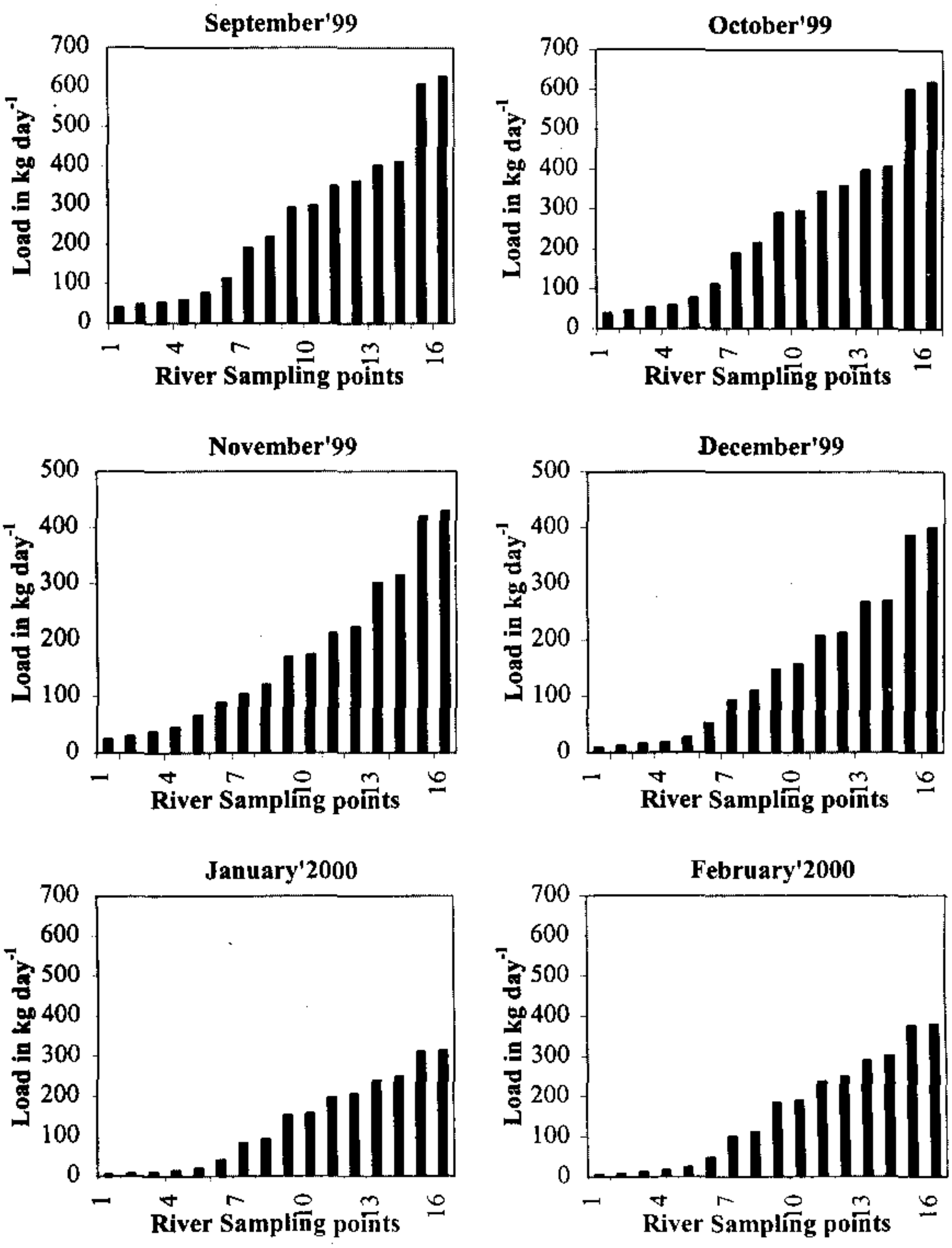

Fig. 12(b): Phosphate (o-PO_4) load for one annual cycle
(September-February)

