CS/AR-9/2000-2001

STATISTICAL ANALYSIS OF WATER QUALITY DATA OF RIVER YAMUNA

NATIONAL INSTITUTE OF HYDROLOGY
JALVIGYAN BHAWAN
ROORKEE - 247 667 (UTTARANCHAL)

2000-2001

PREFACE

The increasing use of water to meet the domestic, industrial, agricultural and other needs obviously affect the quality of water. Rapid increase in the population, particularly in the metropolitan areas coupled with location of industrial and chemical plants in and around river lead to increased pollutants entering the river system. Simultaneously the increase in the utilization of water resources for beneficial purposes results in substantial reduction in water availability in the lower reaches, particularly in the lean period.

The maintainance of quality of river hinges around the understanding of the magnitude of potential pollutants that could travel and reach the river to threaten the aquatic eco-system. Assimilation capacity of river is limited. A pollutant sinking at a river reach, may not be resting place, but it could prove potential source for another stretch and another pollutant.

Evaluation of fitness of water for various uses requires monitoring of water quality at various locations of the rivers. The CWC have a strong network of Water Quality Monitoring stations maintained by CWC at the strategic points on all the important rivers of India. The present report brings out the work done by the CWC on the water quality survey in the Yamuna System for the period of 6 years (1990-1996) projecting the overall status (spatial and temporal) of the water quality for the Yamuna system. The data have been reproduced showing the longitudinal and spatial variation of water quality variables, its basic statistics, cross-correlation of different water quality variables and statistical modelling.

The report entitled "Statistical analysis of water quality data of River Yamuna" has been prepared by Dr. Ramakar Jha, Scientist 'C', Dr. C.K.Jain, Scientist 'E' & Head, and Dr. K.K.S.Bhatia, Scientist 'F' & Technical Co-ordinator, of the Environmental Hydrology Division. The data provided by the CWC, New Delhi are duly acknowledged.

(K.S.Ramasastri)
Director

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

The determination of water quality parameters in a river is very important for overall water quality management. The water quality variations in a river may be modelled by the deterministic approach or by the stochastic approach. The former approach has been used for predicting the steady state water quality conditions along a river and to predict the short-term transient state of a water quality parameter. The later approach, which is used in this study, enables the identification of trends and periodic phenomena present in natural data series, their decomposition and subsequent synthesis for data generation and forecasting. In the stochastic approach, it is necessary to probe some of the characteristics viz., non-normal distributions, seasonality, missing values, values below the limit of detection, external interventions and serial correlation, which complicate the analysis of water quality time series along the river.

In the present work, data of twenty-two important water quality variables obtained from sixteen sampling stations of River Yamuna in India have been utilized for trend analysis, cross-correlation, statistical estimations and ARIMA modelling. Monthly data for the period from June 1990 to May 1995 have been utilized for the analysis. Multiplicative auto regressive integrated moving average (ARIMA) model has been fitted to the time series of water quality data. The developed ARIMA model $(1,0,1)*(0,1,0)_{12}$ has been used for forecasting water quality for the year 1996 and the results obtained for different water quality variables have been compared with the observed values. The results obtained are satisfactory and stress the need for future applications.

Chapter 1
INTRODUCTION

The water quality condition of watercourses is a subject of ongoing concern. During the last few decade there has been increasing demands for monitoring water quality of many rivers by regular measurements of various water quality variables (Wolman, 1971; Steel et al., 1974; Lettenmaier, 1977; Liebetrau, 1979). Several qualitative as well as quantitative aspects have been considered in the analysis of the resulting series. Consequently, various statistical methods have been designed for trend analysis (Hirsch et al., 1982; McLeod et al., 1983; Hirsch and Slack, 1984; Fox et al., 1991; Zetterqvist, 1991; Mattikalli, 1996). These methods range from descriptive and exploratory studies of tendencies to confirmatory trend analysis, where the subject of analysis is to estimate trends or to perform significance tests for presence of trends.

For water quality modelling and management, the following types of questions about dynamic nature of water quality nee to be addressed as:

- What is the general water quality at a given site?
- Is the water quality improving or getting worse?
- How do certain variables relate to one another at given sites?
- What are the mass loads of materials moving in and out of water systems?
- What are the sources of pollutants and what is their magnitude?
- Can water quality be predicted from past water quality?

When these and other questions are re-stated in the form of hypotheses then inductive statistics, such as detecting significant differences, correlation and regressions can be used to provide the answers. Several statistical methods, for example, intervention analysis, regression models and transfer function noise model have been used in literature in order to relate water quality variables and other variables (Hipel, 1985; Hipel and McLeod, 1989).

Statistical methods used in trend analysis should be sufficiently flexible to meet various needs in practice. They should; (i) satisfactorily model relationships between water quality variable and casual variables, (ii) enable an assessment of trends, either exploratory of confirmatory, (iii) take seasonal variation of water quality variables into account, (iv) take auto-correlation of series, (v) be robust for outliers, (vi) be able to handle missing observations.

India has a large network of river systems, which serve as the major source of water supply and carry the wastewater of cities situated along the river systems. In India, the water quality of rivers have also been monitored and statistical analysis has been accomplished (ADSORBS/2/1981-1982;ADSORBS/7/1982-83; MINARS/1/198687, MINARS/6/1990-91). For effective management of water quality in these rivers, the Central Pollution Control Board (CPCB) has classified surface water into 5 categories from A to E on the basis of their designated best use. The classification is made in respect of eight basic water quality parameters. The CPCB has created an inventory of water pollution of Yamuna sub-basin, developed possible relationship between human activities and different aspects relating to water quality in the Ganges basin and conducted combined study for the status and trend of water quality of rivers Godavari, Pariyar, Cauveri etc.

The river Yamuna, which is an important tributary of River Ganges, is one of the most important rivers in India and supports the life of millions of people. The river receives domestic effluents without prior treatment from the towns situated on both the sides of River Yamuna. In view of the above, there is a need for accurate and reliable estimate of river water quality for effective management of river basin and taking adequate measures to keep River Yamuna either free from pollution or to keep the concentration of various pollutants of water within the permissible limits.

In the present work stochastic approach has been applied to estimate water quality parameters as a function of time. The stochastic approach involves the identification of the trend, basic statistics, interventions in the data series by different approaches, cross-correlation between water quality variables at different stations and analysis by considering the seasonal behaviour along with non-seasonal behaviour of the data using Auto Regressive Integrated Moving Average (ARIMA) model. The identification of the model is based mainly on two statistical parameters, the auto-correlation function (ACF) and the partial auto-correlation function (PACF). Multiplicative auto regressive integrated moving average (ARIMA) model $(1,0,1)*(0,1,0)_{12}$ has been fitted to the time series of water quality data for the years 1990-1995. The developed model has been used for forecasting for the year 1996 and the results obtained for different water quality variables have been compared with the observed values.

Chapter 2
THE STUDY AREA

2.1 Physiography

The Yamuna is the largest tributary of Ganga and its catchment area comprises about 42% of the Ganga basin area in the Indian Territory. Total catchment area of Yamuna in 3,66,223 sq.km. Its drainage area comprises parts of the States of Himanchal Pradesh, Uttaranchal, Haryana, Rajasthan, Madhya Pradesh, Uttar Pradesh, and entire Union Territory of Delhi (Figure 1). Of the total catchment, about 3% come under hilly area and the remaining is almost equally distributed between plains and plateau regions.

The river Yamuna originates from the Yamunotri glacier near Bandarpunch at an elevation of about 6320 metres above mean sea level in the Tehri Garhwal district of Uttaranchal. The Tons, the largest Himalayan tributary, joins the Yamuna below Kalsi on the south- west fringe of the Musnoorie range. The combined stream of Yamuna and the Tons after the confluence forces its way through the Shivalik range of hills before entering the plains of U.P. in the Saharanpur district. Near Bidauli in the Muzaffarnagar district, it meanders to South for a distance of about 130 km. to reach Delhi. Before its confluence with the river Ganga at Allahabad, many tributaries join the Yamuna namely the Hindon, the Karon, the Sangar and the Rind on its left bank while the Chambal, the Sind, the Betwa and the Ken join on its right bank. The flow chart of the River Yamuna and its tributaries are shown in Figure 2.

The total length of Yamuna from its source at Yamunotri to its confluence with the Ganga at Allahabad is about 1376 km.. Historically important places like Delhi and Agra and holy places like Mathura and Allahabad are situated on its banks.

The ground level of the basin varies from about 6320 m. above MSL near the Yamunotri glacier to around 100 m above MSL near the confluence of the Yamuna with the Ganga at Allahabad.

2.2 Climatic features

In the northern region of the basin the Himalayas dominantly influence the climate. Regions situated near Himalayan ranges have a moderate climate. In the plains, the climate varies from intense heat in summer to intense cold in winter. The maximum summer temperature in the plains is occasionally touches freezing point.

The Yamuna catchment experiences major precipitation through the monsoon months of June to October. The normal date of onset of monsoon varies from 15th June for lower reaches near outfall point at Allahabad to 15th July for upper reaches around Paonta of Himachal Pradesh. The south- west monsoon generally withdraws over a period of one month between 1st September and 1st October. The annual rainfall is

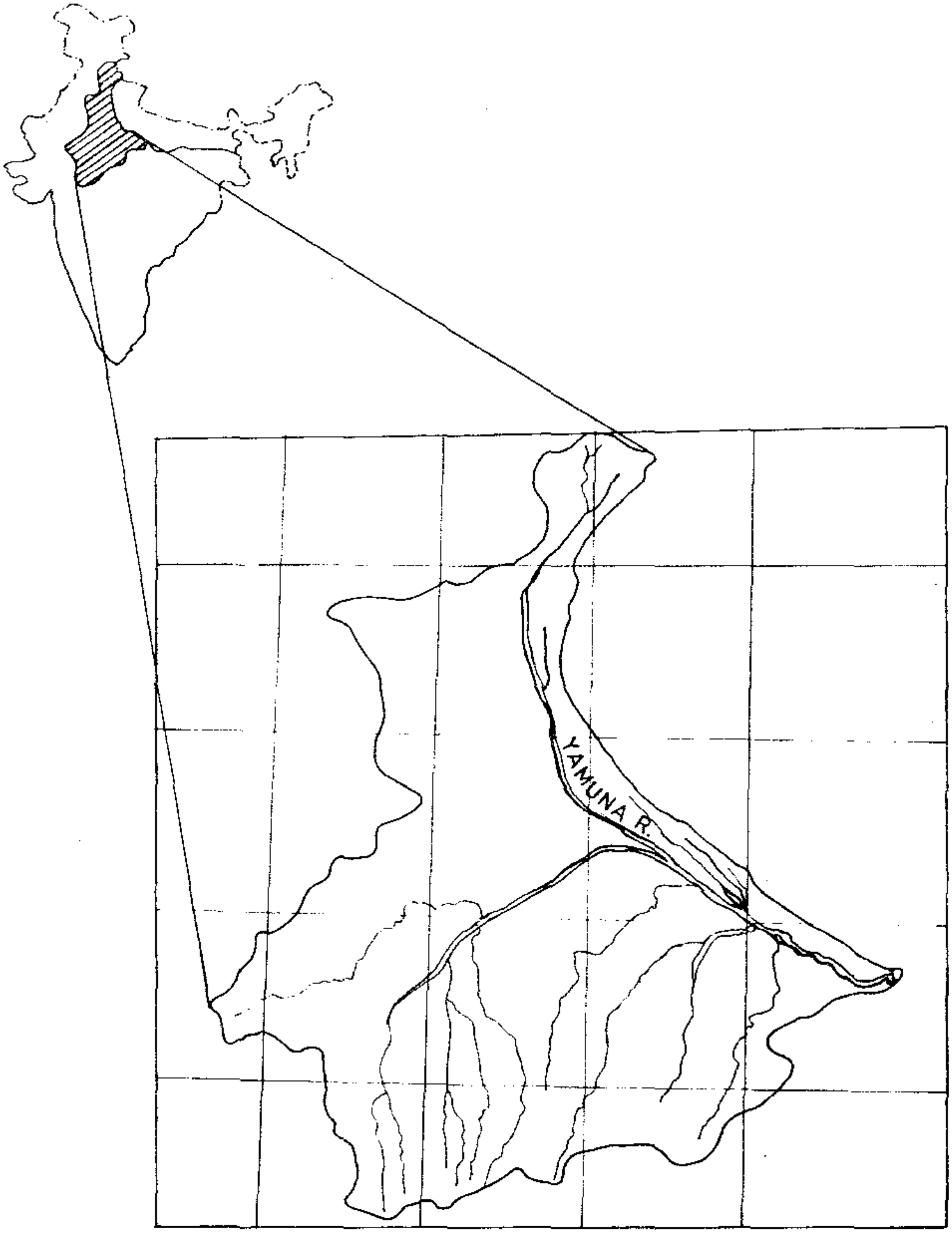


Fig. 1: Index map of Yamuna River System

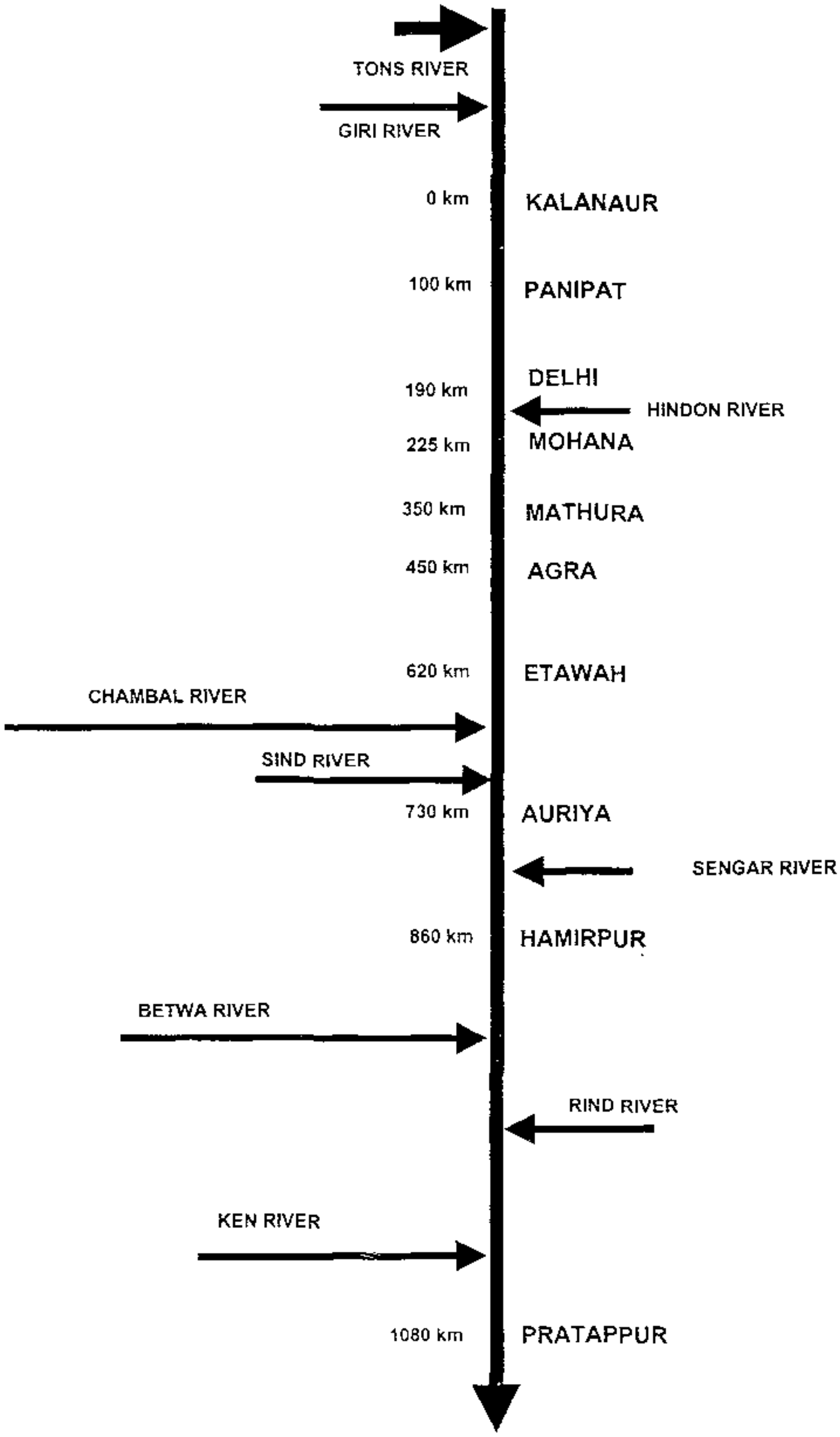


Fig.2: Flow Chart of Yamuna River System

minimum in the western parts of the basin and it increases gradually towards the East and more steeply towards the south-east.

2.3 Human activity

The extent of human and economic activities in any area is indicated in a way by the existing land use pattern. From the point of view of economical use, land may be broadly, classified into two types, namely, arable and non-arable. Arable land covers both cultivable and forests land. Cultivable land in Yamuna basin in about 60% of the total area, while the forest cover in about 12.5% leaving the non-arable land to about 27.5% which in essentially steep and rocky. The mining activities for lime stone, building stone, various mineral ores etc. are generally confined within non-arable land. Land for habitation, transport and other amenities and economic activities account for about three percent. The land use pattern at a glance in terms of basin areas in different constituent States in shown in Table 1. In the Yamuna basin developmental activities vary in nature and degree from place to place because of various factors such as availability of resources, infra-structural facilities etc.

2.4 Agriculture

Modern scientific agricultural practices involving application of chemical fertilisers, pesticides and insecticides are extensively developed in the Yamuna basin. The main support of economy in the Chambel sub-basin in agriculture. In the upper reaches of Chambal there are forests which occupy only 8.8% of the Chambal sub-basin area whereas out of the total cultivable area of 10.4 million hectares nearly 7.24 million hectares is cultivated annually. However, the full irrigation development in the Chambal sub-basin in yet to be achieved. Barring Himachal Pradesh, the Southern districts of U.P. and parts of M.P. and the Chambal, the Yamuna basin lies in the Gangetic plain with about 75% of the total area as culturable. out of 16.78% million hectares, more than 13 million hectares is cultivated. on an average, 23.4% of the total cropped area has irrigation facilities.

2.5 Industries

Industrially the Chambal Sub-basin is less developed. However, after implementation of the Chambal Project and the atomic power plant at Ranapratap Sagar, a number of industries on agriculture, textiles etc. have come up at Kota, Jaipur, Bhilwara etc. in Rajasthan and at Indore, Ujj4in, Ratlam etc. in M.P. In the rest of the Yamuna basin a number of industrial complexes have come up due to availability of power and the other infra-structural facilities like communication network, water, raw materials etc. Important industries in the Yamuna basin include fruit processing, breweries and distilleries in the hilly tract, sugar mills and distilleries in Saharanpur district, bicycle and textile industries around Panipat and Sonepat, automobile manufacture, chemicals, drugs, electronics, thermal power station and food processing industries around Delhi, Faridabad and Gurgaon. Lower down, there are heavy industries like oil refinery at Mathura, foundries and hard chemicals at Agra, glass factories around Dholpur and Ferozabad. In the Chambal sub-basin, the atomic power station at Rota, marble and textile industries at Jaipur and a cluster of medium scale industries around Indore are worth mentioning.

2.6 Flow diversion

Before emerging from the hills to the plains, waters of Yamuna are diverted for irrigation at the Tajewala headwork through two important canals namely, the Western Yamuna and Eastern Yamuna canals. The Agra canal takes off water from the river at Delhi from the Okhla head-works to irrigate areas in U.P. The Gurgaon canal which drawn water from Agra canals irrigates lands in Haryana and Rajasthan. The potential for irrigation by simple diversion in the Yamuna sub-basin exists only in some northern and North- Eastern districts of U.P. and Haryana.

Table 1: Land use pattern in the Yamuna Catchment in different States

State	Area (as % of total catchment	Non-arable land (%)	Forest land	Cultivable land (%)	Land actually sown %	Land under habitatio-nal use
Himachal Pradesh	1.2	25	59.4	15.6	14.2	1.5
Harayana	8.6	18.1	2.4	79.5	59.9	3.6
U.T.of Delhi	0.4	51	1.0	48.0	46.5	43.7
Uttar Pradesh	20.5	14.5	7.4	78.1	65.3	4.8
Rajasthan	31.0	40.8	8.8	50.4	43.9	2.2
Madhya Pradesh	38.3	26.0	18.0	56.0	50.7	1.8
Total Yamuna catchment	100	27.5	12.5	60.0	51.9	2.9

Chapter 3
METHODOLOGY

To achieve the objectives of the present study, a number of stochastic approaches have been proposed which can be applied for water quality modelling and forecasting. The methodology includes general procedure, steps required for analysis of data and fitting of a specific model to a data set. The theoretical basis underlying these approaches has been presented. The methodology has broadly been discussed under the following heads:

1) Pretreatment of the historical data
2) Intervention model
3) Cross-correlation analysis
3) Autoregressive integrated moving average (ARIMA) model
4) Diagnostic Checks

3.1 Pretreatment of Data

The time series modelling approach is based on the premise that the data belong to stationary process and also to a normal population. Otherwise the assumption that the associated residuals of the model have the property of the Gaussian distribution may not hold good. The water quality data in general, violates the assumption of normal distribution (Ward and Loftis, 1986; Makridakis and Wheelright, 1983). The data, therefore, needs transformation to make the series normal or close to normal. This can be achieved if the coefficient of skewness (g), given by the following equation, is nearly equal to zero.

$$g = \frac{\frac{1}{N}\sum_{t=1}^{N}\left(Y_t - \bar{Y}\right)^2}{\sigma^3} \qquad (1)$$

in which σ is given by

$$\sigma^2 = \frac{1}{N}\sum_{t=1}^{N}\left(Y_t - \bar{Y}\right)^2 \qquad (2)$$

where N is the number of data and Y_t is the data series such that t= 1, 2,……. ,N. $\bar{Y}$ and σ^2 are the mean and sample variance of the series.