Table 2: NPS loads of computed by different approaches (Steps 1 and 3)							
Reach 1				By Step 1	By Step 1	By Step 3	By Step 3
Month	Discharge	Phosphate	Nitrate	NPSL of o-PO_4	NPSL of NO_3	NPSL of o-PO_4	NPSL of NO_3
March	0.95	0.2	1.2	5.79	33.61	6.62	41.55
April	1.05	0.2	0.37	12.65	11.76	14.41	16.04
May	1.14	0.21	1.25	21.32	58.48	19.3	67.7
June	1.1514	0.21	1.25	21.55	59.11	19.51	68.47
July	1.64	0.2	0.65	11.43	18.69	11.48	29.94
August	3	0.1	0.65	13.46	45.55	12.18	49.29
September	1.85	0.25	0.45	8.78	16.51	12.24	22.8
October	1.8315	0.25	0.45	8.64	16.3	12.05	22.45
November	1.12	0.25	0.55	6.29	14.89	6.7	27.28
December	1.1	0.1	0.31	3	20.16	2.77	15.28
January	0.6	0.1	0.56	2.23	12.49	3.27	13.51
February	0.66	0.11	0.616	2.7	15.11	3.95	16.34
Reach 2				By Step 1	By Step 1	By Step 3	By Step 3
Month	Discharge	Phosphate	Nitrate	NPSL of o-PO_4	NPSL of NO_3	NPSL of o-PO_4	NPSL of NO_3
March	1.15	0.22	1.32	7.29	35.65	5.62	35.31
April	1.3	0.27	0.4	20.38	25.26	19.6	21.82
May	1.5	0.32	1.39	17.19	70.13	21.44	75.22
June	1.515	0.32	1.39	17.4	70.91	21.68	76.08
July	1.85	0.24	0.68	14.5	45.17	15.31	39.92
August	3.7	0.12	0.66	8.33	39.13	8.7	35.21
September	2.15	0.255	0.47	8.07	15.55	6.12	11.4
October	2.1285	0.255	0.47	7.92	15.34	6.02	11.22
November	1.3	0.265	0.6	9.49	40.88	9.31	37.89
December	1.3	0.11	0.44	3.95	12.62	3.46	19.1
January	0.7	0.12	0.68	4.49	12.3	3.27	13.51
February	0.77	0.132	0.748	5.43	14.88	3.95	16.34
Reach 3				By Step 1	By Step 1	By Step 3	By Step 3
Month	Discharge	Phosphate	Nitrate	NPSL of o-PO_4	NPSL of NO_3	NPSL of o-PO_4	NPSL of NO_3
March	1.32	0.251	1.45	6.1	46.29	6.62	41.55
April	1.64	0.35	0.49	16.94	16.49	14.99	16.68
May	1.9	0.35	1.51	19.49	67.55	16.08	56.41
June	1.919	0.35	1.51	19.72	68.29	16.26	57.06
July	2.13	0.275	0.82	17.27	40.28	15.31	39.92
August	4.2	0.125	0.68	13.73	48.92	13.92	56.33
September	2.3	0.27	0.51	7.05	8.34	4.9	9.12
October	2.277	0.27	0.51	6.93	8.22	4.82	8.98
November	1.55	0.285	0.8	8.24	37.86	7.45	30.31
December	1.55	0.12	0.46	2.61	18.76	3.18	17.57
January	0.8	0.165	0.76	2.93	13.23	2.94	12.16
February	0.88	0.1815	0.836	3.55	16	3.56	14.71

sampling points 1 and 4 of River Kali are considered to be entry and exit points for the stream flow in a cell. The results are shown in Table 2.

Step 3: The C_{np} obtained between sampling point 1 to sampling point 4 using Step (2) has been utilized to generate the non-point load of pollutants at reach 1, reach 2, and reach 3 using the equation (2). The results are shown in Table 2.

Step4: The non-point source load obtained for reach 1, reach 2 and reach 3 using step (1) and step (3) have been compared. It can be seen from the Figures 13 and 14 that the non-point source pollutant loads obtained using step 1 and step 3 mark very close agreement. Therefore, the C_{np} obtained for the total length of river reach can be used to compute the non-point load of any smaller sub-reach lying within the total river reach length.

The error criteria obtained using equation (14) and (15) were applied to further test the model for different sets of data.

After testing the validity of equation (13), these equations were utilized to estimate NPSL and C_{np} of all the reaches of River Kali. A comparison between the results obtained using developed generalized model in the present work and existing models have been accomplished. The result obtained using these equations has been compared with the results obtained using equation (13)(Figures 13 and 14). It can be seen from the Figure 13 that the NPSL computed using existing equations and modified equations indicate difference.

4.2 NPSL in Relation to Basin Characteristics

The quantum of non-point source pollutants in a stream varies with the land use of the contributing area and the chemicals applied in the irrigated field. During monsoon period, due to intensive rainfall, the chemicals applied in the cropland are transported with runoff. Several researchers have estimated export coefficients and used different equations to compute the contribution of different water quality constituents from the watershed (Young et al., 1986; Warwich, 1997; Leon et al., 2001). However, during non-