3.2 Detection of Intervention

Intervention analysis is a useful tool for modelling time series when the process mean undergoes changes as a result of external perturbation (Box & Tiao, 1975). Both man-induced and natural interventions can be modelled for seasonal and non-seasonal time series of water quality parameters in a number of different areas. For example, when a pollution abatement procedure is implemented, an intervention model can be developed for ascertaining how effective the procedure is for reducing the level of pollutants. For detecting the possible intervention in water quality time series the exploratory data analysis tool such as time series plots, Box-and-Whisker plots (annual) and the cumulative sum (cusum) plots technique may be employed. The Cusum is estimated and plotted for each season to study how the seasonal averages changes after the intervention (Lucas, 1985).

Let the data for season i over n years .be denoted by y_{1i} , y_{2i},....., y_{ni} then kth cusum, S_{ki}, for season i is defined as :

$$S_{ki} = S_{k-1,i} + \left(y_{ki} - \bar{y}_{bi}\right) = \sum_{j=1}^{k} y_{ji} - k\bar{y}_{bi} \qquad , \qquad k=1, 2, \ldots\ldots\ldots, n \qquad (3)$$

where $S_{0i} = 0$ and $\bar{y}_{bi}$ is the mean of season i before the intervention.

Before the beginning of the intervention, the cusum values should theoretically fluctuate around a horizontal line. If the cusum follows a constant upward or downward slope, it indicates an intervention.

3.3 Cross-correlation Analysis

The cross-correlation of a water quality variable between different sampling station is essential. Linear and non-linear models have been used earlier to correlate water quality variables of one station with the other station (CBPCWP, 1982; CWC, 1990). In the present work, attempt has been made to develop linear regression equations for each water quality variable and to estimate the coefficient of determination, r^2, for the equation.

3.4 Autoregressive Integrated Moving Average (ARIMA) Model

The data often occur in the form of time series, where the observations with some time lag may be dependent. For such a series of data, the time series analysis may be performed using autoregressive integrated moving average (ARIMA) modelling approach. Using this approach future values can be predicted. A number of models in this family are available. The ARIMA modelling is a three-stage process. The first stage is model identification, then estimation of model parameters, and, finally, diagnostic checking of the estimated model parameters. The process is repeated till adequate model is obtained.

3.4.1 Autocorrelation Structure

The identification of the various possible models is based upon the two functions, the autocorrelation function (ACF) and partial autocorrelation function (PACF). The ACF of the variable y_t provides an idea of linear dependence between observations of a time series which are separated by k time lags. The PACF are like ordinary partial correlations. The PACF show the relationship of points in a series to preceeding points after partialing out the influence of intervening points. The ACF is controlled by moving average (MA) process and the PACF is controlled by autoregressive (AR) process. The ACF and PACF are computed and their correlograms are drawn up to a maximum lag of approximately N/4 with 95% confidence limits.

The autocorrelation coefficient at lag k is given by

$$\rho_K = \frac{\frac{1}{N-K}\sum_{i=1}^{(N-K)}\left(Y_i-\overline{Y}\right)\left(Y_{i+k}-\overline{Y}\right)}{\frac{1}{N}\sum_{i=1}^{N}\left(Y_i-\overline{Y}\right)\left(Y_i-\overline{Y}\right)} \quad (4)$$

The 95 % confidence limits for ρ_k are estimated as

$$\left(-\frac{1}{N-1}+1.96\frac{(N-K-1)^{0.5}}{(N-K)},-\frac{1}{N-1}-1.96\frac{(N-K-1)^{0.5}}{(N-K)}\right) \quad (5)$$

The PACF, $\phi_{k,k}$ may be obtained by means of Durbin's equation given by

$$\phi_{k,k} = \frac{\rho_k - \sum_{j=1}^{k-1}\phi_{j,k-1}\rho_{k-j}}{1-\sum_{j=1}^{k-1}\phi_{j,k-1}\rho_j} \quad (6)$$

and

$$\phi_{j,k} = \phi_{j,k-1} - \phi_{k,k}\phi_{k-j,k-1} \quad (7)$$

For a stationary data series the linear stationary models given in the following section may be identified.

3.4.2 Linear Stationary Models

A stationary and normally distributed stochastic process may be represented by the following models.

3.4.2.1 Autoregressive (AR) model

The autoregressive (AR) model describes how an observation directly depends upon one or more previous measurements plus a white noise term (Vandaele, 1983). This form of a time series model is intuitively appealing and has been widely applied in hydrology. These models are the simplest to use.

Let us consider a stationary time series y_t normally distributed with mean μ and variance σ^2, then

$$Y_t = \phi_1 Y_{t-1} + \phi_2 Y_{t-2} + \ldots\ldots\ldots\ldots\ldots + \phi_p Y_{t-p} + \varepsilon_t \quad (8)$$

is called an autoregressive process of order p, abbreviated as AR (p), ξ_t is the white noise term at time t that is independently distributed with mean 0 and variance σ^2; ϕ_1, ϕ_2, ϕ_p, are first order, second order and p^{th} order AR coefficient.

If B is the backward shift operator such that B (Y_t) = Y_{t-1}, then AR(p) process can be written in terms of backward shift operator as

$$Y_t = (\phi_1 B + \phi_2 B^2 + \ldots\ldots\ldots\ldots + \phi_p B^p)Y_t + \varepsilon_t \quad (9)$$

$$(1 - \phi_1 B + \phi_2 B^2 + \ldots\ldots\ldots\ldots + \phi_p B^p)Y_t = \varepsilon_t \quad (10)$$

Let $\phi(B) = 1 - \phi_1 B + \phi_2 B^2 + \ldots\ldots\ldots\ldots + \phi_p B^p$ where $\phi(B)$ is the autoregressive operator of order p, AR(p) process then becomes

$$\phi(B)Y_t = \varepsilon_t \quad (11)$$

The variance of Y_t (σ^2) and variance of ξ_t (σ_ξ^2) are related by:

$$\sigma_\varepsilon^2 = \sigma^2\left(1 - \sum_{j=1}^{p} \phi_j \rho_j\right) \quad (12)$$

where ϕ_j is the j^{th} autoregressive coefficient and ρ_j is the lag j autocorrelation coefficient of the variable Y_t.

For AR(1) and AR(2) models, Equation 12 may be simplified, respectively, as

$$\sigma_\varepsilon^2 = \sigma^2(1 - \phi_1^2) \quad (13)$$

$$\sigma_\varepsilon^2 = \sigma^2 \frac{(1+\phi_2)}{(1-\phi_2)}\left[(1-\phi_2)^2 - \phi_1^2\right] \quad (14)$$

3.4.2.2 Moving Average (MA) Model

Moving average (MA) models are also of a great importance in representation of time series. These models incorporate past random shocks to represent the time series. Thus moving average model of order q is represented as (Ellis and Grasso):

$$Y_t = \varepsilon_t - \theta_1 \varepsilon_{t-1} - \theta_2 \varepsilon_{t-2} - \ldots\ldots\ldots\ldots - \theta_q \varepsilon_{t-q} \quad (15)$$

$$Y_t = (1 - \theta_1 B - \theta_2 B^2 - \ldots\ldots\ldots\ldots\ldots\ldots - \theta_q B^q)\varepsilon_t \quad (16)$$

where θ_1, θ_2 and θ_q are first order, second order and q^{th} order MA coefficients.

Let $\theta(B) = (1 - \theta_1 B - \theta_2 B^2 - \ldots\ldots\ldots\ldots\ldots\ldots - \theta_q B^q)$, where $\theta(B)$ is nonseasonal MA operator or polynomial of order q. Thus,

$$Y_t = \theta(B)\varepsilon_t \quad (17)$$

The above equation is called a moving average process of order q and is abbreviated as MA(q). The random shocks ξt are assumed normally and independently distributed with mean zero and constant variance.

3.4.2.3 Autoregressive Moving Average (ARMA) Model

It is desirable to represent the statistical structure of a time series with a parsimonious model. Parsimony often can be achieved using a mixed model rather than a pure AR or MA model (Irvine and Eberhardt, 1992). For example, it will be more parsimonious to represent a time series with an ARMA (1,1) model than AR(3) model because relatively fewer model parameters need to be estimated. It is theoretically possible to write ARMA model as pure AR or MA models of infinite order (Salas et al., 1980).

The ARMA(p, q) model can be written in mathematical form as

$$Y_t = \phi_1 Y_{t-1} + \phi_2 Y_{t-2} + \ldots\ldots\ldots\ldots + \phi_p Y_{t-p} + \varepsilon_t - \theta_1 \varepsilon_{t-1} - \theta_2 \varepsilon_{t-2} - \ldots\ldots\ldots\ldots - \theta_q \varepsilon_{t-q} \quad (18)$$

$$\theta(B) Y_t = \theta(B) \varepsilon_t \quad (19)$$

3.4.3 Linear Non-stationary Models

It has been discussed in Section 3.4.2 that AR(p), MA(q) and ARMA (p,q) models can be applied to stationary time series. However, the water quality parameters may not always be stationary, but may have non-stationarity due to trend and seasonality. Therefore, trends and seasonality should be detected and properly removed from the data.

3.4.3.1 Detection of Time Series and Trend

Long term tendencies of water quality are of great importance. By the information of water quality trends, it can be determined whether the quality of water is improving, deteriorating, or remaining stationary under the prevailing conditions. The purpose of this section is to present a general procedure for analysing trends in the water quality time series of rivers.

The process of detecting trends in water quality may be considered as a stepwise procedure. The visual examination of simple graphical methods like Box-and-Whisker plots may reveal sufficient information about the trend. A Box- and-Whisker graph is based upon what is called 5-number summary. The box in the Box-and-Whisker plot refers to the rectangular portion of the graph. The lower edge of the box represents the 25^{th} percentile and the upper end represents the 75^{th} percentile which when taken together, constitute the horizontal line in the middle of box represents the median of the data. The length of the whiskers reflects the spread of the remainder of the data. The error bars denote the 5^{th} and 95^{th} percentile values. The two symbol below the 5^{th} percentile error bar represent 0^{th} and 1^{st} percentile values, The two symbols above the 95^{th} percentile error bar denote the 99th and 100th percentiles. The square symbol in the box denotes the mean of the data.

However, trend can also be estimated by statistical tests and its significance assessed using non-parametric procedure. Kendall (1975) proposed a test for detection of trend in a time series commonly known as "Mann-Kendall test".

Let $Y_1, Y_2, \ldots\ldots\ldots, Y_N$ be a time series of N values. The Mann-Kendall statistic (S) is given by

$$S = \sum_{k=1}^{N-1} \sum_{j=k+1}^{N} \operatorname{sgn}(y_j - y_k) \tag{20}$$

where

$$\operatorname{sgn}(y) = \begin{cases} +1 & y > 0 \\ 0 & y = 0 \\ -1 & y < 0 \end{cases} \tag{21}$$

Mann-Kendall Statistic (S) is asymptotically normally distributed. The mean and variance of S are given, respectively, as

$$E[S] = 0$$

$$Var[S] = \left\{ N(N-1)(2N+5) - \sum_{j=1}^{p} t_j (t_j - 1)(2t_j + 5) \right\} / 18 \tag{22}$$

where p is the number of tied groups in the data set and t_j is the number of data points in the j^{th} tied group.

Kendall's tau (τ) is defined as

$$\tau = \frac{S}{\frac{1}{2} N(N-1)} \tag{23}$$

A positive value of S or τ indicates upward trend (increasing value with time). On the other hand, a negative value of S or τ shows a downward trend.
The standard normal variate is estimated by

$$Z = \frac{S}{Var(S)^{1/2}} \tag{24}$$

Using standard normal variate (Z), the null hypothesis of no trend is tested against the alternative upward or downward trend from the table of a two tailed test.

For detecting trend in water quality having seasonality, the Kendall non-parametric test as suggested by Hirsch et al. (1982) may be used. This test, however, is insensitive to the presence of seasonality. The method computes the Kendall statistics for each season individually.

Let Y_{ij} represent a time series in the i^{th} year and j^{th} season where i=1, 2, ……..,n year and j=1, 2, ………… ,s.

$$S_j = \sum_{k=1}^{n-1} \sum_{i=k+1}^{n} \operatorname{sgn}(y_{ij} - y_{kj}) \tag{25}$$

S_j is asymptotically normally distributed with mean zero and variance given by

$$\sigma_j^2 = n(n-1)(2n+5)/18 \tag{26}$$

The overall statistics S' can be obtained as

$$S' = \sum_{j=1}^{s} S_j \tag{27}$$

which is asymptotically and normally distributed with mean zero and variance V(S')

$$V(S') = \sum_{j=1}^{s} \sigma_j^2 \tag{28}$$

The standard normal variate (Z') is estimated as

$$Z' = \frac{S'}{Var(S')^{1/2}} \tag{29}$$

The level of significance and the trend sign can be determined from the value of Z' and the sign of S', respectively.

3.4.3.2 Seasonality

The time series can be transformed to reveal Gaussian distribution as discussed in Section 3.1. However, the transformed data exhibits most of the seasonal properties of the original series (Bender and Simonovic, 1994) which, besides, e trend, can bring non-stationarity in the series. A close review of the time series plots and Box-and-Whisker plots (monthly) may reveal considerable information of the periodic behaviour (seasonality). However, to confirm the seasonality in the data based on time series plots, the autocorrelation function (ACF) and partial autocorrelation function (PACF) can be drawn. For seasonal data , the ACF often follows a wave pattern with peaks at s, 2s, 3s. and the other integer multiple of s, where s is the seasonal length. The nonstationarity due to seasonality can be removed either by seasonal differenceing or by the method of seasonalisation such as harmonic analysis using Fourier Series coefficients (Lungu and Sefe, 1991; Bender and Simonovic, 1994). These methods will be discussed later in Sections 3.4.3.4 and 3.5, respectively.

3.4.3.3 Nonseasonal Autoregressive Integrated Moving Average (ARIMA) Model

A time series is called homogeneous if it can be reduced to stationary by suitable degree of differencing. The model that describes such homogeneously stationary behaviour is called autoregressive integrated moving average (ARIMA) model of order (p,d,q). In which, p is the non-seasonal AR order, q is the non-seasonal MA order and d is the order of non-seasonal differencing. These type of models are called non-seasonal ARIMA models. The purpose of using these model is that any possible annual trend in the data may be accounted in addition to dependence on the previous values.

The following notations have been used in the mathematical modelling:
The backward shift operator B is such that

$$BY_t = Y_{t-1} \tag{30}$$

and in general

$$B^n Y_t = Y_{t-n} \tag{31}$$

The differencing operator is such that

$$\nabla = 1 - B \tag{32}$$

The first difference can be represented by the difference operator

$$\nabla Y_t = (1-B)Y_t = Y_t - Y_{t-1} \tag{33}$$

The second difference is represented as

$$\nabla^2 Y_t = (1-B)^2 Y_t = Y_t - 2Y_{t-1} + Y_{t-2} \tag{34}$$

and the d^{th} difference is given as

$$\nabla^d Y_t = (1-B)^d Y_t \tag{35}$$

A suitable d^{th} differenced series can be represented in the ARMA model form as

$$\phi(B)(1-B)^d Y_t = \theta(B)\varepsilon_t \tag{36}$$

The process $\phi(B)(1-B)^d Y_t = \theta(B)\varepsilon_t$ can be obtained by summing or integrating d times the stationary process $\phi(B)U_t = \theta(B)\varepsilon_t$ where U_t is the d_{th} differenced series. Therefore, the above model is called autoregressive integrated moving average (ARIMA) model of order (p,d,q). Once the series has been made stable by suitable differencing I further analysis is similar to that of ARMA (p,q) model applied to differenced series.

3.4.3.4 Multiplicative ARIMA Model

For seasonal data such as water quality monthly data there are two time intervals of importance. Relationships can be expected to occur (i) between observations in successive months of a particular year and (ii) between observations in the same months in successive years (Loftis et al., 1991). However, the non-stationarity of correlation structure in the shape of cosine series which represents the seasonality can be removed simply through differencing which leads to the seasonal ARIMA model of the order (P ,D,Q)s. The combination of seasonal and nonseasonal ARIMA model lead to the general form multiplicative ARIMA(p~d,q)x(P,D,Q)s model. In this form, p is the nonseasonal AR order, P is the seasonal AR order, q is the nonseasonal MA ,order, Q is the seasonal MA order, d is the order of nonseasonal differencing, D is the order of seasonal differencing and s is the seasonal span (e.g., s=12 for monthly data)

The various seasonal differencing operators are as follows :

The first seasonal difference of period 12

$$\nabla_{12} Y_t = \left(1 - B^{12}\right) Y_t = Y_t - Y_{t-12} \tag{37}$$

The second difference is represented as

$$\nabla_{12}^{2} Y_t = \left(1 - B^{12}\right)^2 Y_t = Y_t - 2Y_{t-12} + Y_{t-24} \tag{38}$$

and the dth difference is given as

$$\nabla_s^{d} Y_t = \left(1 - B^s\right)^d Y_t \tag{39}$$

A series which is governed by a mixed seasonal process ARIMA(P ,D,Q)s can be expressed as

$$\phi\left(B^s\right)\left(1 - B^s\right)^d Y_t = \Theta\left(B^s\right)\varepsilon_t \tag{40}$$

where β_t= residuals of the ARIMA(P ,D,Q} model.

$$\begin{aligned} \phi\left(B^s\right) &= 1 - \phi_1 B^s - \phi_2 B^{2s} - .... - \phi_p B^{ps} \\ \Theta\left(B^s\right) &= 1 - \Theta_1 B^s - \Theta_2 B^{2s} - .... - \Theta_p B^{ps} \end{aligned} \tag{41}$$

An ARIMA(p,d,q) model is fitted to the residuals β_t as

$$\phi(B)\left(1 - B^s\right)^d \beta_t = \theta(B)\varepsilon_t \tag{42}$$

We can now combine models of Equation 40 and 42 into a single general class of time series model. This model yields excellent fits and generate accurate forecasts. This broad class of model is (:ailed multiplicative ARIMA model and denoted as ARIMA(p,d,q)x(P ,D,Q)s and expressed as

$$\phi((B)\phi((1 - B)^d \left(1 - B^s\right)^D Y_t = \theta(B)\Theta\left(B^s\right)\varepsilon_t \tag{43}$$

The multiplicative ARIMA model being the most general form of the ARIMA modelling approach, the models described in Sections 3.3.2.1, 3.3.2.2, 3.3.2.3 and 3.3.3.3 can be derived from the multiplicative ARIMA model. For example, if the parameters d, P, D and Q become equal to zero, the model can be expressed as ARIMA(p,0,q)x(0,0,0), which is equivalent to ARMA(p,q) model. Similarly, other models can also be obtained with suitable values of the defining parameters in the above general form.

The modelling steps for multiplicative ARIMA(p,d,q) x $(P,D,Q)_s$ using SYSTAT software have been summarized as under

1. Check the normality of the data and make the appropriate transformation (such as the power transformation) if the data are non-normally distributed.
2. From a plot of the normalized series check the periodicity or the nonstationarity in the series.
3. Check the autocorrelation of the normalized series. Usually the ACF of monthly series shows a 12 month periodicity superposed on a decaying autocorrelation. The periodicity indicates the need of seasonal differencing. It is useful to observe the behavior of the ACF for several combinations of seasonal and nonseasonal differencing. Use of the lowest level of differencing is necessary to achieve stationarity. If y_t is the original series and U_t is the differenced series, the following differencing have been considered.
4. Determine the maximum likelihood estimates of the model parameters for the minimum sum of squares of the residuals.
5. Forecasting develop the forecasting function by taking the conditional expectations of the expanded finite difference form of the models.

Chapter 4

RESULTS AND DISCUSSION

4.1 Interpretation of Time Series

The time series plots of twenty-two water quality variables obtained from sixteen sampling stations, as shown in Figure 2, have been analyzed and critically examined. The description of different water quality variables, Figure 3 (a, b, c, d), are as given below:

The river water temperature is measured to be lowest (4 °C) in Panipat and highest (37 °C) in Mathura (d/s). The temperature from June-1990 to May-1996 is gradually varying form winter to summer. It has been found that the river water temperature is above 25 °C at many sampling stations, which in turn affects the stream chemical and biological conditions.

The pH ranged between 6 to 9, which is within permissible limits. The lowest (5.26) values of pH has been observed in Pratappur(d/s) and the highest (9.15) value in Agra.

As can be seen from Figure 3, the values of electrical conductivity has been above permissible limits in New Delhi, Mathura, Agra and Etawah. The tolerance limit for the EC is 1500 umhos/cm. It represents the presence of chemical constituents in flowing water of River Yamuna. The hardness is found to be high in New Delhi, Mathura, Agra and Etawah. The maximum value measured to be 685 mg/l. The basic statistics is also given in Table 2.

The bi-carbonate is found to be high from Delhi to Etawah. The yearly trend ranges from 50.0 mg/l to 450 mg/l. Whenever the pH touches 8.30, the presence of carbonates is indicated. Below pH 8.3, the carbonates are converted into equivalent amount of bicarbonates. The carbonate obtained in river Yamuna indicates the river water carbonate highest (107 mg/l) in Delhi. The yearly trend is similar and the values ranges from 0.0 mg/l to 60 mg/l.

The calcium obtained in river Yamuna is found to be lowest (9.52 mg/l) in Panipat and Highest (89 mg/l) in Mathura. The calcium is within permissible limits in Delhi, Mathura, Agra and Etawah. The tolerance limit of Calcium is 200 mg/l. The magnesium obtained in river Yamuna is Highest in Mathura (83 mg/l). The values are high in Delhi, Mathura, Agra and Etawah but within tolerance limit of 250 mg/l. The sodium and Potassium obtained in river Yamuna is found to be highest in Agra(56 mg/l). The values are higher in Delhi, Mathura, Agra and Etawah as compare to other stations.

The chloride obtained in river Yamuna are highest in Mohana (686 mg/l) in the year 1993. In general, the values are higher than the tolerance limit in many cases at stations Mathura, Agra and Etawah. The yearly trend is not similar and the values ranges from 20.0 mg/l to 400 mg/l. The tolerance limit for Chloride is 250 mg/l. The sulphate

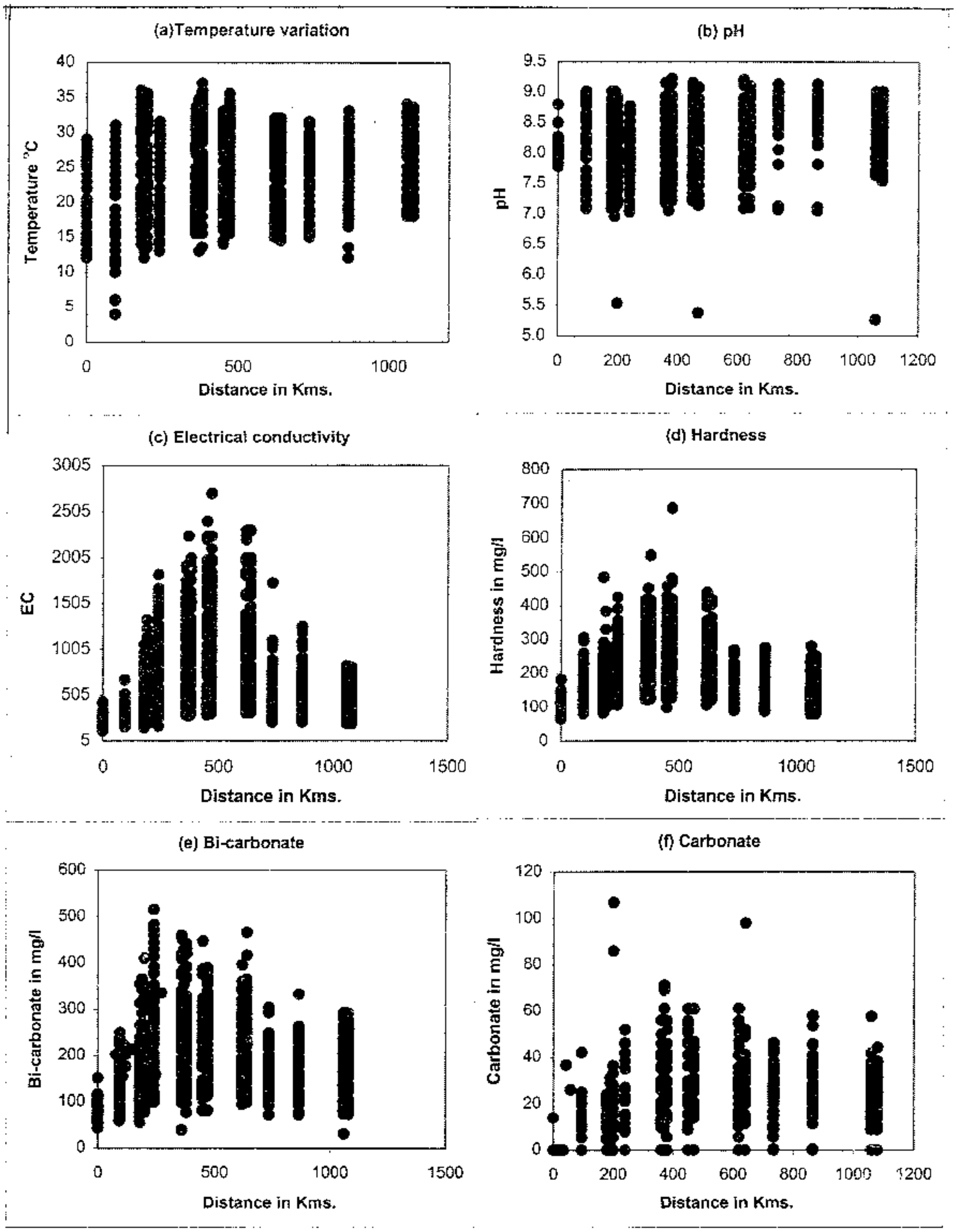


Fig.3 a: Range of water quality variables along River Yamuna

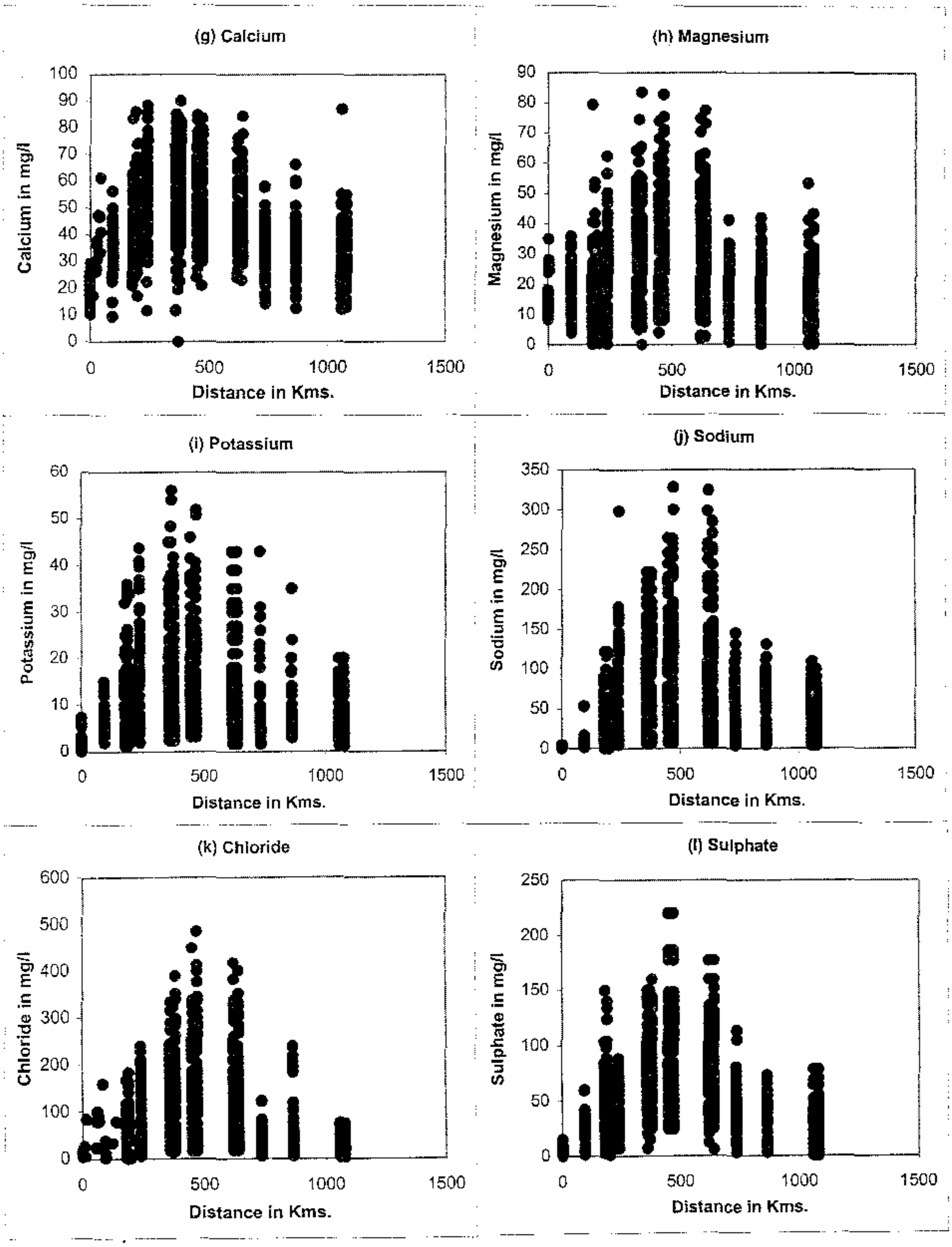


Fig.3 b: Range of water quality variables along River Yamuna

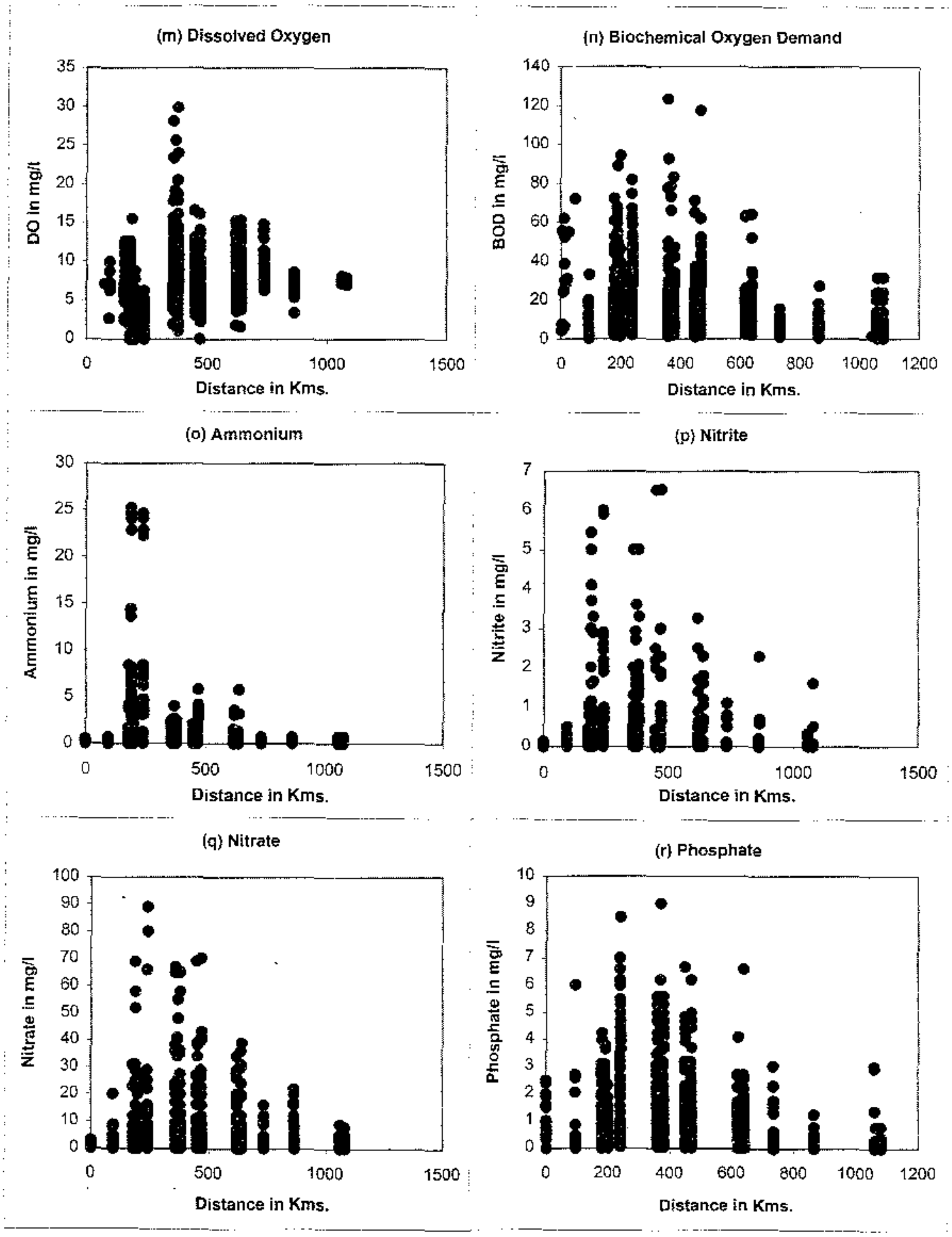


Fig.3 c: Range of water quality variables along River Yamuna

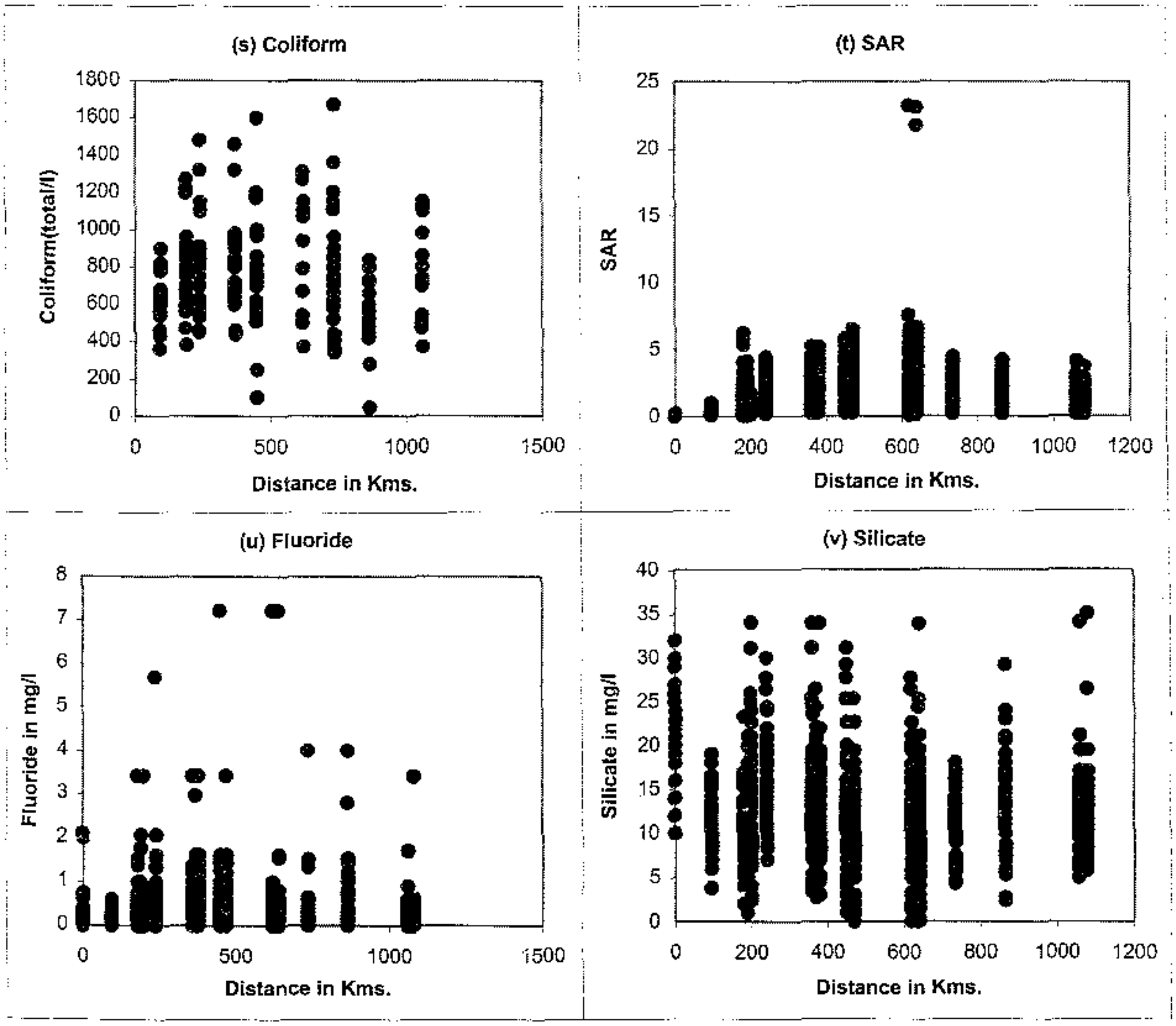


Fig.3 d: Range of water quality variables along River Yamuna

Table 2: Basic statistics of water quality variables

Parameter	Statics	Kalanaur	Panipat	Delhi(u/s)	Delhi(c/l)	Delhi(d/s)	Mohana	Mathura(u/s)	Mathura(c/l)
Temperature	Mean	21.8402778	20.48611	26.3777778	24.355556	25.8972222	23.956944	25.43611111	26.04166667
	Median	23	20	27.5	25.75	27	24.25	27	26.8
	Mode	27	15	30	29	30	30	30	21
	S.D.	4.98506671	6.947982	6.07470447	5.8578679	6.19227079	5.5905561	5.602522208	5.745561667
	Variance	24.8508901	48.27445	36.9020344	34.314617	38.3442175	31.254317	31.38825509	33.01147887
	Kurtosis	-1.0599391	-0.88741	-1.19606852	-1.0628493	-1.0534295	-1.233108	-1.403750215	-1.218062954
	Skewness	-0.465203	-0.22831	-0.2904589	-0.416842	-0.3823939	-0.372777	-0.285564322	-0.294045208
pH	Mean	8.05652778	8.415139	8.22902778	8.0966667	8.13277778	8.0069444	8.045694444	8.242777778
	Median	8.025	8.53	8.295	8.155	8.245	7.945	8.055	8.29
	Mode	8	9.01	8.65	7.69	8.53	7.81	8.05	8.53
	S.D.	0.15861336	0.534882	0.5029579	0.5198646	0.57857334	0.4352776	0.467064029	0.432712448
	Variance	0.0251582	0.286099	0.25296665	0.2702592	0.3347471	0.1894666	0.218148807	0.187240063
	Kurtosis	6.12103474	-0.12641	-0.34446956	-0.841724	4.30225413	-0.449926	-0.707172176	0.159072674
	Skewness	1.60531574	-0.87093	-0.59167347	-0.2224917	-1.4211218	-0.112921	0.003445853	-0.469494164
EC	Mean	213.763889	326.9861	430.569444	665.02778	412.166667	977.56944	1005.816389	1069.722222
	Median	207.5	310	348.5	701	365	1022	937	1045
	Mode	230	310	380	800	340	1450	291	1390
	S.D.	62.432046	79.63464	219.668689	268.62183	150.763877	437.01255	458.0543731	486.6312837
	Variance	3897.76037	6341.676	48254.3331	72157.689	22729.7465	190979.97	209813.8087	236810.0063
	Kurtosis	1.81414974	3.992565	0.33369999	-0.6741304	0.17604972	-1.05138	-0.917908309	-0.801232431
	Skewness	1.02369208	1.184573	1.18503462	-0.02072	0.991537	-0.168371	0.236112406	0.203248123
Hardness	Mean	106.728333	166.6626	167.2325	190.14146	169.364963	250.69575	265.292525	266.5267875
	Median	103.82	157.05	156.07	180.08	170.23845	267	275.875	267.99
	Mode	108	119	91	159	119	261.73	178	159
	S.D.	24.6072234	47.87916	63.8952556	52.216923	44.5740519	70.508357	84.95721046	88.02633808
	Variance	605.515442	2292.414	4082.60369	2726.607	1986.8461	4971.4284	7217.727609	7748.636196
	Kurtosis	0.77277575	0.937002	7.05396779	1.6521945	-0.7130956	-0.352326	-1.08566187	-1.066312736
	Skewness	0.79470328	1.008699	1.89040298	0.8920744	0.48205088	-0.233846	-0.002938626	0.105747187
Bi-carbonate	Mean	78.7843056	147.6347	141.244583	159.71875	176.43375	255.23861	244.0780556	242.505
	Median	78.08	143.175	133.68	143.395	172.76	247.435	253.09	258.07
	Mode	68.32	107	78	140	110.45	102	276	211
	S.D.	18.8773809	45.44412	55.4437908	59.066387	71.9341809	102.00844	89.09265493	79.0326085
	Variance	356.355509	2065.168	3074.01394	3488.8381	5174.52639	10405.721	7937.501162	6246.153206
	Kurtosis	1.81001454	-0.69471	2.87132416	1.9226613	1.00404414	-0.244369	-0.261510475	-0.848009644
	Skewness	0.929046	0.22086	1.32210373	1.3234396	0.98417357	0.4886801	0.093185773	-0.104576499
Carbonate	Mean	0.38888889	10.09444	7.9375	8.0430556	11.6777778	10.159722	11.16111111	18.44166667
	Median	0	10.2	9.95	0	10.1	0	0	12.45
	Mode	0	0	0	0	0	0	0	0
	S.D.	2.31684314	8.981137	7.45473547	10.055127	17.3966099	16.003051	16.1246077	22.37832043
	Variance	5.36776213	80.66081	55.573081	101.10558	302.642034	256.09765	260.0029734	500.7892254
	Kurtosis	33.3844898	0.717956	-1.01899083	-1.0693511	16.0211668	0.4553794	0.184464158	0.324699522
	Skewness	5.87005645	0.72955	0.36849964	0.7110821	3.49237963	1.3683626	1.230799606	1.133149991
Calcium	Mean	18.715	33.91875	40.5720833	46.124306	41.4669444	55.423194	55.13347222	53.93458333
	Median	18.92	33.635	38.74	46	39.48	56.5	54.155	53.955
	Mode	15	33	44	46	32	60	49	43
	S.D.	4.24950801	8.154878	11.1087135	9.535331	9.90090672	15.224686	16.84650556	17.62237813
	Variance	18.0583183	66.50203	123.403515	90.922538	98.0279539	231.79108	283.8047497	310.5482111
	Kurtosis	-0.1853933	0.859925	2.00973565	3.9857343	1.42965787	0.0320321	-0.401915976	-0.109401579
	Skewness	0.52957899	0.055147	1.08078744	0.7051009	0.78752623	-0.236113	-0.229255033	-0.389692899