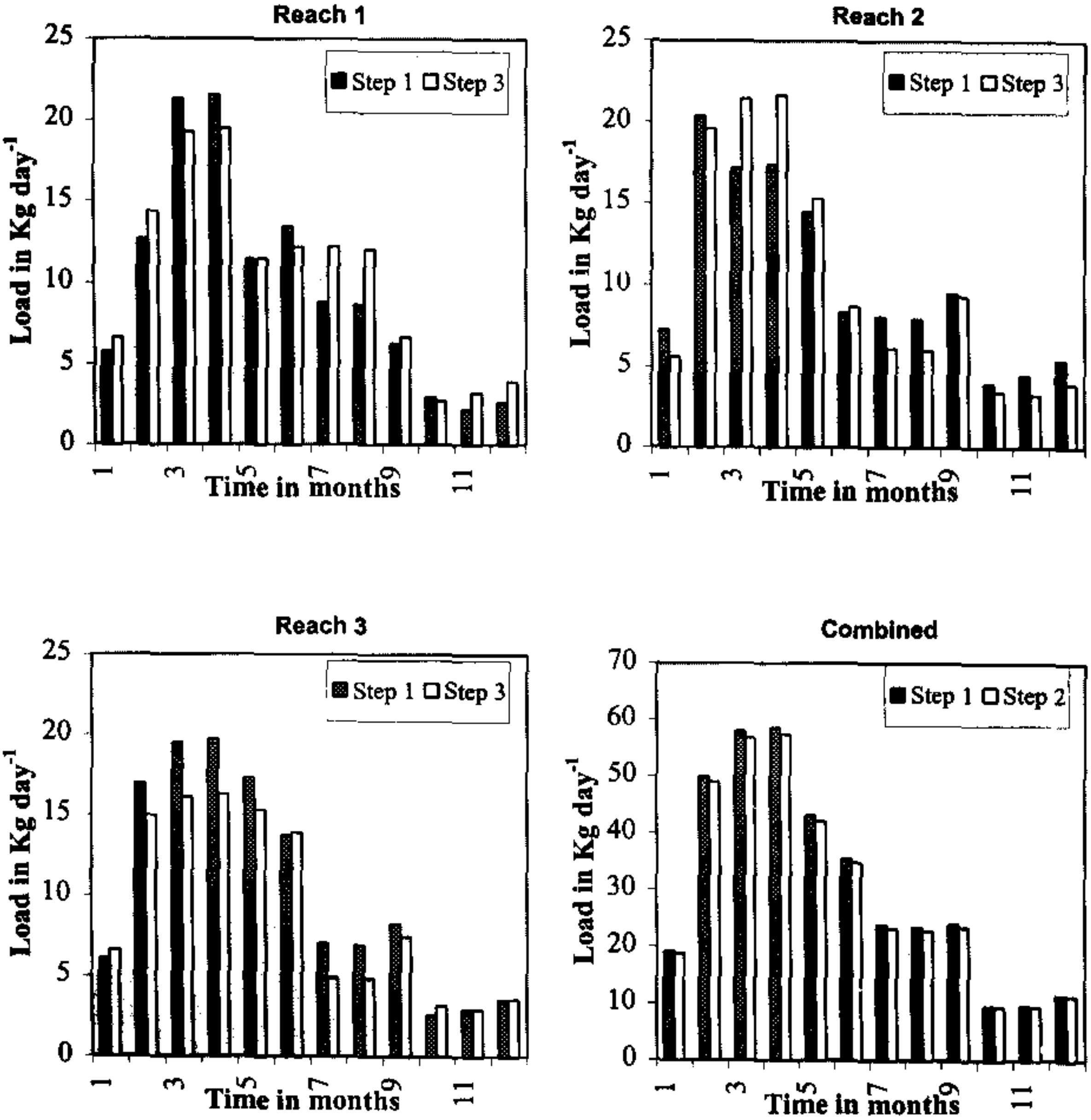

Fig.13: Model Validation for o-PO_4 in different reaches of River Kali

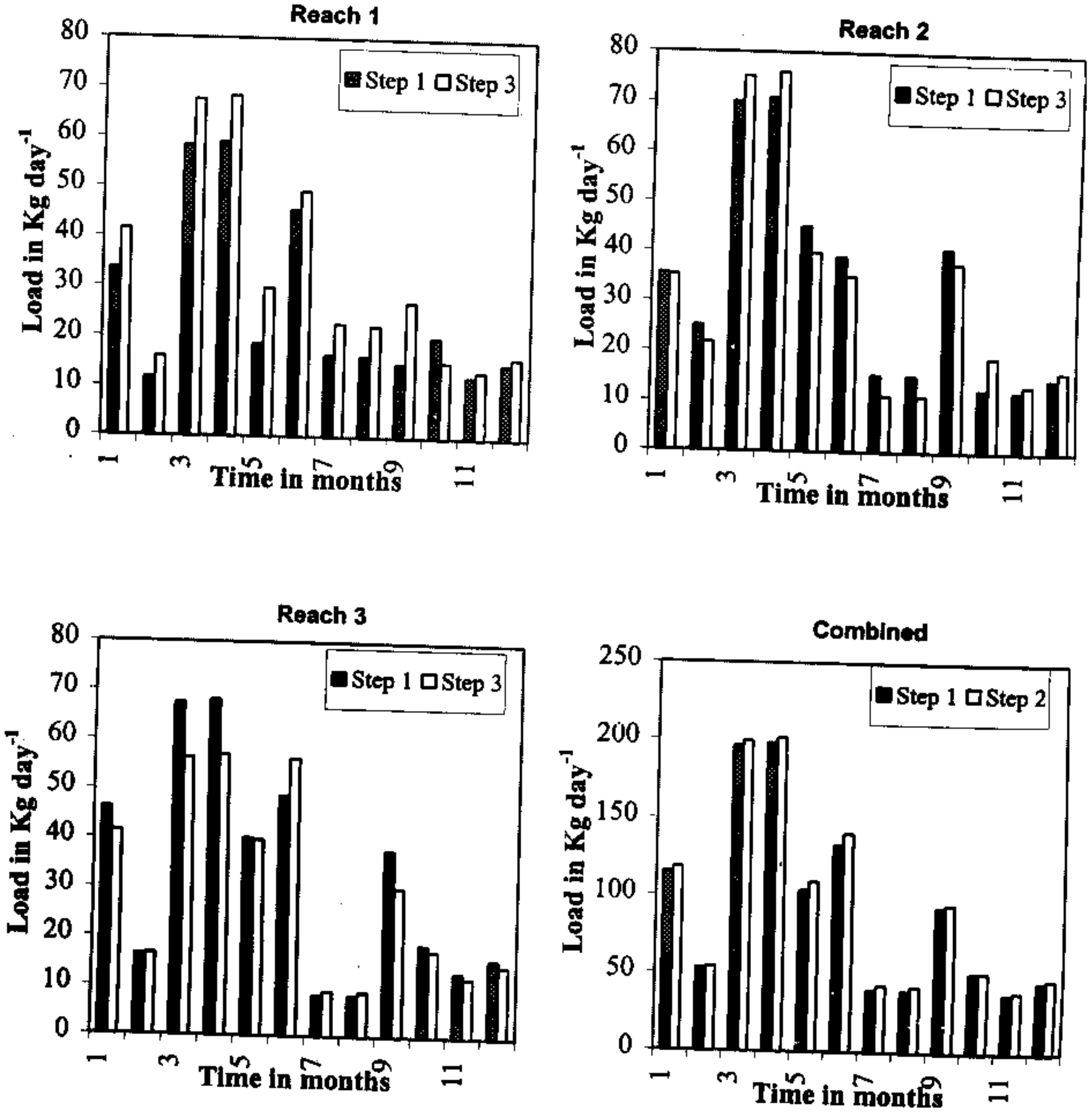

Fig.14: Model Validation for NO_3 in different reaches of River Kali

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.

In the present work, attempts have been made to explore the possibility of any correlation between basin characteristics and non-point source loads within a river reach. Remote sensing and GIS techniques have been used for the analysis. To verify the results obtained using remote sensing data, ground truth verification has been done. The statistical data pertaining to different crops and fertilizer applications were also collected from State Govt. offices. Field survey has been done on monthly basis and farmers interaction have been continued to evaluate the results obtained using satellite data. It is interesting to look that the ortho-phosphate (o-PO_4) and Nitrate (NO_3) load due to non-point sources are increasing with increase in sub-basin area and reach length. The regression equations developed are shown in Figure 15.