Mathura(d/s)	.Agra(u/s)	Agra(d/s)	Etawah(u/s)	Etawah(d/s)	Auriya	Hamirpur	Pratappur(u/s)	Pratappur(d/s)
27.28472222	24.555556	26.6875	24.70138889	24.45138889	23.66667	24.625	26.36805556	26.32638889
29.[illegible]	26.5	28.25	26	26	24.5	25	27.25	27.25
31	30	33.5	28.5	30	21	24	29	29
5.882527475	5.9915172	6.09227027	4.913806162	4.975404097	4.898404	4.46248052	4.888901671	4.852151927
34.6041295	35.898279	37.115757	24.145491	24.75464593	23.99437	19.9137324	23.90135955	23.54337833
-0.92017684	-1.3722313	-1.324695	-1.081983713	-1.098646738	-1.27523	0.08950474	-1.381886797	-1.3872849
-0.410595797	-0.3899351	-0.3421954	-0.484341681	-0.478436439	-0.17494	-0.5663549	-0.273863618	-0.280945382
8.1275	8.2020833	8.12041667	8.252638889	8.14375	8.660694	8.60819444	8.432916667	8.420555556
8.17	8.26	8.19	8.29	8.29	8.77	8.65	8.53	8.41
8.17	8.41	8.05	8.17	8.41	8.89	8.89	8.89	8.65
0.478023366	0.4502204	0.52900235	0.434993907	0.751789298	0.361839	0.36225556	0.533033935	0.324644503
0.228506338	0.2026984	0.27984349	0.189219699	0.565187148	0.130928	0.13122909	0.284125176	0.105394053
-0.54233773	-0.6005739	9.24250047	-0.135445683	29.48777811	8.582356	7.5[illegible]28561	16.66761725	0.31514417
-0.028117147	-0.1739658	-2.0281327	-0.316097606	-4.477302343	-2.5398	-2.2225507	-3.118318269	-0.643817582
1039.319444	1108.1528	1120.86111	1024.75	1012.916667	612.8056	609.388889	497.3333333	493.25
980	1098	1040	915	930	578	590	502.5	495
850	740	360	610	480	580	305	539	539
473.865757	547.99105	553.066568	538.863691	492.8619711	252.5028	253.966093	181.0706811	177.0699512
224548.7557	300294.19	305882.628	290374.0775	242912.9225	63757.65	64498.7762	32786.59155	31353.76761
-0.874916914	-0.864419	-0.4320005	-0.506738023	-0.477329631	4.088687	-0.4687133	-0.920507881	-0.941295422
0.282400462	0.3134024	0.46569922	0.663246811	0.592852146	1.274268	0.4091499	-0.005950418	0.023634245
275.5265222	263.35264	279.863185	240.0023694	241.5176028	168.5548	173.007065	155.9510153	149.9792181
278.38	259.5	274.625	226.46475	224.0034	174.6644	173.6215	152.23885	145.94325
341.2996	171	238	178	272	146	107	164	146
94.79318357	88.540084	105.001905	86.09259463	83.70030546	38.16244	45.8104341	44.81406969	40.16119949
8985.747652	7839.3464	11025.4	7411.934851	7005.741134	1456.372	2098.59587	2008.300842	1612.921945
0.166548835	-1.0130798	1.65022966	-0.631134974	-0.757800454	-0.2301	-0.4837437	0.316054175	0.065159936
0.449970337	0.0040776	0.8294284	0.517080687	0.495096102	-0.00959	0.15884589	0.586570468	0.522788106
245.0320833	225.11972	238.993194	215.3888889	225.1790278	173.8101	184.479861	184.0356944	184.0304167
251.4	229.915	245.175	216.925	224.75	173.76	195.26	193.215	197.705
306.93	107	178	270	127	217.23	107	225	207
85.24340662	78.178293	83.5425648	73.36531411	79.99895019	50.14336	59.7034333	61.03233241	53.43230548
7266.438372	6111.8455	6979.36013	5382.469314	6399.832031	2514.357	3564.49995	3724.9456	2855.011269
-0.544352034	-0.2850939	-1.0819373	-0.751319576	-0.048287493	-0.42953	-0.799351	-0.63568925	-0.565133191
0.175936978	0.1539721	-0.0305242	0.335070674	0.540094953	0.16833	-0.2172729	-0.44782379	-0.424536463
16.25416667	17.902778	15.5416667	16.475	18.79861111	23.51569	25.0227778	16.81111111	18.39305556
2.85	13.5	0	10.2	19.8	24.5	24.95	15.6	19.8
0	0	0	0	0	0	20.7	0	0
19.28670956	20.258832	18.1424003	18.22267393	19.74274331	12.47339	13.1206687	13.06049366	13.62602446
371.9771655	410.42027	329.14669	332.0658451	389.7759135	155.5855	172.151947	170.5764945	185.6685426
-0.793406887	-0.8251585	-0.7161994	-0.568330821	1.839467449	-0.61656	0.77565833	-0.088648095	-1.364591635
0.774810273	0.7199557	0.72000485	0.8033801	0.991941914	-0.33031	0.26370307	0.365802678	-0.125642874
57.39347222	51.594306	51.9268056	44.71027778	45.94527778	33.96736	34.3223611	30.96263889	30.48041667
56.455	50.05	49.85	42.985	43.245	33.47	35	28.23	29.66
40.48	32	40	34.47	39	37.07	35	26	26
15.23888301	15.43512	14.3664317	12.33564091	12.80071686	8.42873	10.091961	11.81045216	10.11555119
232.2235554	238.24292	206.39436	152.1680365	163.858352	71.0435	101.847677	139.4867803	102.3243759
-0.899068107	-0.9115662	-0.8586372	-0.050156366	0.214874808	0.311471	1.12481791	5.893333531	-0.221062061
0.008031651	0.1736219	0.2561402	0.690562451	0.787200364	0.068732	0.41595095	1.672455584	0.527770208

Parameter	Statics	Kalanaur	Panipat	Delhi(u/s)	Delhi(c/l)	Delhi(d/s)	Mohana	Mathura(u/s)	Mathura(c/l)
Magnesium	Mean	15.1323611	17.45333	15.7501389	19.296111	15.1793056	26.766806	31.22013889	32.35791667
	Median	13.59	17.99	13.305	17.68	13.865	28.86	31.83	32.46
	Mode	10.46	9	24.3	13	7.78	32	38	5
	S.D.	5.95385435	7.20151	11.8463045	10.322253	8.52734348	12.855639	14.0579316	15.1193781
	Variance	35.4483817	51.86174	140.334931	106.54892	72.7155868	165.26745	197.6254408	228.5955942
	Kurtosis	2.31270505	-0.43293	10.4559765	1.8644793	-0.6469308	0.0030664	-0.857849559	-0.118441744
	Skewness	1.6250756	0.255456	2.39476492	1.0760241	0.36489875	0.17101	0.058398658	0.118765028
Potassium	Mean	1.12319444	5.845278	6.97861111	12.374722	7.92611111	19.155417	15.43388889	21.19986111
	Median	0.78	4.695	4	9.66	6	18.77	13.7	16.095
	Mode	0.39	4	3	7	6	20	16	18
	S.D.	1.3785222	3.020374	6.18178248	8.7804801	5.28383678	10.327977	9.534843818	13.69101777
	Variance	1.90032345	9.122662	38.2144347	77.096831	27.9189311	106.6671	90.91324664	187.4439676
	Kurtosis	7.18116658	1.093959	4.01245718	0.8048507	7.4688944	-0.420057	0.407536036	0.362662247
	Skewness	2.50454212	1.27119	1.98807363	1.2418954	2.24125274	0.408437	0.934516182	1.051811056
Sodium	Mean	1.40416667	6.766528	21.8180556	51.724861	18.3783333	92.614444	92.87569444	97.3025
	Median	1	5.61	12	54.5	14	104.025	100	100
	Mode	1	8	6	54	10	120	100	100
	S.D.	0.86673054	6.331878	25.0203103	31.568856	14.1328226	57.89442	55.30075533	56.43711821
	Variance	0.75122183	40.09268	626.015929	996.59267	199.736676	3351.7638	3058.17354	3185.148312
	Kurtosis	6.55448837	39.13972	3.47835097	-0.6831167	1.36816289	0.6050689	-0.61199028	-0.974975899
	Skewness	2.37171173	5.512518	1.87739713	0.1435854	1.32532102	0.3405144	0.26617273	0.135330251
Chloride	Mean	8.52722222	7.106806	33.4398611	69.58	17.1520833	119.59528	137.21375	137.9241667
	Median	8.525	6.03	15	74	13.83	141.8	135.77	137.55
	Mode	6	6.03	8	74	12.05	107.77	135.77	34
	S.D.	2.517232	5.448794	35.8970267	41.597565	13.1128898	67.710437	80.88608347	75.499082
	Variance	6.33645696	29.68935	1288.59653	1730.3574	171.947879	4584.7033	6542.5585	5700.111382
	Kurtosis	-0.1045609	24.14386	1.85241622	-0.2405577	12.8655121	-1.235787	-0.700061652	-0.712945508
	Skewness	0.49855298	4.617737	1.54202312	0.2136466	3.14269982	-0.282905	0.257524411	0.154115395
Sulphate	Mean	6.02986111	22.87042	39.9308333	60.4825	24.3463889	55.389306	77.15138889	77.05611111
	Median	5.25	23.91	36.7	62	23	60	83.1	80
	Mode	2	9	30	64	20	60	62	70
	S.D.	3.33575994	12.05293	26.3708094	29.794994	13.3405782	20.616742	32.82591875	33.22499931
	Variance	11.1272943	145.2731	695.419588	887.74164	177.971026	425.05007	1077.540942	1103.900579
	Kurtosis	0.48398654	-0.11181	3.04526848	0.5428703	2.12890335	-0.559265	-0.559189992	-0.825671479
	Skewness	0.73976593	0.11069	1.21668607	0.5697664	0.85705671	-0.612481	-0.000124794	-0.067639546
DO	Mean	-1	7.054444	6.18222222	1.6944444	3.65347222	3.2063889	9.1575	8.651666667
	Median	-1	7	6.24	0.07	3.8	3	8.24	7.785
	Mode	-1	7	0	0	4.02	3	6.5	9.24
	S.D.	0	0.727192	3.3098752	2.7058132	1.72013114	1.3259356	4.175893174	3.925325859
	Variance	0	0.528808	10.9552739	7.321425	2.95885115	1.7581051	17.4380838	15.4081831
	Kurtosis	#DIV/0!	21.95023	-0.4867642	8.3976206	0.78334505	-0.02309	6.416351439	4.483996056
	Skewness	#DIV/0!	-1.72203	-0.2787564	2.3655465	0.11514446	0.3123638	2.033778451	1.737545764
BOD	Mean	-1	5.226806	17.1081944	31.210694	19.4255556	31.326111	21.26736111	18.70777778
	Median	-1	3.8	12	30.54	17.475	29.04	17.75	16.82
	Mode	-1	6	7	9	7	27	6	6
	S.D.	0	5.721998	15.519654	18.876821	14.2200237	18.024837	19.5923701	14.08943098
	Variance	0	32.74126	240.85966	356.33436	202.209073	324.89476	383.8609662	198.5120654
	Kurtosis	#DIV/0!	7.852956	2.15311547	0.1701874	9.56449705	-0.102884	12.21442043	7.566212934
	Skewness	#DIV/0!	2.557957	1.56695285	0.6840114	2.26778908	0.5232488	3.0814591	2.417409946

Mathura(d/s)	Agra(u/s)	Agra(d/s)	Etawah(u/s)	Etawah(d/s)	Auriya	Hamirpur	Pratappur(u/s)	Pratappur(d/s)
31.23486111	32.296806	35.8904167	30.80611111	31.39166667	20.47778	21.1523611	19.09291667	17.96194444
30.92	32	34.75	28.98	29.58	22.11	22.72	21.01	19
13	32	36	28	12	18	3	24	19
16.4307106	15.760671	18.3519756	17.12307549	16.17752614	8.768889	10.3552161	9.524910031	8.994498575
269.9682507	248.39874	336.79501	293.1997142	261.7123521	76.89342	107.2305	90.72391109	80.90100462
0.091606798	-0.385307	-0.5249079	-0.48339186	0.082460673	-0.56976	-0.4948419	1.432226335	0.263773912
0.351228094	0.2894077	0.34763989	0.385602027	0.563961631	-0.30246	-0.2584705	0.330472017	0.096733152
17.10902778	16.753194	17.8491667	16.16444444	16.16444444	8.071944	7.48152778	6.030416667	5.685694444
15	14	15.82	12.8	12.8	5.45	5.36	4.46	4
15	14	16	14	14	4	3.1	4	4
10.33312575	10.37303	11.1981682	10.41801499	10.41801499	7.578218	5.86826525	4.120553921	4.174246943
106.7734878	107.59975	125.398971	108.5350363	108.5350363	57.42938	34.4365371	16.97896461	17.42433754
-0.248624978	0.0845878	0.8660941	-0.275872961	-0.275872961	7.082728	6.96865836	0.888626342	2.5845115
0.735658067	0.8922872	1.03592093	0.796647126	0.796647126	2.516127	2.38424715	1.426651514	1.804700131
98.09361111	103.795	112.165833	104.3831944	107.3468056	53.82819	53.9273611	46.57569444	44.12375
100.025	100	102.625	100	100	51.955	54.655	52.6	49.405
76	100	100	100	27	78	14	57	54
57.54074702	66.650876	75.0693321	71.50981201	71.94077186	32.46274	31.441461	27.42922369	26.26435116
3310.937567	4442.3392	5635.40462	5113.653214	5175.474656	1053.829	988.56547	752.3623122	689.8161421
-0.844144609	-0.6528342	0.12942639	0.662722592	-0.119948729	-0.12978	-0.7895228	-0.802193694	-0.965044604
0.227522424	0.4094553	0.70312813	0.92133428	0.702188405	0.422354	0.14784781	-0.005347266	-0.062192279
156.2251389	157.00264	167.312361	145.49375	147.4977778	46.71417	65.8043056	36.42430556	36.25763889
149.925	149.85	161.825	136.71	135.775	47.86	48.92	37.93	37.93
15.95	32	62	58	56	49.98	45.73	48	46
91.30510127	97.910821	108.923798	96.70386307	93.82491052	21.50134	56.801799	17.91762582	17.90481849
8336.621518	9586.5288	11864.3938	9351.637134	8803.113834	462.3078	3226.44437	321.041315	320.5825253
-0.565662747	-0.2007093	0.0387847	0.098044508	-0.212305898	1.098317	2.72669062	-0.745866961	-0.549147974
0.303847544	0.5264568	0.70968593	0.813523807	0.67589282	0.514312	1.81314164	-0.009270282	0.040894456
81.18041667	-91.954347	91.9543472	79.935	82.58972222	39.47181	35.4830556	26.77263889	26.01
82.1	95	95	78	86	42	40	30	29.3
25	100	100	30	25	20	40	30	30
33.72253376	44.57595	44.5759497	38.87532495	38.1284863	21.12592	18.4198945	16.57164573	16.79816087
1137.209283	1987.0153	1987.01529	1511.29089	1453.781468	446.3043	339.292512	274.6194422	282.1782085
-0.619359823	0.6075084	0.60750843	-0.684473422	-0.653937581	1.925907	-0.8959269	0.398291979	0.4956712
0.131866853	0.6751871	0.67518713	0.253158902	0.149008689	0.893675	-0.1983953	0.493910849	0.603602635
9.083055556	7.2575	6.35333333	8.800694444	7.932083333	8.905278	6.95833333	7.701111111	7.685416667
7.85	6.9	5.645	8.73	7.54	8.475	7.1	7.79	7.735
8.84	6.9	0	7.3	5.6	7.1	6.8	7.6	7.9
5.018533156	2.8601392	3.44691166	2.970987092	2.725601594	2.358868	1.29660879	0.236694107	0.227397632
25.18567504	8.1803965	11.8812	8.8267643	7.428904049	5.564256	1.68119437	0.0560241	0.051709683
3.942481657	0.3711399	0.46049673	-0.308466323	0.407933014	4.160347	19.7920303	-0.379397239	1.470484634
1.542352593	0.7706318	0.76284498	0.257681921	0.639404887	-0.15205	-3.5150705	-0.807919122	-1.331542356
18.77472222	17.524444	26.1363889	13.98388889	15.50097222	4.660278	5.72041667	5.307777778	5.065833333
16.905	14.165	23.945	11.37	13.87	4	5.395	3	3
16	6	19	8	10	4	6	3	3
12.55373924	12.818116	17.6022076	10.61885919	10.34414527	2.667101	4.20098326	5.680553738	5.707612596
157.5963689	164.30409	309.837711	112.7601706	107.0013413	7.113425	17.6482604	32.26869077	32.57684155
8.80153627	5.11514	9.04989188	10.97618159	7.229591943	4.113735	9.13105715	8.011915518	8.650580596
2.177029786	1.8097262	2.17668515	2.756799143	2.129529904	1.563139	2.40440048	2.674923874	2.813016943