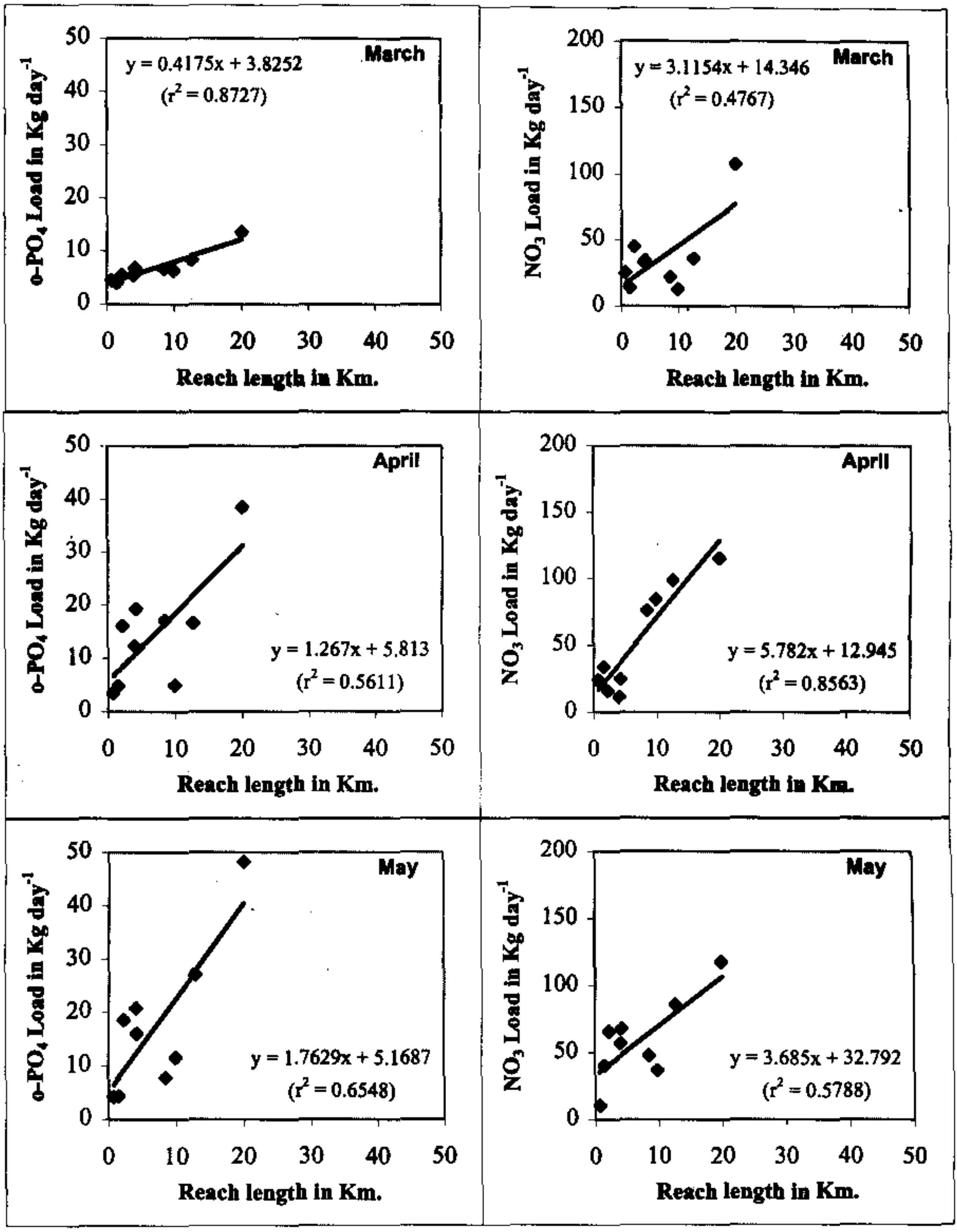

Fig.15(a): Non-point loads in relation to reach length

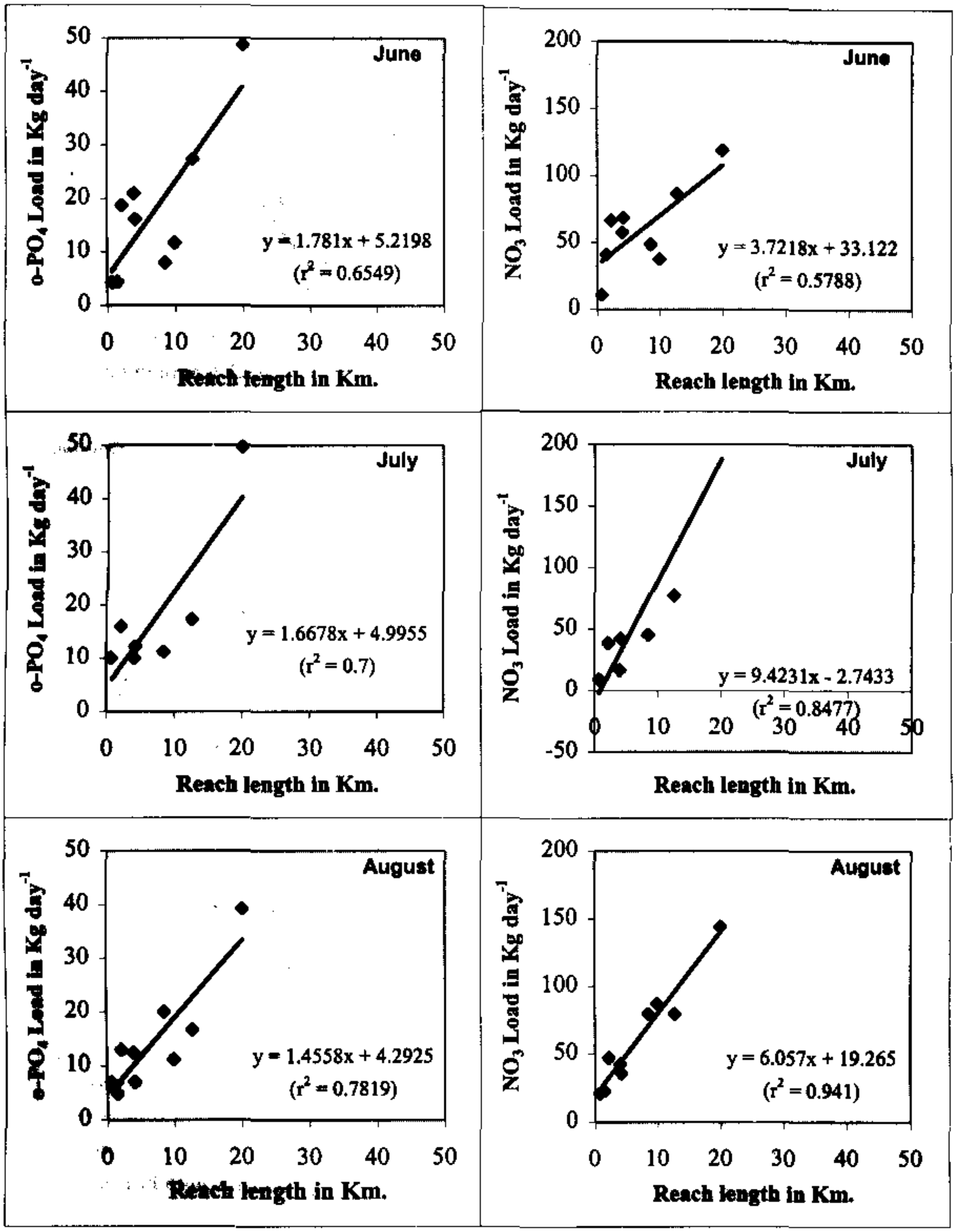

Fig.15(b): Non-point loads in relation to reach length

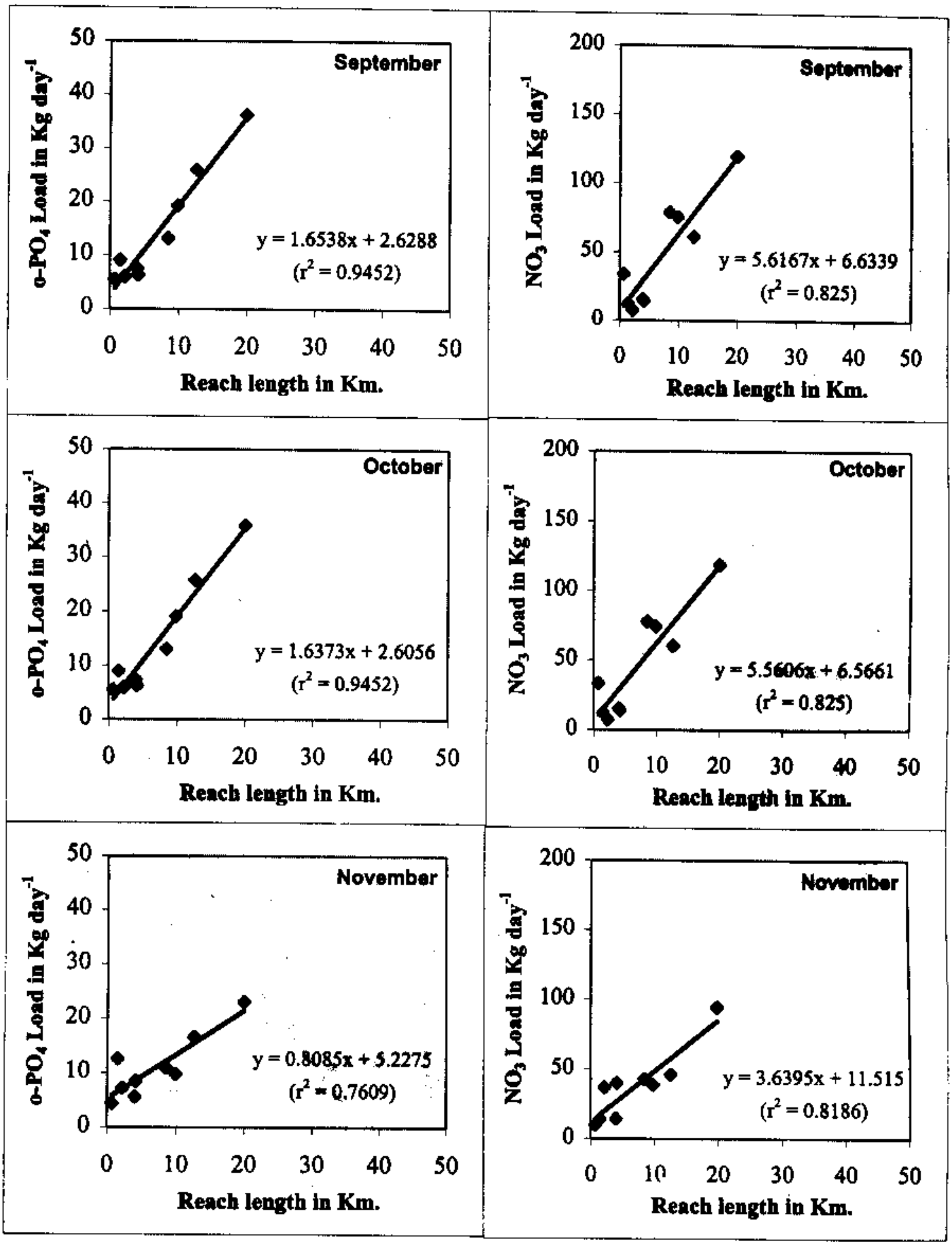

Fig.15(c): Non-point loads in relation to reach length

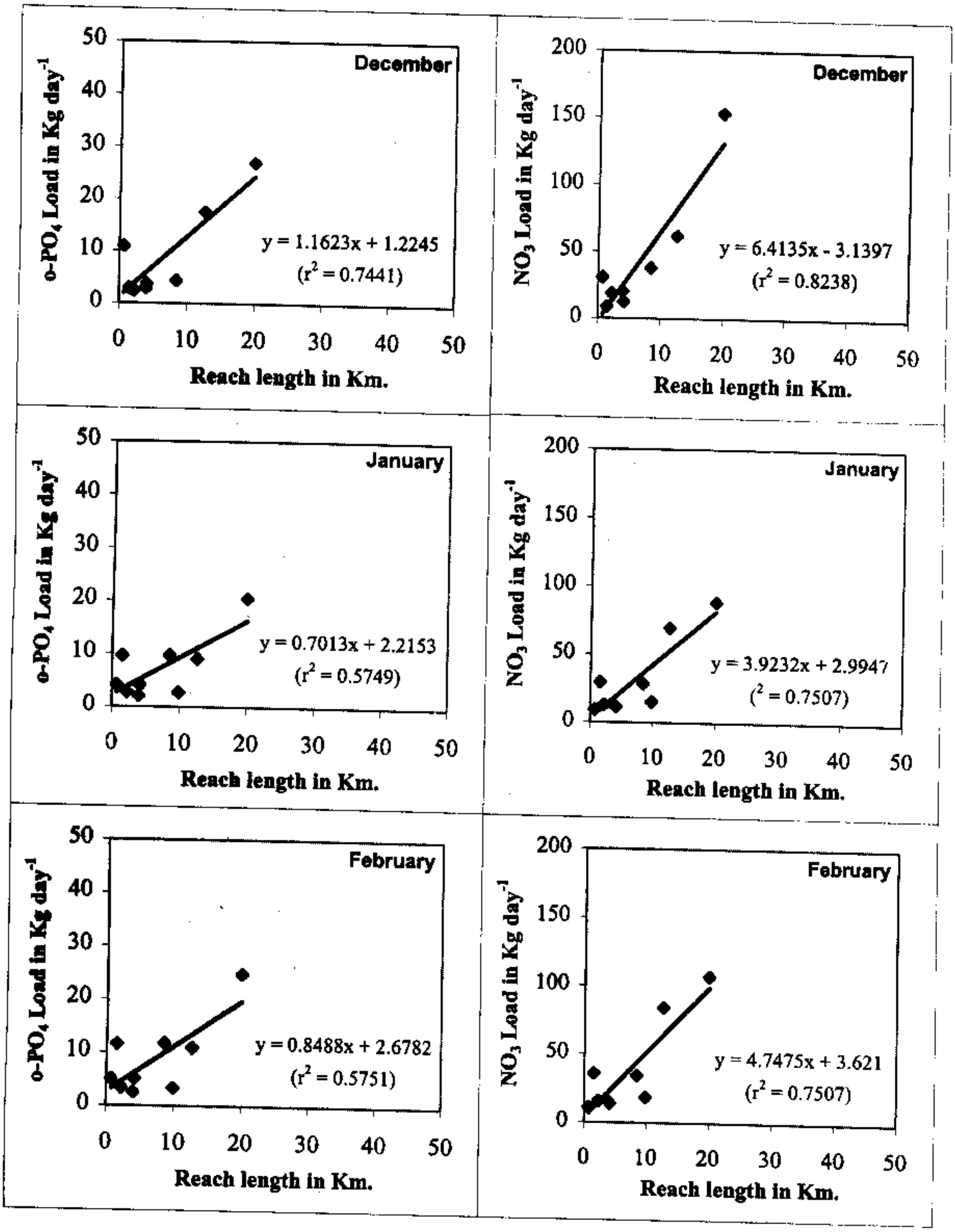

Fig.15(d): Non-point loads in relation to reach length

Chapter 5
CONCLUSIONS

The following conclusions have been drawn:

1. Inconsistencies in the mass balance equation related to estimation of non-point load have been identified from the literature review. Considering that non-point pollutants may also go under a process of attenuation due to a variety of mechanisms including settling, disintegration / decay due to reaction, a modification to the mass balance equation is proposed. The practice of concentrating the non-point load at the upstream of any computational reach may not lead to the better description of the distribution of non-point load within the stream reach. Rather, the non-point load under the assumption of uniform distribution along the stream reach is found to perform consistently better. This hypothesis has been utilized to arrive at a general equation for computing non-point concentration at different sections. Using this modified mass balance equation concentration of certain non-point indicators is interpolated within a stream reach. A comparison of such values with the corresponding observed values has indicated the need and utility of the modifications of the mass balance equation.
2. Non-point loads have been often related to basin characteristics, incident rainfall, applied fertilizer doses and prevailing cropping pattern in the areas. With the help of remote sensing and GIS, a variety of basin characteristics such as land use / land cover, area under different crops, digital elevation model, slope, aspect map showing flow direction have been assessed. In addition, the information pertaining to fertilizer doses were collected through public interaction and the available statistics at concerned authorities. The correlation of non-point load with reach length are investigated to ascertain the relative importance of various parameters. A good correlation is found only between non-point source nutrient load and reach length.