Parameter	Statics	Kalanaur	Panipat	Delhi(u/s)	Delhi(c/l)	Delhi(d/s)	Mohana	Mathura(u/s)	Mathura(c/l)
Ammonium	Mean	0.08986111	0.027778	0.50111111	3.8058333	0.43888889	3.8158333	0.370555556	0.445833333
	Median	0	0	0	0.215	0	0.29	0	0
	Mode	0	0	0	0	0	0	0	0
	S.D.	0.16789075	0.123587	1.32821977	6.5363581	0.81673958	6.5824401	0.730234168	0.835301666
	Variance	0.0281873	0.015274	1.76416776	42.723977	0.66706354	43.328518	0.533241941	0.697728873
	Kurtosis	1.46786536	20.65557	18.7543101	4.5252726	9.20432136	4.240331	2.797970718	4.787410249
	Skewness	1.71295611	4.605391	4.01263725	2.2461873	2.86265853	2.2253403	2.044472321	2.208046019
Nitrite	Mean	0.03861111	0.036528	0.09513889	0.5731944	0.18888889	0.7877778	0.293055556	0.366111111
	Median	0	0	0	0.08	0.01	0.21	0.05	0.05
	Mode	0	0	0	0	0	0	0	0
	S.D.	0.04804064	0.081312	0.21262937	1.1093925	0.5610467	1.2608071	0.671923115	0.700887879
	Variance	0.0023079	0.006612	0.04521125	1.2307516	0.3147734	1.5896344	0.451480673	0.491243818
	Kurtosis	-1.4278223	17.32409	10.6338975	9.3619773	20.5322341	6.3894101	34.57414691	9.154626471
	Skewness	0.57791182	3.897022	3.17631945	3.0546156	4.41132082	2.3957938	5.285498293	2.945899437
Nitrate	Mean	0.96097222	1.715556	2.53791667	6.4923611	4.70472222	7.5113889	7.693472222	8.870138889
	Median	0.99	0.7	0.725	0.77	1.045	1.7	4.34	5
	Mode	0.6	0.6	0	0	0	0	1	6.2
	S.D.	0.66016677	2.876799	4.83180395	14.792966	6.85670515	16.170309	12.61771705	12.37317766
	Variance	0.43582017	8.275974	23.3463294	218.83184	47.0144056	261.47889	159.2067835	153.0955253
	Kurtosis	1.13201983	24.72413	20.5965501	7.994514	3.219542	15.669542	11.95283104	3.899127844
	Skewness	0.88199228	4.361706	4.19326595	2.9024854	1.98315141	3.866383	3.262671385	2.108201281
Phosphate	Mean	1.19569444	0.315	0.64347222	1.18125	0.58	2.88	1.874166667	1.849027778
	Median	1	0.06	0.25	1.04	0.405	2.755	1.48	1.205
	Mode	0.51	0.06	0.06	1.1	1.1	7	0.25	0.2
	S.D.	0.74546106	0.846551	0.97373994	0.9841046	0.53295086	2.2621434	1.6362485	1.863968324
	Variance	0.55571219	0.716648	0.94816946	0.9684618	0.28403662	5.117293	2.677309155	3.474377915
	Kurtosis	-1.2187228	30.7389	4.0008027	-0.4038854	0.26884937	-0.779985	-0.296692473	2.135856808
	Skewness	0.45617635	5.167411	2.11221219	0.7331618	0.98438122	0.5108941	0.89979167	1.460024471
Coliform	Mean	-1	259.9306	-1	294.51389	-1	285.05556	-1	277.9722222
	Median	-1	-1	-1	-1	-1	-1	-1	-1
	Mode	-1	-1	-1	-1	-1	-1	-1	-1
	S.D.	0	352.3412	0	405.17042	0	415.30687	0	398.9618561
	Variance	0	124144.3	0	164163.07	0	172479.8	0	159170.5626
	Kurtosis	#DIV/0!	-1.24146	#DIV/0!	-0.8126313	#DIV/0!	0.0016842	#DIV/0!	-0.108998038
	Skewness	#DIV/0!	0.741677	#DIV/0!	0.8577546	#DIV/0!	1.11067	#DIV/0!	1.045405886
SAR	Mean	0.05347222	0.299109	1.10388129	1.5130006	0.61368928	2.3597407	2.367061876	2.448645726
	Median	0.05	0.2301	0.4834198	1.755	0.54	2.8115764	2.47	2.450327427
	Mode	0	0.3	0.21	0.4	0.3	3.5	3	3.9
	S.D.	0.04348092	0.211542	1.41504313	0.9225993	0.35494237	1.2505182	1.223318162	1.292618955
	Variance	0.00189059	0.04475	2.00234706	0.8511895	0.12598409	1.5637959	1.496507325	1.670863762
	Kurtosis	3.77607324	3.893716	4.5884656	-0.4314234	0.68181549	-1.193669	-0.711463432	-1.005373878
	Skewness	1.56558077	1.952861	2.19270872	0.2017774	0.93500327	-0.314554	0.033464514	0.042544698
Fluoride	Mean	0.45166667	0.191944	0.36055556	0.4070833	0.24125	0.5202778	0.426666667	0.456805556
	Median	0.18	0.2	0.2	0.38	0.19	0.38	0.33	0.38
	Mode	0	0	0	0.4	0	0.6	0	0.4
	S.D.	0.65835262	0.163273	0.50579985	0.393634	0.43391418	0.7380751	0.520224762	0.500168497
	Variance	0.43342817	0.026658	0.25583349	0.1549477	0.18828151	0.5447549	0.270633803	0.250168525
	Kurtosis	2.24169539	-0.43335	18.8349242	6.6680542	41.222868	34.561601	14.59691936	8.736967433
	Skewness	1.88610686	0.498099	3.74111724	2.2604052	5.77805834	5.1785377	3.052471354	2.554921078

Mathura(d/s)	Agra(u/s)	Agra(d/s)	Etawah(u/s)	Etawah(d/s)	Auriya	Hamirpur	Pratappur(u/s)	Pratappur(d/s)
0.371111111	0.2531944	0.89083333	0.348611111	0.351944444	0.077083	0.12513889	0.073611111	0.063888889
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0.68112491	0.4264093	1.41995016	0.742874709	0.891655588	0.185908	0.20315118	0.159217325	0.135631601
0.463931142	0.1818249	2.01625845	0.551862833	0.795049687	0.034562	0.0412704	0.025350156	0.018395931
1.701739076	4.3940531	1.11284813	10.55835074	20.58571152	6.608975	1.28097643	4.120606241	7.525666984
1.763698919	2.0335375	1.44569301	3.137362995	4.175492196	2.724797	1.52733952	2.213900179	2.606329468
0.533472222	0.2141667	0.36208333	0.198333333	0.195138889	0.065833	0.07375	0.033472222	0.041527778
0.05	0.01	0.02	0.01	0.05	0.01	0.01	0	0
0	0	0	0	0	0	0	0	0
0.881971479	0.8784794	0.95361719	0.549424795	0.444538035	0.200954	0.28793308	0.071229835	0.195906414
0.777873689	0.7717261	0.90938574	0.301867606	0.197614065	0.040382	0.08290546	0.005073689	0.038379323
9.077498122	38.934998	25.3165589	17.64372519	9.78827303	14.1533	52.1608824	8.711753202	58.71361341
2.592834031	5.8940984	4.55695769	4.0391398	3.112199624	3.805925	6.92576899	3.022129594	7.472537827
7.551805556	7.5472222	7.62819444	4.640555556	5.034722222	2.077222	4.15694444	1.052777778	1.085972222
3.97	4.27	1.9	1.1	2.1	0.9	1.89	0.6	0.375
0.6	7	0.14	0	0	0	0	0	0
12.07219181	11.45818	13.0454195	7.44349189	8.456693319	3.149334	5.52040431	1.497968786	1.583079242
145.737815	131.28988	170.18297	55.40557152	71.51566189	9.918305	30.4748638	2.243910485	2.506139887
10.59027974	12.037843	7.90935169	5.537332912	6.846439021	6.610072	2.49701249	11.31081928	9.069805945
3.074486814	3.1193445	2.68143119	2.42529298	2.682362853	2.552804	1.85495048	2.931254945	2.760017725
1.824722222	1.4801389	1.62944444	0.739444444	1.086666667	0.262917	0.15777778	0.169166667	0.078194444
1.445	1.01	1.225	0.51	0.655	0.075	0.09	0.06	0.05
0.5	0.3	0.35	0.06	0.6	0.06	0.06	0.06	0
1.58238897	1.439207	1.44494348	0.706720035	1.171720776	0.564687	0.20050796	0.505649074	0.115066746
2.503954851	2.0713169	2.08786166	0.499453208	1.372929577	0.318872	0.04020344	0.255680986	0.013240356
-0.241794119	1.7267102	0.68406097	7.0975436	12.20765471	10.71548	12.4624831	26.43718827	20.77306408
0.914491552	1.4022984	1.05699391	2.227766676	3.039684002	2.950049	2.95769684	5.131226619	3.938966224
-1	264.91667	-1	156.9583333	-1	274.4861	559.097222	148.5	-1
-1	-1	-1	-1	-1	-1	560	-1	-1
-1	-1	-1	-1	-1	-1	560	-1	-1
0	397.89633	0	364.6389856	0	423.0186	108.904036	324.6796037	0
0	158321.49	0	132961.5898	0	178944.8	11860.089	105416.8451	0
#DIV/0!	0.640835	#DIV/0!	3.307821463	#DIV/0!	0.833808	7.97102215	2.559331875	#DIV/0!
#DIV/0!	1.2487587	#DIV/0!	2.167278494	#DIV/0!	1.331139	-0.8535635	1.979728525	#DIV/0!
2.492506165	2.6636111	2.76350097	3.089356475	3.392005237	1.740989	1.76471307	1.603567341	1.538992446
2.576767499	2.615	2.68258171	2.917913441	2.835	1.69	1.69750862	1.650553026	1.62
1.1	0.9	3.4	3.3	0.7	2.2	0.6	2	1.9
1.24380625	1.5042178	1.62500999	2.919830981	3.618294409	1.112668	1.01557747	0.9396829	0.899405615
1.547053988	2.2626713	2.64065746	8.525412959	13.09205443	1.23803	1.03139759	0.883003953	0.808930461
-0.808600177	-0.8368928	-0.5866239	31.67271763	20.65382262	-0.28498	-0.6197122	-0.268010905	-0.71188854
0.098919238	0.2342706	0.40319377	4.743765855	4.185290298	0.254721	0.33902026	0.263363108	0.101466356
0.433888889	0.4526389	0.39291667	0.424027778	0.451666667	0.274583	0.40291667	0.235416667	0.2125
0.335	0.2	0.2	0.27	0.38	0.19	0.2	0.19	0.19
0	0.2	0.19	0.2	0.4	0	0.2	0.19	0
0.528635116	0.8916593	0.48349502	0.843504861	0.866568431	0.536338	0.61751304	0.259549651	0.415321867
0.279455086	0.7950563	0.23376743	0.71150045	0.750940845	0.287659	0.38132236	0.067366021	0.172492254
13.59206005	47.874941	21.6202658	61.46889757	54.04608749	33.46049	18.3680225	14.50981622	51.46699341
2.990214444	6.4181436	3.96525202	7.567198524	6.970007678	5.215889	3.88194203	3.129159578	6.686409679

Parameter	Statics	Kalanaur	Panipat	Delhi(u/s)	Delhi(c/l)	Delhi(d/s)	Mohana	Mathura(u/s)	Mathura(c/l)
Silicate	Mean	22.1111111	12.24722	10.5111111	12.933333	13.1125	15.384722	13.48888889	13.36111111
	Median	24	12.6	10	13	12.85	13.8	12.95	12.9
	Mode	27	14	10	13.2	13.2	12	10.9	10
	S.D.	5.20442811	2.804171	3.38174701	3.2330163	5.89764664	5.3737143	6.09459598	5.130838977
	Variance	27.086072	7.863372	11.4362128	10.452394	34.7822359	28.876806	37.14410016	26.32550861
	Kurtosis	-0.4644482	0.387336	2.17732268	2.4863148	2.28807673	0.4186488	2.923650926	-0.084479286
	Skewness	-0.6286446	-0.30554	0.77798068	-0.4998573	1.13543055	0.986544	1.329872607	0.199644986

Mathura(d/s)	Agra(u/s)	Agra(d/s)	Etawah(u/s)	Etawah(d/s)	Auriya	Hamirpur	Pratappur(u/s)	Pratappur(d/s)
13.44722222	12.319444	11.1580556	10.48291667	10.82916667	11.14306	12.3013889	11.74166667	12.40694444
12.3	11.85	11.7	10.4	10.4	11.4	12.15	11.4	11.85
11	11.1	12.6	7	13	15	13.2	11	15
5.788428774	5.6249855	4.81754325	5.803581565	6.270394275	3.863656	5.22993801	4.546372955	4.479069521
33.50590767	31.640462	23.2087229	33.68155898	39.31784437	14.92784	27.3522516	20.66950704	20.06206377
4.749664671	2.6018855	0.83555122	0.850272783	1.910706669	0.045665	0.86187252	6.878161359	8.994089935
1.652751761	0.9945655	-0.1034314	0.681095012	0.897868545	-0.42323	0.52333752	1.585544147	2.01969652

obtained in river Yamuna is found to be within permissible limit at all the places. The yearly trend shows the values ranging from 0.0 mg/l to 250.0 mg/l. The tolerance limit for sulphate is 400 mg/l.

The dissolved oxygen must be measured at the river site as it changes with time. The DO obtained in river Yamuna is found to be very high on some cases, which seems to be wrong. However, in many cases, the DO is zero at Delhi, Mathura and Agra in lean period. The yearly trend shows the values ranging from 0.0 mg/l to 15.0 mg/l and the tolerance limit for sulphate is 4.0 mg/l.

The BOD obtained in river Yamuna is highest in Mathura (123.4 mg/l) in the year 1993. The BOD from June-1990 to May-1996 is found to be very high in Delhi, Mathura, Agra and Etawah in lean period. The yearly trend shows the values ranging from 0.0 mg/l to 80.0 mg/l whereas the tolerance limit for sulphate is 2.0 mg/l.

The ammonium obtained in river Yamuna ranges between 0 –10 mg/. In some case cases its values goes very high. The maximum value of nitrite 7 mg/l. However, in general, it ranges between 0 to 2 mg/l. The nitrate concentration ranges between 0 to 40 mg/l.

The phosphate and silicate obtained in river Yamuna are highest in Mathura (9 mg/l) in the year 1991 and in Mathura (33.9 mg/l) in the year 1995 respectively. The yearly trend shows the values ranging from 0.0 mg/l to 35.0 mg/l.

The Fluoride obtained in river Yamuna are highest in Mohana (18 mg/l) in the year 1991. The Fluoride from June-1990 to May-1996 is found to be very high at all the places. The yearly trend shows the values ranging from 0.0 mg/l to 4.0 mg/l, which is above the tolerance limit of 1.5 mg/l.

The Coliform obtained in river Yamuna are highest in Auraiya (1670 mg/l) in the year 1993. The yearly trend shows the values ranging from 0.0 mg/l to 1200.0 mg/l, which is very high as compared to the tolerance limit of 50.0 mg/l.

The sodium adsorption ratio (SAR) is moderately low along the entire length of the river and therefore this water does not cause alkalinity hazards to the soils. The values ranges from 0 to 6 mg/l.

4.2 Trend Analysis

Trend analysis has been carried out in two ways:

(i) Box- and Whisker plot

(ii) Kendall's tau test

The first method has been used to give a qualitative visual identification of possible trend in the data and the later has been used to give a quantitative index. The analysis has been undertaken for all twenty two variables at each of the 16 stations. The sample plots of temperature, pH, hardness, electrical conductivity, bi-carbonate and carbonate are shown in Figure 4 (a, b, c). The Kendall's tau test also indicates that the values are not close to zero and there is no definite trend in most of the cases. Therefore, it may not require a rigorous detrending operation. However, wherever marginal decrease or increase is seen, they can be taken care of through suitable differencing schemes, such as taking a first differenced series and seasonal difference series as in case of ARIMA models.

4.3 Intervention Analysis

Many of human decisions, both deliberate and inadvertent, result in interventions which can affect the stationarity aspect of a time series. In order to detect the time of possible intervention, the time series plots have been determined

The time series plots have been visually examined for determination of the time of start of intervention and to ascertain the significant changes in the mean values. It is inferred from the time series plots that none of the stations have shown any significant change in the mean values.

4.4 Cross-correlation Analysis

It is found essential to study the cross-correlation of a water quality variable between different stations. For this, attempts have been made and Figures 5 and 6 illustrates the cross-correlation between different stations location in River Yamuna. The regression equations and corresponding correlation coefficient, r^2, are given in Table 3. It can be seen that the cross-correlation is very perfect in some of the cases and in other cases it shows very poor correlation.

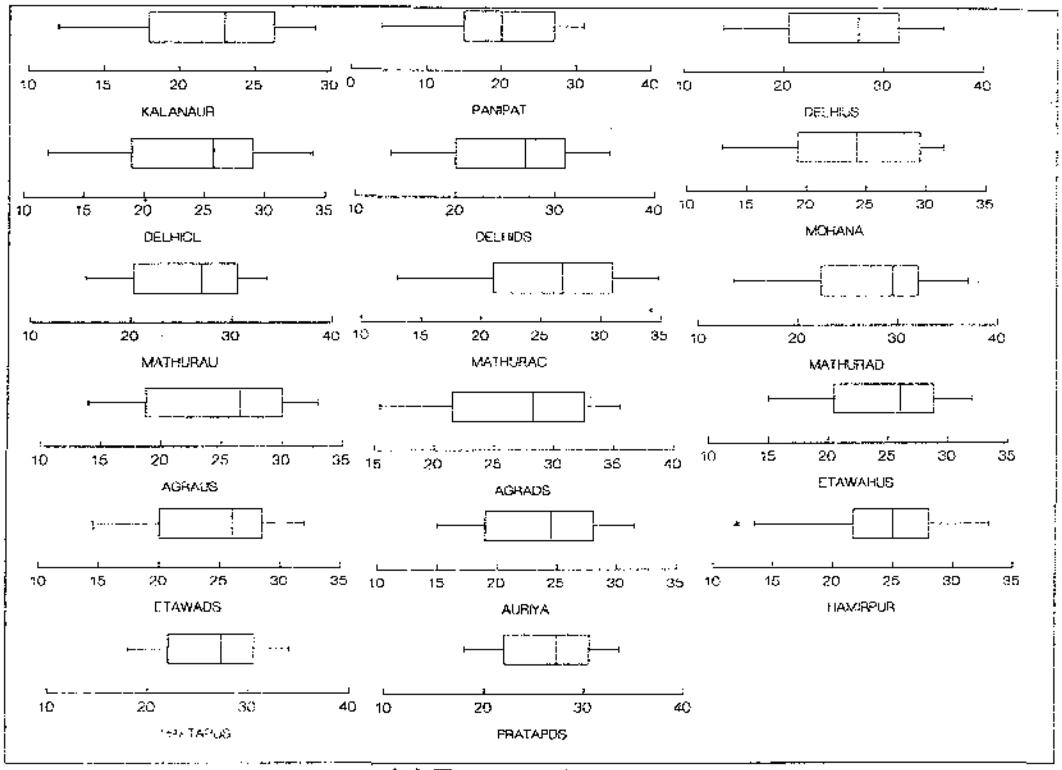
Attempt is also made to study the inter-station cross-correlation, as shown in Figure 7, to correlate water quality variable at one station with the water quality variable in other stations. However, no definite trend were received and a sample plot is shown in Figure 7.

4.5 Detection of Persistence Structure in the Data

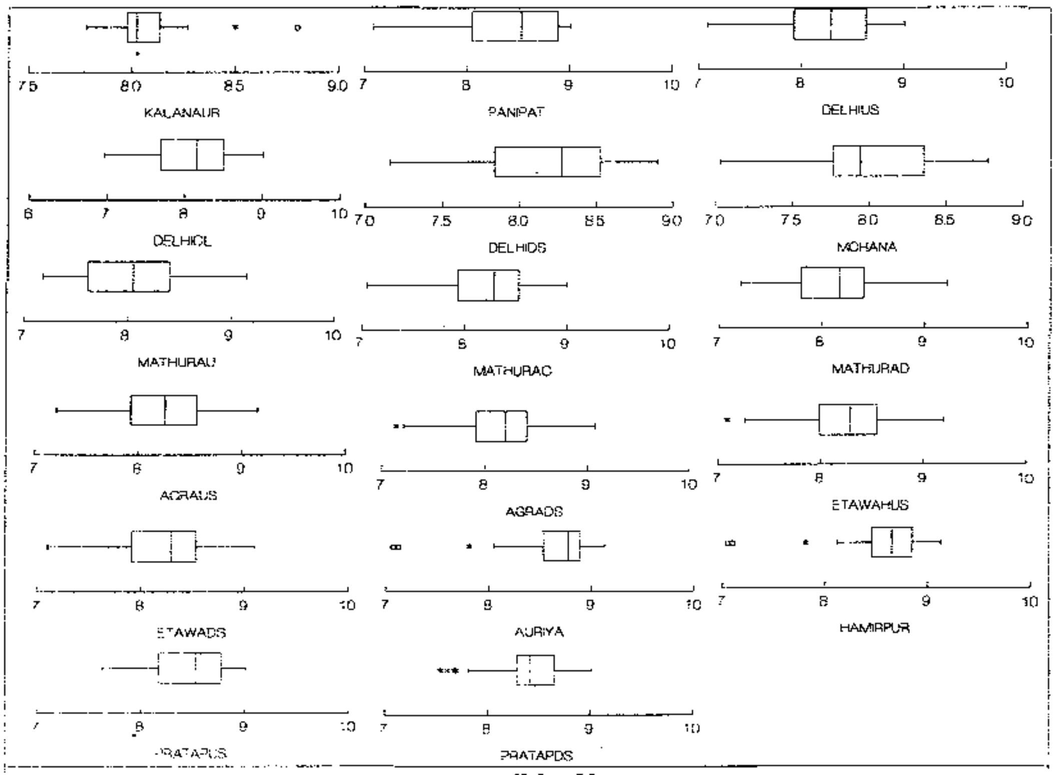
To determine the persistence structure in the water quality data of the River Yamuna, autocorrelation coefficients and partial autocorrelation coefficients have been computed for the various identified parameters at different stations up to a maximum lag of 12 months with their 95% confidence limits. The autocorrelation function (ACF) and partial autocorrelation function (PACF) of the station Kalanaur are shown in Figures 8 and 9. The figure indicates the presence of non-stationarity due to seasonality in the data. The non-stationarity can also be observed in the Box-and Whisker plots. Therefore, to make the data non-seasonal, a seasonal differencing (D-1) of data has been used. The ACF and PACF for various non-seasonal and seasonal differencing combinations have been obtained with 95% confidence limits.

4.6 Identification of Multiplicative ARIMA Models

For modelling a data series, a large number of models need to be considered due to the fact that identification methods often do not clearly determine the single best model

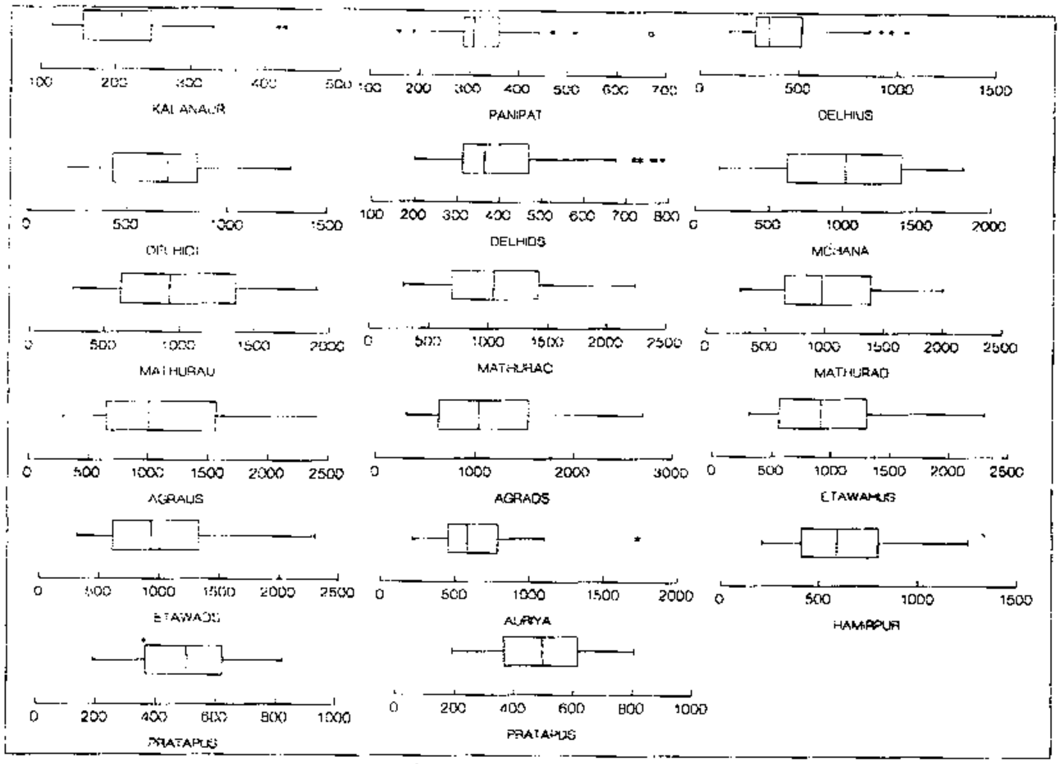


(a) Temperature

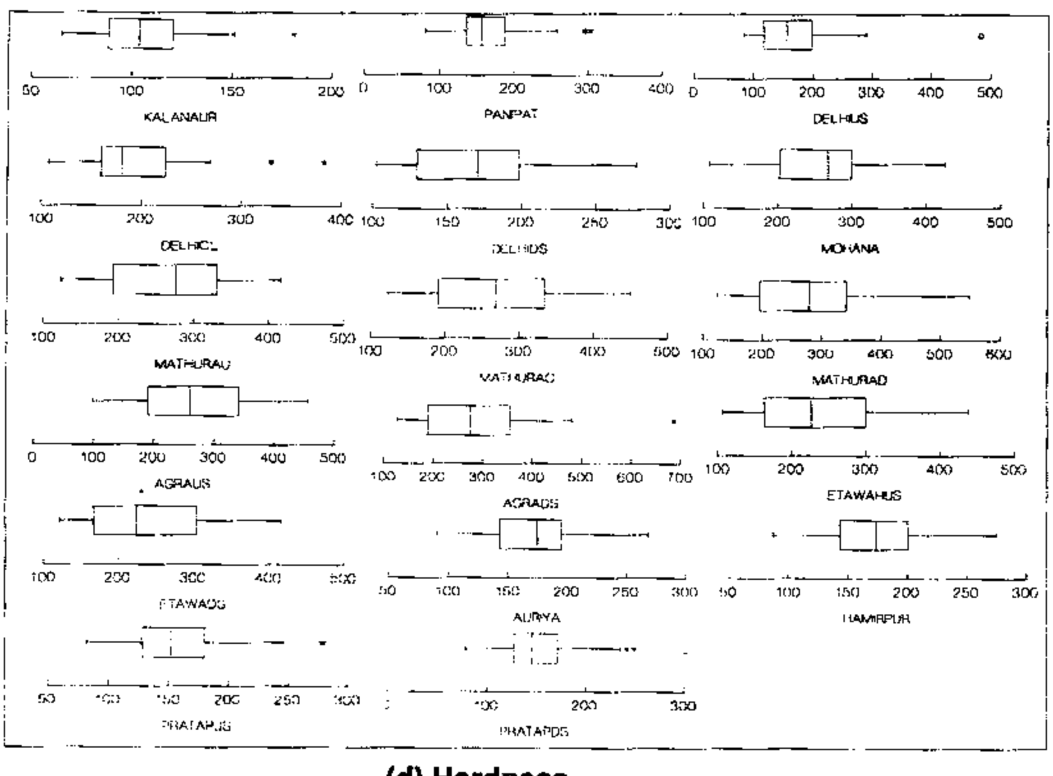


(b) pH

Fig.4 a: Box- and Whisker Diagram for water quality variables

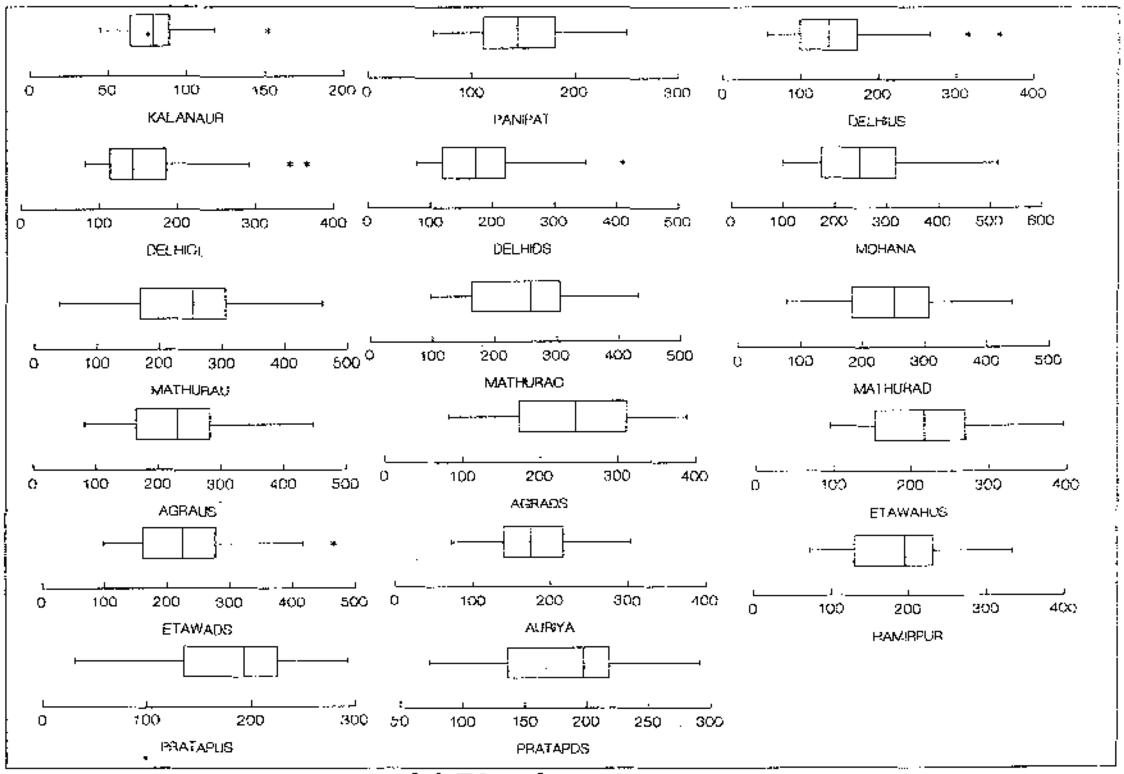


(c) Electrical conductivity

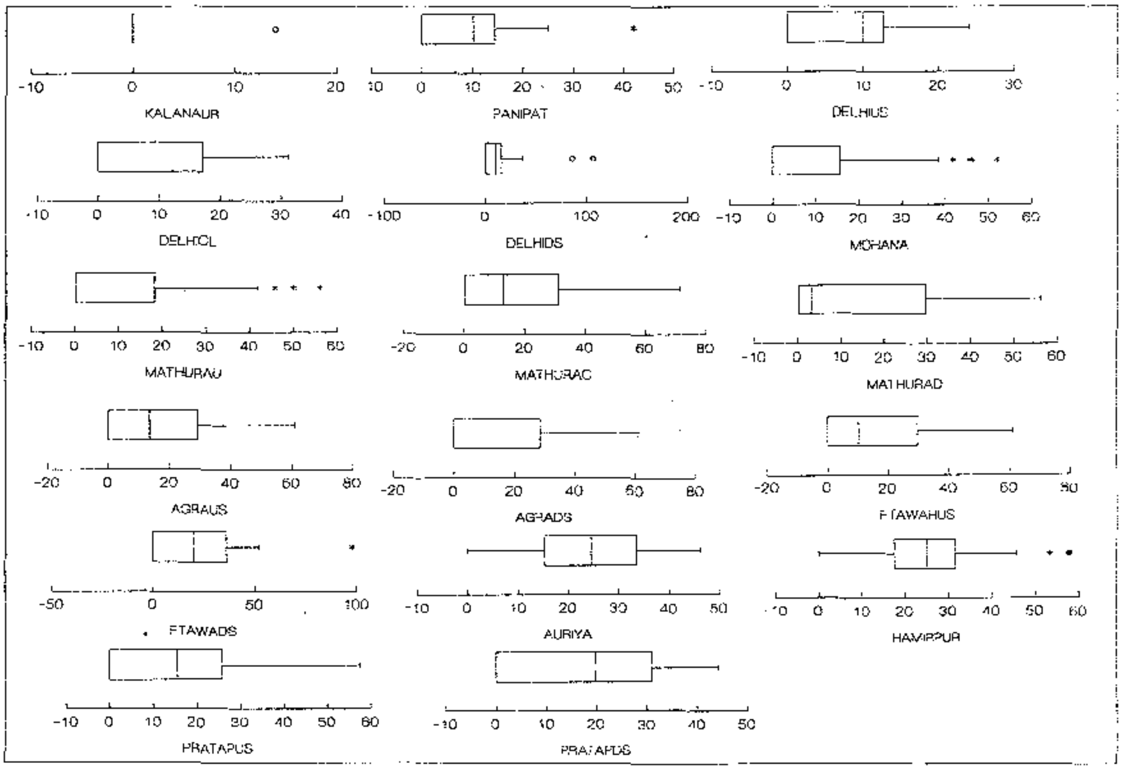


(d) Hardness

Fig.4 b: Box- and Whisker Diagram for water quality variables



(e) Bicarbonate



(f) Carbonate

Fig.4 c: Box- and Whisker Diagram for water quality variables

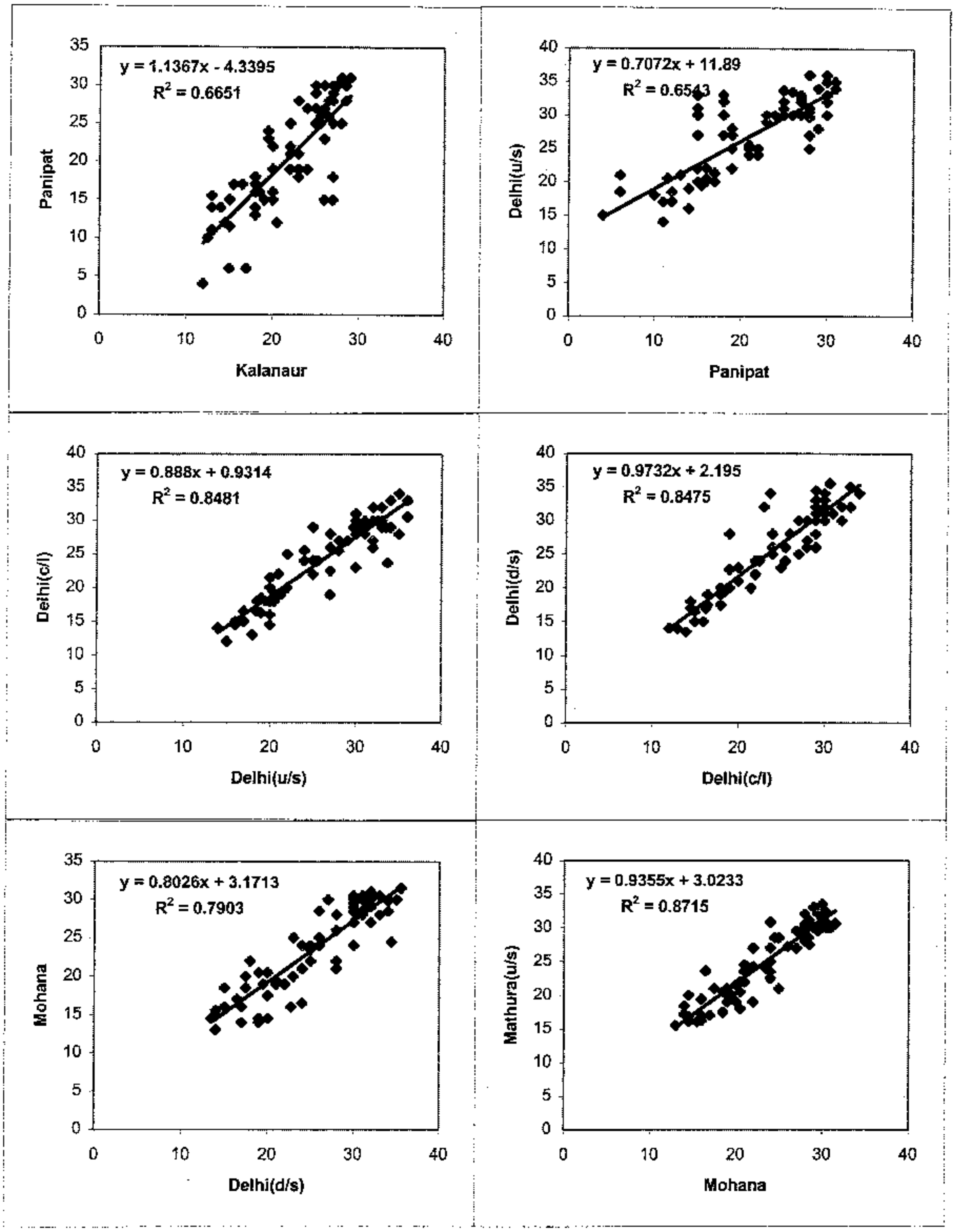


Fig.5a: Cross-correlation between Sampling stations for Temperature

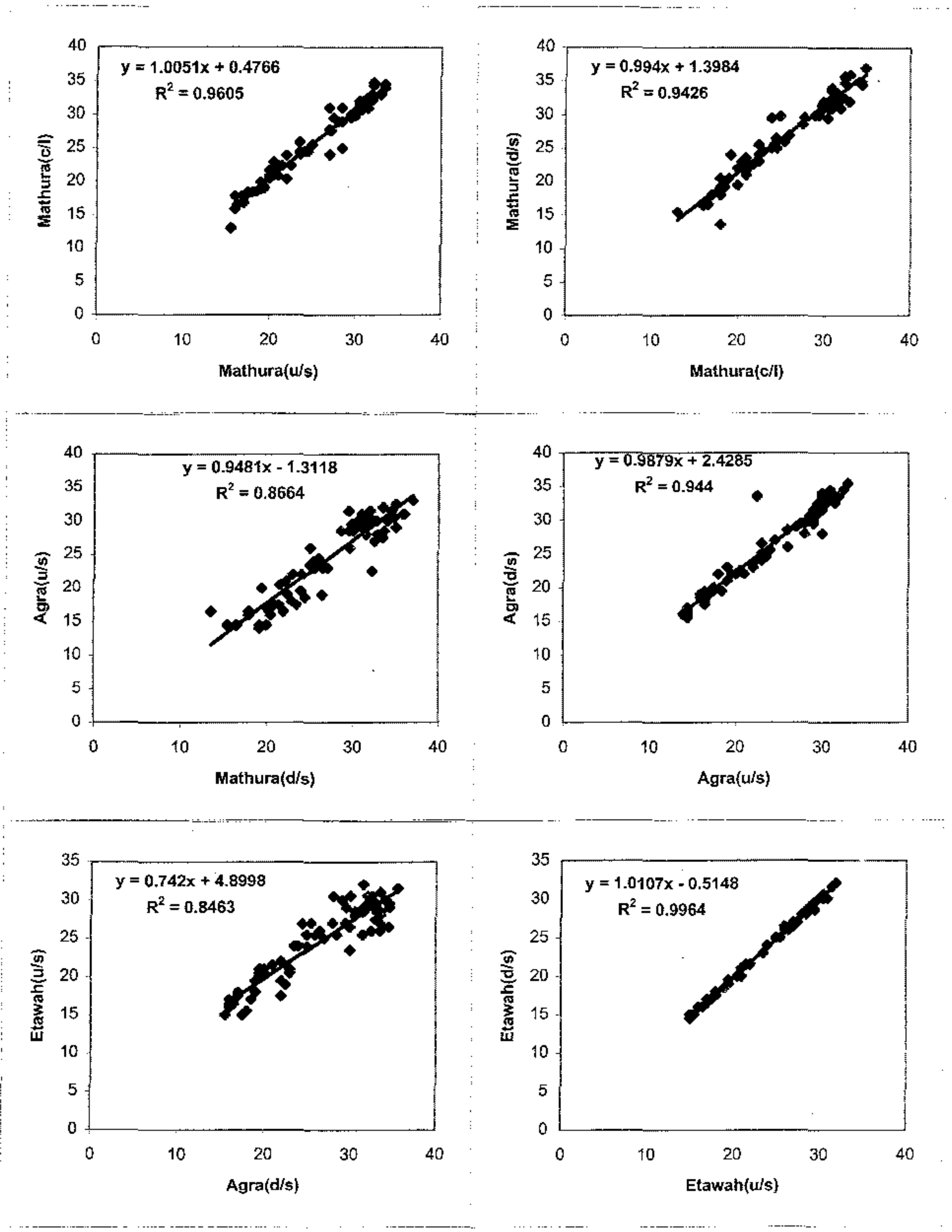


Fig.5b: Cross-correlation between Sampling stations for Temperature

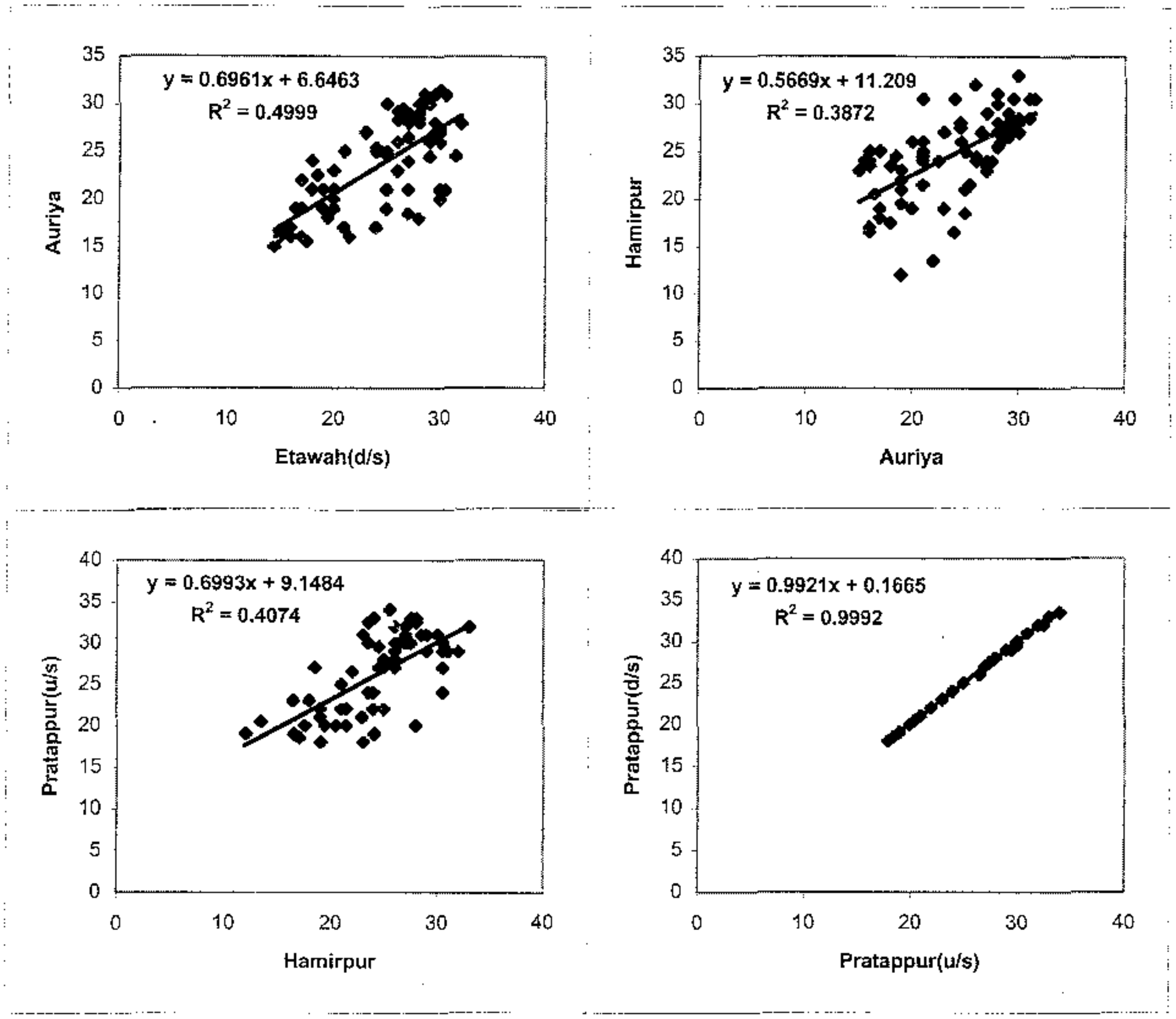


Fig.5c: Cross-correlation between Sampling stations for Temperature

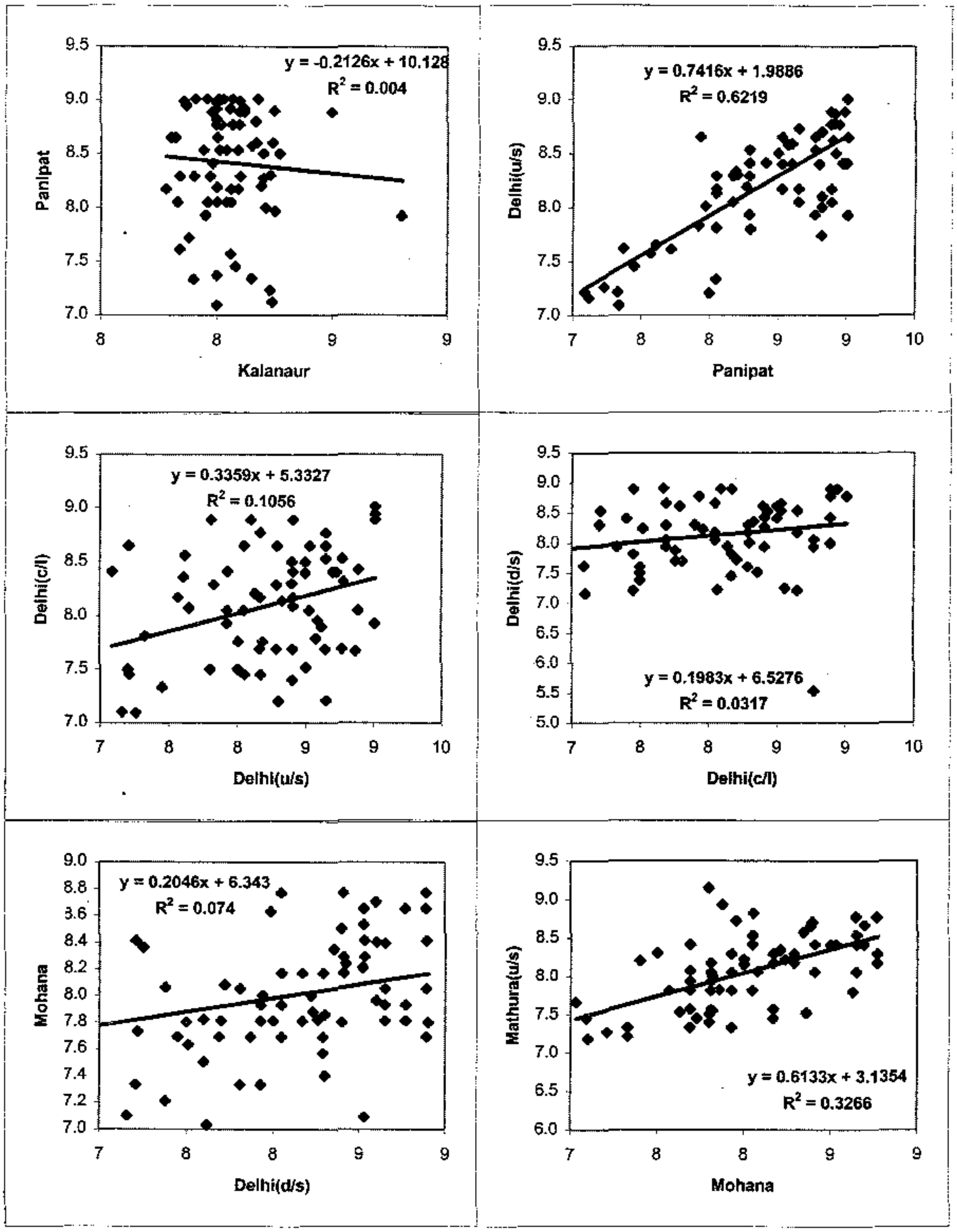


Fig.6a: Cross-correlation between Sampling stations for pH

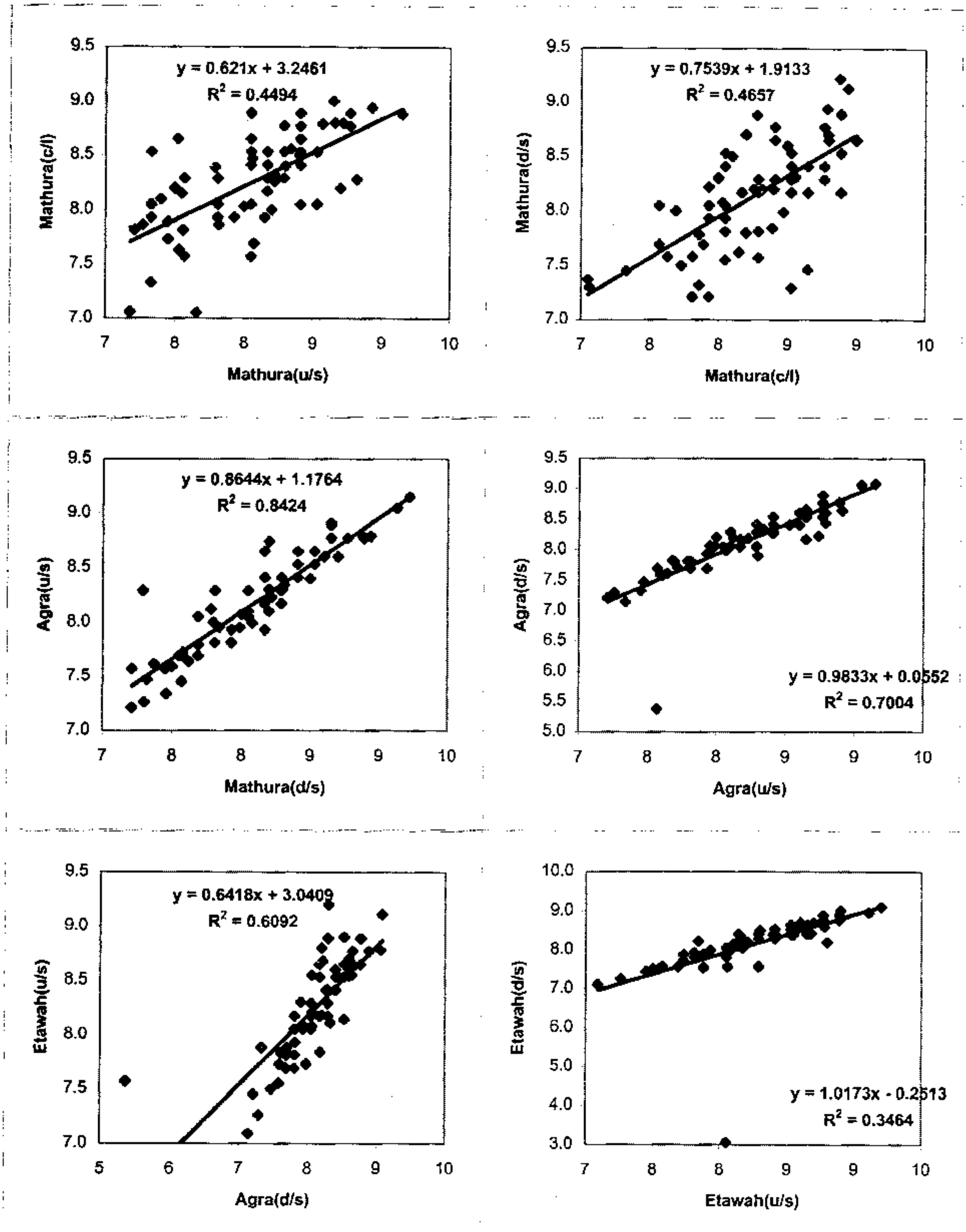


Fig.6b: Cross-correlation between Sampling stations for pH

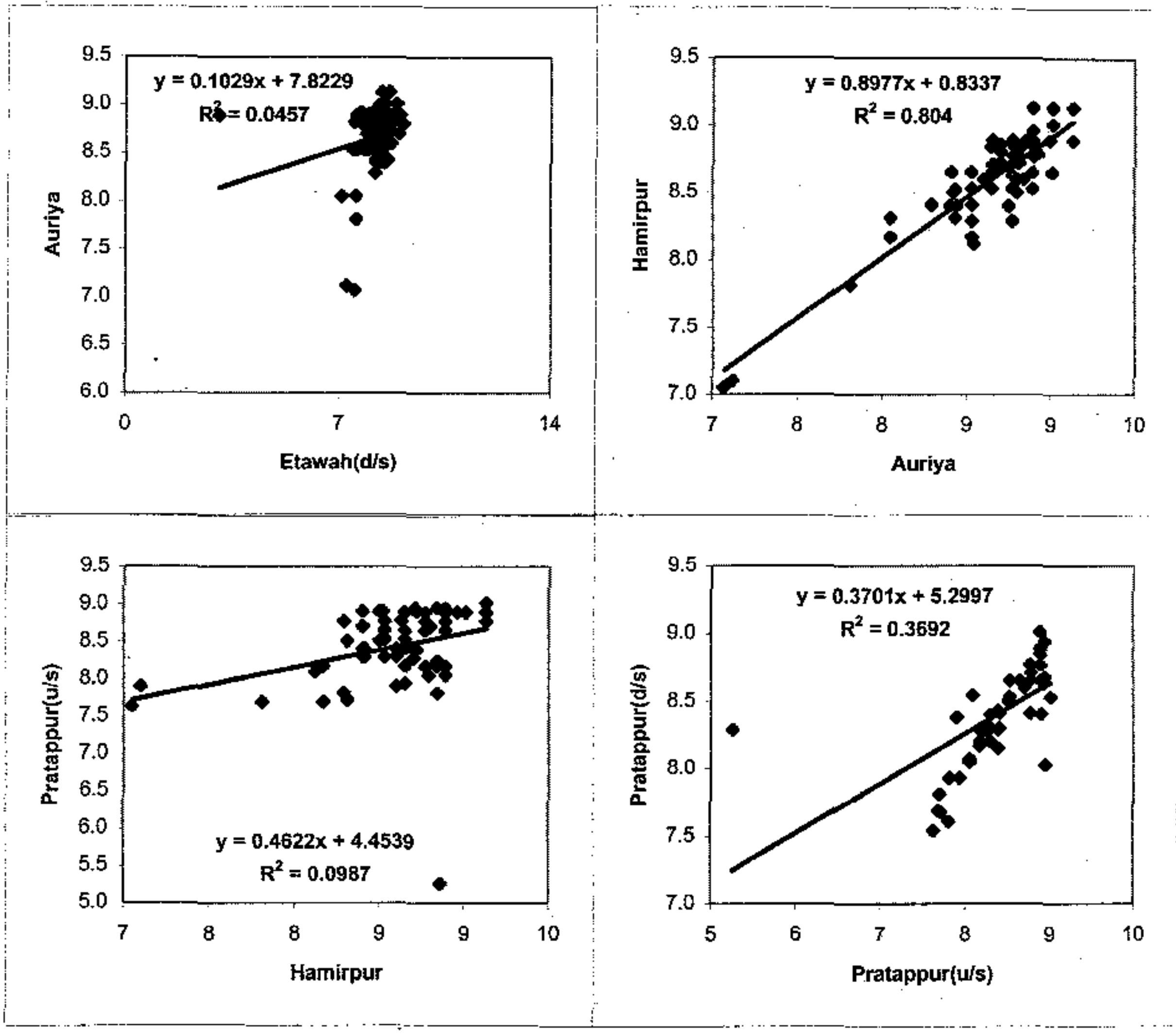


Fig.6c: Cross-correlation between Sampling stations for pH

Table 3: Cross-correlation of water quality variables between two adjacent stations

Water quality variable	stations	Regression Equation	Correlation coefficient, r^2
Temperature	Kalanaur to Panipat	y = 1.1367x - 4.3395	0.6651
	Panipat to Delhi (u/s)	y = 0.7072x + 11.89	.6543
	Delhi (u/s) Delhi (c/l)	y = 0.888x + 0.9314	.8481
	Delhi 9c/l) to Delhi (d/s)	y = 0.9732x + 2.195	.8475
	Delhi (d/s) to Mohana	y = 0.8026x + 3.1713	.7903
	Mohana to Mathura (u/s)	y = 0.9355x + 3.0233	.8715
	Mathura(u/s) to Mathura(c/l)	y = 1.0051x + 0.4766	.9605
	Mathura (c/l) Mathura (d/s)	y = 0.994x + 1.3984	.9426
	Mathura (d/s) to Agra (u/s)	y = 0.9481x - 1.3118	.8664
	Agra (u/s) to Agra (d/s)	y = 0.9879x + 2.4285	.944
	Agra (d/s) to Etawah (u/s)	y = 0.742x + 4.8998	.8463
	Etawah (u/s) to Etwah (d/s)	y = 1.0107x - 0.5148	.9964
	Etawah (d/s) to Auriya	y = 0.6961x + 6.6463	.4999
	Auriya to Hamirpur	y = 0.5669x + 11.209	.3872
	Hamirpur to Praptapur(u/s)	y = 0.6993x + 9.1484	.4074
	Pratappur(u/s) to Pratappur (d/s)	y = 0.9921x + 0.1665	.9992
pH	Kalanaur to Panipat	y = -0.2126x + 10.128	.004
	Panipat to Delhi (u/s)	y = 0.7416x + 1.9886	.6219
	Delhi (u/s) Delhi (c/l)	y = 0.3359x + 5.3327	.1056
	Delhi 9c/l) to Delhi (d/s)	y = 0.1983x + 6.5276	.0317
	Delhi (d/s) to Mohana	y = 0.2046x + 6.343	.074
	Mohana to Mathura (u/s)	y = 0.6133x + 3.1354	.3266
	Mathura(u/s) to Mathura(c/l)	y = 0.621x + 3.2461	.4494
	Mathura (c/l) Mathura (d/s)	y = 0.7539x + 1.9133	.4657
	Mathura (d/s) to Agra (u/s)	y = 0.8644x + 1.1764	.8424
	Agra (u/s) to Agra (d/s)	y = 0.9833x + 0.0552	.7004
	Agra (d/s) to Etawah (u/s)	y = 0.6418x + 3.0409	.6092
	Etawah (u/s) to Etwah (d/s)	y = 1.0173x - 0.2513	.3464
	Etawah (d/s) to Auriya	y = 0.1029x + 7.8229	.0457
	Auriya to Hamirpur	y = 0.8977x + 0.8337	.804
	Hamirpur to Praptapur(u/s)	y = 0.4622x + 4.4539	.0987
	Pratappur(u/s) to Pratappur (d/s)	y = 0.3701x + 5.2997	.3692
Electrical conductivity	Kalanaur to Panipat	y = 0.4232x + 236.53	.1101
	Panipat to Delhi (u/s)	y = 0.5746x + 242.67	.0434
	Delhi (u/s) Delhi (c/l)	y = 0.3868x + 498.47	.1001

	Delhi 9c/l) to Delhi (d/s)	y = 0.0803x + 358.75	.0205
	Delhi (d/s) to Mohana	y = 1.0656x + 538.37	.1351
	Mohana to Mathura (u/s)	y = 0.6888x + 332.43	.4319
	Mathura(u/s) to Mathura(c/l)	y = 0.969x + 95.051	.832
	Mathura (c/l) Mathura (d/s)	y = 0.8881x + 89.339	.8317
	Mathura (d/s) to Agra (u/s)	y = 1.0052x + 63.389	.7556
	Agra (u/s) to Agra (d/s)	y = 0.9673x + 48.981	.9185
	Agra (d/s) to Etawah (u/s)	y = 0.6897x + 251.66	.5011