REFERENCES

1. Ambrose, R. B., Wool, T. a., Martin, J. L., Collolly, J. P., and Schanz, R. W.. (1991). WASP5X: A hydrodynamic and water quality model- Model theory, user's manual and programmer's guide. U. S. Environmental Protection Agency, Athens, Ga.
2. APHA. (1985). Standard methods for the examination of water and wastewater (sixteenth edn.). American Public Health Association, Washington DC, 1268 pp.
3. Elder, J.F., 1985. Nitrogen and phosphorus speciation and flux in a large Florida river wetland system. Wat. Resour. Res., Vol. 21, no. 5; pp. 724-732.
4. Ghosh, N. C. and McBean, E. A. (1998). Water quality modelling of the Kali River, India. Water, Air, and Soil Pollution. Vol 102, pp. 91-103.
5. Hagebro, C., Bangs, S., and Somer, E., (1983). Nitrate load/discharge relationships and nitrate load trends in Danish rivers. In dissolved loads in rivers and surface water quality/ quantity relationships. Webb BW (ed.) IAHS: Wallingford, New York, 377-386.
6. Hoare, R.A., (1982). Nitrogen and Phosphorus in the Ngongotaha Stream. New Zealand Journal of Marine and Freshwater Research, Vol.16, pp. 339-349.
7. Jain, C.K. (1996). Application of chemical mass balance to upstream/downstream river monitoring data. J. Hydrol., Vol. 182, pp. 105-115.
8. Jain, C.K., Bhatia, K.K.S., Seth, S.M. (1998). Assessment of point and non-point sources of pollution using a chemical mass balance approach. Hydrol. Sci. J., Vol. 43, no.3, pp. 379-390.
9. Jain, C.K. and Sharma, M.K. (2000). Estimation of nutrients loading from a mountainous watershed. NIH Report.
10. Jha, R., Ojha, C.S.P., Bhatia, K.K.S. (2001). Refinement of predictive reaeration equations for a typical Indian River. Hydrol. Process.Vol 15, no.6. p 1047-1060.

11. Killorn, R. (1990). *Trends in Soil Test P and K in Iowa,* Paper Presented at the 20th North Central Extension-Industry Soil Fertility Workshop, 14-15 November, Bridgeton, MO.
12. Leon, L. F., Soulis, E. D., Kouwen, N. and Farquhar, G. J. (2001). Non-point source pollution: A distributed water quality modelling approach. Wat. Res., Vol. 35, no. 4, pp. 997-1007.
13. Moore, I.D., Gallant, J.C. and Guerra, L. (1993). Modelling the spatial variability of hydrological processes using GIS in: HydroGIS 93: Application of Geographic Information system in Hydrology and water resources Management. Proceedings of Vienna Conference, IAHS publ No. 211, pp 161-169.
14. Munn, N., and Prepas, E. (1986). Seasonal dynamics of phosphorus partitioning and export in two streams in Alberta, Canada. Canadian Journal of Aquatic Science, Vol. 43, pp. 2464-2471.
15. Novais, R., and Kamprath, E.J. (1978). Phosphorus Supplying Capacities of Previously Heavily Fertilized Soils. Soil Science Society of America Journal, Vol. 42, pp.931-935.
16. Novotny, V., Olem, H. (1994). Water quality: prevention, identification and management of diffuse pollution. Van Nostrand-Reinhold, New York.
17. Oborne, A.C., Brooker, M.P., Edwards, R.W. (1980). The chemistry of the River Wye. J. Hydrol., Vol. 45, pp.233-252.
18. Plummer, I.N., Back, W. (1980). The mass balance approach: application to interpreting the chemical evolution of hydrologic systems. Am. .J. Sci., Vol. 280, pp. 130-142.
19. Thomann, R.V. and Mueller, J.A. (1987). " Principles of surface water quality modelling and control." Harper and Row Publisher, New York.
20. USEPA (1989a). U.S. Environmental Protection Agency. National Primary and Secondary Drinking Water Standards; Proposed Rule. 40 CFR Parts 141, 142, and 143.
21. Verma, S.R., Dalela, R.C., Tyagi, M.P., Gupta, S.P. (1974). Studies on the characteristics and disposal problems of the industrial effluents with reference to ISI standards: Part I. Ind.J. Env. Hlth., Vol. 16, pp. 289-299.

Young, R. A., Onstad, C. A., Bosch, D. D. and Anderson, W. P.. (1986). AGNPS Agricultural non-point source pollution model : A large watershed analysis tool. USDA, ARS Conserv. Res. Report. No. 35. Springfield, VA.

Yuretich, R.F., Batchelder, G.L. (1988). Hydro-geochemical cycling and chemical denudation in the Fort River water shed, Central Massachusetts: an approach of mass balance studies. Wat. Resour. Res., Vol. 24, no. 1, pp. 105-114.

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