	Etawah (u/s) to Etwah (d/s)	y = 0.8391x + 153.01	.8417
	Etawah (d/s) to Auriya	y = 0.2874x + 321.72	.3146
	Auriya to Hamirpur	y = 0.7954x + 121.95	.6254
	Hamirpur to Praptapur(u/s)	y = 0.5629x + 154.31	.6233
	Pratappur(u/s) to Pratappur (d/s)	y = 0.9719x + 9.8846	.9878
Hardness	Kalanaur to Panipat	y = -0.0864x + 175.89	.002
	Panipat to Delhi (u/s)	y = 0.9263x + 12.853	.4818
	Delhi (u/s) Delhi (c/l)	y = 0.465x + 112.38	.3238
	Delhi 9c/l) to Delhi (d/s)	y = 0.4573x + 82.417	.287
	Delhi (d/s) to Mohana	y = 0.8679x + 103.7	.3011
	Mohana to Mathura (u/s)	y = 0.8583x + 50.11	.5075
	Mathura(u/s) to Mathura(c/l)	y = 0.9693x + 9.388	.8751
	Mathura (c/l) Mathura (d/s)	y = 0.8991x + 35.892	.6971
	Mathura (d/s) to Agra (u/s)	y = 0.7623x + 53.331	.666
	Agra (u/s) to Agra (d/s)	y = 1.0937x - 8.1588	.8505
	Agra (d/s) to Etawah (u/s)	y = 0.5818x + 77.165	.5036
	Etawah (u/s) to Etwah (d/s)	y = 0.9515x + 13.148	.9579
	Etawah (d/s) to Auriya	y = 0.2681x + 103.8	.3458
	Auriya to Hamirpur	y = 0.809x + 36.639	.4542
	Hamirpur to Praptapur(u/s)	y = 0.616x + 49.375	.3965
	Pratappur(u/s) to Pratappur (d/s)	y = 0.8019x + 24.92	.8007
Bicarbonate	Kalanaur to Panipat	y = 0.1163x + 138.47	.0023
	Panipat to Delhi (u/s)	y = 0.7173x + 35.35	.3456
	Delhi (u/s) Delhi (c/l)	y = 0.7251x + 57.302	.4633
	Delhi 9c/l) to Delhi (d/s)	y = 0.6765x + 68.377	.3086
	Delhi (d/s) to Mohana	y = 0.754x + 122.2	.2827
	Mohana to Mathura (u/s)	y = 0.4646x + 125.49	.283
	Mathura(u/s) to Mathura(c/l)	y = 0.7305x + 64.209	.6781
	Mathura (c/l) Mathura (d/s)	y = 0.9424x + 16.502	.7634
	Mathura (d/s) to Agra (u/s)	y = 0.7101x + 51.131	.5994
	Agra (u/s) to Agra (d/s)	y = 0.9505x + 25.017	.7912
	Agra (d/s) to Etawah (u/s)	y = 0.5611x + 81.285	.4083

	Etawah (u/s) to Etwah (d/s)	y = 0.9854x + 12.933	.8167
	Etawah (d/s) to Auriya	y = 0.317x + 102.43	.2558
	Auriya to Hamirpur	y = 0.8932x + 29.224	.5628
	Hamirpur to Praptapur(u/s)	y = 0.7007x + 54.773	.4698
	Pratappur(u/s) to Pratappur (d/s)	y = 0.8408x + 29.287	.9224
Carbonate	Kalanaur to Panipat	y = -0.2273x + 10.183	.0034
	Panipat to Delhi (u/s)	y = 0.3008x + 4.9012	.1313
	Delhi (u/s) Delhi (c/l)	y = 0.3576x + 5.2043	.0703
	Delhi 9c/l) to Delhi (d/s)	y = 0.4419x + 8.1239	.0652
	Delhi (d/s) to Mohana	y = 0.2512x + 7.2268	.0745
	Mohana to Mathura (u/s)	y = 0.1868x + 9.2634	.0344
	Mathura(u/s) to Mathura(c/l)	y = 0.4347x + 13.59	.0981
	Mathura (c/l) Mathura (d/s)	y = 0.5874x + 5.4217	.4645
	Mathura (d/s) to Agra (u/s)	y = 0.817x + 4.6232	.605
	Agra (u/s) to Agra (d/s)	y = 0.7026x + 2.9636	.6155
	Agra (d/s) to Etawah (u/s)	y = 0.7321x + 5.0973	.5312
	Etawah (u/s) to Etwah (d/s)	y = 0.6942x + 7.3619	.4105
	Etawah (d/s) to Auriya	y = 0.0672x + 22.253	.0113
	Auriya to Hamirpur	y = 0.7421x + 7.572	.4977
	Hamirpur to Praptapur(u/s)	y = 0.5042x + 4.1955	.2565
	Pratappur(u/s) to Pratappur (d/s)	y = 0.7664x + 5.5091	.5396
Calcium	Kalanaur to Panipat	y = 0.0825x + 32.375	.0018
	Panipat to Delhi (u/s)	y = 0.316x + 29.854	.0538
	Delhi (u/s) Delhi (c/l)	y = 0.4257x + 28.852	.246
	Delhi 9c/l) to Delhi (d/s)	y = 0.4158x + 22.289	.1603
	Delhi (d/s) to Mohana	y = 0.2314x + 45.828	.0226
	Mohana to Mathura (u/s)	y = 0.6105x + 21.298	.3044
	Mathura(u/s) to Mathura(c/l)	y = 0.6139x + 20.088	.3444
	Mathura (c/l) Mathura (d/s)	y = 0.5789x + 26.169	.4482
	Mathura (d/s) to Agra (u/s)	y = 0.6174x + 16.158	.3716
	Agra (u/s) to Agra (d/s)	y = 0.7471x + 13.38	.6443
	Agra (d/s) to Etawah (u/s)	y = 0.4394x + 21.896	.2618
	Etawah (u/s) to Etwah (d/s)	y = 0.8223x + 9.1778	.628
	Etawah (d/s) to Auriya	y = 0.1563x + 26.784	.0564
	Auriya to Hamirpur	y = 0.7348x + 9.3626	.3766
	Hamirpur to Praptapur(u/s)	y = 0.558x + 11.811	.2273
	Pratappur(u/s) to Pratappur (d/s)	y = 0.6347x + 10.828	.5492
Magnesuim	Kalanaur to Panipat	y = -0.3193x + 22.286	.0697
	Panipat to Delhi (u/s)	y = 1.0142x - 1.9514	.3801
	Delhi (u/s) Delhi (c/l)	y = 0.584x + 10.099	.4491

	Delhi 9c/l) to Delhi (d/s)	y = 0.3519x + 8.3888	.1815
	Delhi (d/s) to Mohana	y = 0.6779x + 16.477	.2022
	Mohana to Mathura (u/s)	y = 0.4768x + 18.458	.1901
	Mathura(u/s) to Mathura(c/l)	y = 0.769x + 8.3481	.5113
	Mathura (c/l) Mathura (d/s)	y = 0.8916x + 2.385	.6731
	Mathura (d/s) to Agra (u/s)	y = 0.8164x + 6.798	.7243
	Agra (u/s) to Agra (d/s)	y = 1.0642x + 1.5214	.8352
	Agra (d/s) to Etawah (u/s)	y = 0.691x + 6.0059	.5485
	Etawah (u/s) to Etwah (d/s)	y = 0.8528x + 5.1195	.8148
	Etawah (d/s) to Auriya	y = 0.2506x + 12.61	.2138
	Auriya to Hamirpur	y = 0.8337x + 4.0808	.4984
	Hamirpur to Praptapur(u/s)	y = 0.5352x + 7.7723	.3385
	Pratappur(u/s) to Pratappur (d/s)	y = 0.8254x + 2.203	.764
Sodium	Kalanaur to Panipat	y = -0.1176x + 6.9316	.0003
	Panipat to Delhi (u/s)	y = 0.8331x + 16.181	.0445
	Delhi (u/s) Delhi (c/l)	y = 0.5267x + 40.234	.1742
	Delhi 9c/l) to Delhi (d/s)	y = 0.0971x + 13.355	.0471
	Delhi (d/s) to Mohana	y = 1.3037x + 68.655	.1013
	Mohana to Mathura (u/s)	y = 0.676x + 30.27	.5008
	Mathura(u/s) to Mathura(c/l)	y = 0.9468x + 9.3665	.8607
	Mathura (c/l) Mathura (d/s)	y = 0.9323x + 7.3781	.8362
	Mathura (d/s) to Agra (u/s)	y = 1.0257x + 3.1828	.7841
	Agra (u/s) to Agra (d/s)	y = 1.091x - 1.0733	.9383
	Agra (d/s) to Etawah (u/s)	y = 0.7123x + 24.488	.5591
	Etawah (u/s) to Etwah (d/s)	y = 0.9x + 13.402	.8003
	Etawah (d/s) to Auriya	y = 0.3051x + 21.079	.4571
	Auriya to Hamirpur	y = 0.8386x + 8.785	.7497
	Hamirpur to Praptapur(u/s)	y = 0.7202x + 7.7366	.6815
	Pratappur(u/s) to Pratappur (d/s)	y = 0.9434x + 0.1828	.9708
Potassium	Kalanaur to Panipat	y = -0.0808x + 5.936	.0014
	Panipat to Delhi (u/s)	y = 1.3219x - 0.7482	.4171
	Delhi (u/s) Delhi (c/l)	y = 0.7017x + 7.4779	.244
	Delhi 9c/l) to Delhi (d/s)	y = 0.2308x + 5.0699	.1471
	Delhi (d/s) to Mohana	y = 0.8295x + 12.581	.1801
	Mohana to Mathura (u/s)	y = 0.5032x + 5.7942	.2971
	Mathura(u/s) to Mathura(c/l)	y = 1.0023x + 5.7299	.4873
	Mathura (c/l) Mathura (d/s)	y = 0.5586x + 5.2659	.5479
	Mathura (d/s) to Agra (u/s)	y = 0.8737x + 1.8046	.7575
	Agra (u/s) to Agra (d/s)	y = 1.0613x + 0.0695	.9664
	Agra (d/s) to Etawah (u/s)	y = 0.7697x + 2.4252	.6846

	Etawah (u/s) to Etwah (d/s)	y = 0.7697x + 2.4252	.6846
	Etawah (d/s) to Auriya	y = 0.3845x + 1.8567	.2764
	Auriya to Hamirpur	y = 0.4093x + 4.1778	.2794
	Hamirpur to Praptapur(u/s)	y = 0.5147x + 2.1798	.5142
	Pratappur(u/s) to Pratappur (d/s)	y = 0.8998x + 0.2594	.789
Chloride	Kalanaur to Panipat	y = 0.007x + 7.0475	.00005
	Panipat to Delhi (u/s)	y = 0.1217x + 32.575	.0003
	Delhi (u/s) Delhi (c/l)	y = 0.4677x + 53.941	.1629
	Delhi 9c/l) to Delhi (d/s)	y = -0.0512x + 20.715	.0264
	Delhi (d/s) to Mohana	y = -1.0488x + 137.59	.0413
	Mohana to Mathura (u/s)	y = 0.8764x + 32.401	.5382
	Mathura(u/s) to Mathura(c/l)	y = 0.889x + 15.943	.9071
	Mathura (c/l) Mathura (d/s)	y = 1.0427x + 12.413	.7434
	Mathura (d/s) to Agra (u/s)	y = 0.9285x + 11.945	.7497
	Agra (u/s) to Agra (d/s)	y = 1.0904x - 3.8901	.9608
	Agra (d/s) to Etawah (u/s)	y = 0.643x + 37.919	.5245
	Etawah (u/s) to Etwah (d/s)	y = 0.9444x + 10.088	.9475
	Etawah (d/s) to Auriya	y = 0.1407x + 25.957	.3771
	Auriya to Hamirpur	y = 0.8852x + 24.453	.1123
	Hamirpur to Praptapur(u/s)	y = 0.0789x + 31.234	.0625
	Pratappur(u/s) to Pratappur (d/s)	y = 0.9876x + 0.2834	.9768
Sulphate	Kalanaur to Panipat	y = 0.1517x + 21.956	.0018
	Panipat to Delhi (u/s)	y = 1.0999x + 14.775	.2527
	Delhi (u/s) Delhi (c/l)	y = 0.5795x + 37.344	.263
	Delhi 9c/l) to Delhi (d/s)	y = 0.0354x + 22.205	.0063
	Delhi (d/s) to Mohana	y = 0.2445x + 49.436	.025
	Mohana to Mathura (u/s)	y = 0.9757x + 23.111	.3755
	Mathura(u/s) to Mathura(c/l)	y = 0.7612x + 18.325	.5657
	Mathura (c/l) Mathura (d/s)	y = 0.7295x + 24.971	.5165
	Mathura (d/s) to Agra (u/s)	y = 1.1192x + 1.0946	.7169
	Agra (u/s) to Agra (d/s)	y = x	1.00
	Agra (d/s) to Etawah (u/s)	y = 0.5862x + 26.034	.4518
	Etawah (u/s) to Etwah (d/s)	y = 0.8668x + 13.299	.7811
	Etawah (d/s) to Auriya	y = 0.3342x + 11.868	.3639
	Auriya to Hamirpur	y = 0.7024x + 7.7565	.649
	Hamirpur to Praptapur(u/s)	y = 0.6118x + 5.0651	.4624
	Pratappur(u/s) to Pratappur (d/s)	y = 0.9692x + 0.0631	.9141
Dissolved Oxygen (DO)	Kalanaur to Panipat		

	Panipat to Delhi (u/s)	y = -0.5534x + 10.086	.0148
	Delhi (u/s) Delhi (c/l)	y = -0.1568x + 2.6641	.0368
	Delhi 9c/l) to Delhi (d/s)	y = 0.1886x + 3.3339	.088
	Delhi (d/s) to Mohana	y = 0.2577x + 2.2648	.1118
	Mohana to Mathura (u/s)	y = -0.4198x + 10.504	.0178
	Mathura(u/s) to Mathura(c/l)	y = 0.8138x + 1.1996	.7495
	Mathura (c/l) Mathura (d/s)	y = 1.078x - 0.2436	.711
	Mathura (d/s) to Agra (u/s)	y = 0.1734x + 5.6827	.0926
	Agra (u/s) to Agra (d/s)	y = 1.0571x - 1.3189	.7694
	Agra (d/s) to Etawah (u/s)	y = 0.2156x + 7.4307	.0626
	Etawah (u/s) to Etwah (d/s)	y = 0.7369x + 1.4468	.6452
	Etawah (d/s) to Auriya	y = 0.3304x + 6.2847	.1457
	Auriya to Hamirpur	y = -0.1932x + 8.6793	.1236
	Hamirpur to Praptapur(u/s)	y = -0.0533x + 8.0722	.0854
	Pratappur(u/s) to Pratappur (d/s)	y = 0.8407x + 1.2113	.7657
Biochemical Oxygen Demand (BOD)	Kalanaur to Panipat	y = 0.8407x + 1.2113	.7657
	Panipat to Delhi (u/s)	y = 0.0993x + 16.589	.0013
	Delhi (u/s) Delhi (c/l)	y = 0.4265x + 23.915	.1229
	Delhi 9c/l) to Delhi (d/s)	y = 0.4457x + 5.5154	.35
	Delhi (d/s) to Mohana	y = 0.2696x + 26.088	.0453
	Mohana to Mathura (u/s)	y = 0.5285x + 4.7111	.2345
	Mathura(u/s) to Mathura(c/l)	y = 0.6594x + 4.6838	.8408
	Mathura (c/l) Mathura (d/s)	y = 0.6986x + 5.7056	.6147
	Mathura (d/s) to Agra (u/s)	y = 0.3634x + 10.701	.1267
	Agra (u/s) to Agra (d/s)	y = 0.8276x + 11.633	.3632
	Agra (d/s) to Etawah (u/s)	y = 0.0948x + 11.506	.0247
	Etawah (u/s) to Etwah (d/s)	y = 0.8438x + 3.7012	.7503
	Etawah (d/s) to Auriya	y = 0.0968x + 3.1599	.1409
	Auriya to Hamirpur	y = 0.4882x + 3.4451	.0961
	Hamirpur to Praptapur(u/s)	y = 0.6644x + 1.507	.2414
	Pratappur(u/s) to Pratappur (d/s)	y = 0.986x - 0.1677	.963
Ammonium	Kalanaur to Panipat	y = -0.0898x + 0.0358	.0149
	Panipat to Delhi (u/s)	y = -0.8873x + 0.5258	.0068
	Delhi (u/s) Delhi (c/l)	y = 1.3538x + 3.1274	.0757
	Delhi 9c/l) to Delhi (d/s)	y = 0.0263x + 0.3387	.0444
	Delhi (d/s) to Mohana	y = 1.5145x + 3.1511	.0353
	Mohana to Mathura (u/s)	y = 0.0344x + 0.2392	.0963
	Mathura(u/s) to	y = 0.8114x + 0.1452	.0531

	Mathura(c/l)		
	Mathura (c/l) Mathura (d/s)	y = 0.5691x + 0.1174	.4871
	Mathura (d/s) to Agra (u/s)	y = 0.453x + 0.0851	.5235
	Agra (u/s) to Agra (d/s)	y = 1.4346x + 0.5276	.1856
	Agra (d/s) to Etawah (u/s)	y = 0.1309x + 0.232	.0626
	Etawah (u/s) to Etwah (d/s)	y = 0.3021x + 0.2466	.0633
	Etawah (d/s) to Auriya	y = 0.0183x + 0.0707	.0077
	Auriya to Hamirpur	y = -0.0861x + 0.1318	.0062
	Hamirpur to Praptapur(u/s)	y = 0.5688x + 0.0024	.5268
	Pratappur(u/s) to Pratappur (d/s)	y = 0.6786x + 0.0139	.6346
Nitrite	Kalanaur to Panipat	y = 0.0363x + 0.0351	.0005
	Panipat to Delhi (u/s)	y = 0.1129x + 0.091	.0019
	Delhi (u/s) Delhi (c/l)	y = -0.2613x + 0.5981	.0025
	Delhi 9c/l) to Delhi (d/s)	y = 0.0255x + 0.1743	.0025
	Delhi (d/s) to Mohana	y = 0.0896x + 0.7709	.0016
	Mohana to Mathura (u/s)	y = 0.0001x + 0.293	.00000004
	Mathura(u/s) to Mathura(c/l)	y = 0.8155x + 0.1271	.6113
	Mathura (c/l) Mathura (d/s)	y = 0.8356x + 0.2275	.4409
	Mathura (d/s) to Agra (u/s)	y = 0.4721x - 0.0377	.2246
	Agra (u/s) to Agra (d/s)	y = 0.9579x + 0.1569	.7786
	Agra (d/s) to Etawah (u/s)	y = 0.3124x + 0.0852	.294
	Etawah (u/s) to Etwah (d/s)	y = 0.3975x + 0.1163	.2414
	Etawah (d/s) to Auriya	y = 0.0886x + 0.0485	.0384
	Auriya to Hamirpur	y = 0.0208x + 0.0724	.0002
	Hamirpur to Praptapur(u/s)	y = -0.0108x + 0.0343	.0019
	Pratappur(u/s) to Pratappur (d/s)	y = 1.6693x - 0.0143	.3684
Nitrate	Kalanaur to Panipat	y = 0.9299x + 0.8219	.0455
	Panipat to Delhi (u/s)	y = 0.5335x + 1.6226	.1009
	Delhi (u/s) Delhi (c/l)	y = 1.4369x + 2.8456	.2203
	Delhi 9c/l) to Delhi (d/s)	y = 0.3115x + 2.6823	.4517
	Delhi (d/s) to Mohana	y = 1.4156x + 0.8513	.3603
	Mohana to Mathura (u/s)	y = 0.4987x + 3.9475	.4085
	Mathura(u/s) to Mathura(c/l)	y = 0.8901x + 2.0223	.8239
	Mathura (c/l) Mathura (d/s)	y = 0.8712x - 0.1756	.7972
	Mathura (d/s) to Agra (u/s)	y = 0.682x + 2.3966	.5164
	Agra (u/s) to Agra (d/s)	y = 1.0663x - 0.4192	.8771
	Agra (d/s) to Etawah (u/s)	y = 0.5264x + 0.6249	.8512
	Etawah (u/s) to Etwah (d/s)	y = 1.0789x + 0.0281	.9018
	Etawah (d/s) to Auriya	y = 0.2789x + 0.673	.5609
	Auriya to Hamirpur	y = 1.1986x + 1.6672	.4675
	Hamirpur to Praptapur(u/s)	y = 0.1236x + 0.5388	.2076

	Pratappur(u/s) to Pratappur (d/s)	y = 0.994x + 0.0395	.8846
Phosphate	Kalanaur to Panipat	y = -0.0237x + 0.3434	.0004
	Panipat to Delhi (u/s)	y = -0.0089x + 0.6463	.000006
	Delhi (u/s) Delhi (c/l)	y = 0.0617x + 1.1416	.0037
	Delhi 9c/l) to Delhi (d/s)	y = 0.1727x + 0.376	.1017
	Delhi (d/s) to Mohana	y = 0.9405x + 2.3345	.0491
	Mohana to Mathura (u/s)	y = 0.2662x + 1.1074	.1355
	Mathura(u/s) to Mathura(c/l)	y = 0.7506x + 0.4422	.4342
	Mathura (c/l) Mathura (d/s)	y = 0.6234x + 0.672	.5393
	Mathura (d/s) to Agra (u/s)	y = 0.6373x + 0.3173	.4909
	Agra (u/s) to Agra (d/s)	y = 0.7487x + 0.5212	.5561
	Agra (d/s) to Etawah (u/s)	y = 0.1935x + 0.4241	.1566
	Etawah (u/s) to Etwah (d/s)	y = 0.536x + 0.6904	.1045
	Etawah (d/s) to Auriya	y = 0.0591x + 0.1986	.0151
	Auriya to Hamirpur	y = 0.0718x + 0.1389	.0408
	Hamirpur to Praptapur(u/s)	y = 0.6614x + 0.0648	.0688
	Pratappur(u/s) to Pratappur (d/s)	y = 0.0858x + 0.0637	.1423
Sodium Adsorption Ratio (SAR)	Kalanaur to Panipat	y = -0.2091x + 0.3103	.0018
	Panipat to Delhi (u/s)	y = 4.4972x - 0.2413	.452
	Delhi (u/s) Delhi (c/l)	y = 0.1788x + 1.3157	.0752
	Delhi 9c/l) to Delhi (d/s)	y = 0.124x + 0.4261	.1038
	Delhi (d/s) to Mohana	y = 1.3682x + 1.5201	.1508
	Mohana to Mathura (u/s)	y = 0.7859x + 0.5125	.6455
	Mathura(u/s) to Mathura(c/l)	y = 0.9608x + 0.1743	.8268
	Mathura (c/l) Mathura (d/s)	y = 0.8611x + 0.384	.8008
	Mathura (d/s) to Agra (u/s)	y = 1.0591x + 0.0237	.767
	Agra (u/s) to Agra (d/s)	y = 1.0674x - 0.0797	.9763
	Agra (d/s) to Etawah (u/s)	y = 1.0752x + 0.1181	.3581
	Etawah (u/s) to Etwah (d/s)	y = 0.2276x + 2.6888	.0337
	Etawah (d/s) to Auriya	y = 0.0768x + 1.4805	.0624
	Auriya to Hamirpur	y = 0.7329x + 0.4887	.6448
	Hamirpur to Praptapur(u/s)	y = 0.7811x + 0.2252	.7126
	Pratappur(u/s) to Pratappur (d/s)	y = 0.9426x + 0.0275	.9698
Fluoride	Kalanaur to Panipat	y = 0.0705x + 0.1601	.0807
	Panipat to Delhi (u/s)	y = 1.1317x + 0.1433	.1334
	Delhi (u/s) Delhi (c/l)	y = 0.2592x + 0.3136	.111
	Delhi 9c/l) to Delhi (d/s)	y = 0.2347x + 0.1457	.0453
	Delhi (d/s) to Mohana	y = 0.0908x + 0.4984	.0029

	Mohana to Mathura (u/s)	y = 0.0695x + 0.3905	.0097
	Mathura(u/s) to Mathura(c/l)	y = 0.2757x + 0.3392	.0822
	Mathura (c/l) Mathura (d/s)	y = 0.3517x + 0.2732	.1107
	Mathura (d/s) to Agra (u/s)	y = 1.4797x - 0.1894	.7696
	Agra (u/s) to Agra (d/s)	y = 0.4828x + 0.1744	.7928
	Agra (d/s) to Etawah (u/s)	y = 1.4544x - 0.1474	.695
	Etawah (u/s) to Etwah (d/s)	y = 0.9743x + 0.0385	.8993
	Etawah (d/s) to Auriya	y = 0.0871x + 0.2353	.0198
	Auriya to Hamirpur	y = 0.3377x + 0.3102	.086
	Hamirpur to Praptapur(u/s)	y = 0.2638x + 0.1291	.3941
	Pratappur(u/s) to Pratappur (d/s)	y = 1.3707x - 0.1102	.7338
Silicate	Kalanaur to Panipat	y = 0.0965x + 10.114	.0321
	Panipat to Delhi (u/s)	y = 0.5177x + 4.1703	.1843
	Delhi (u/s) Delhi (c/l)	y = 0.4269x + 8.4465	.1994
	Delhi 9c/l) to Delhi (d/s)	y = 0.3683x + 8.3489	.0408
	Delhi (d/s) to Mohana	y = 0.4953x + 8.8906	.2954
	Mohana to Mathura (u/s)	y = 0.4014x + 7.3136	.1253
	Mathura(u/s) to Mathura(c/l)	y = 0.7208x + 3.639	.733
	Mathura (c/l) Mathura (d/s)	y = 0.9377x + 0.9192	.6908
	Mathura (d/s) to Agra (u/s)	y = 0.7332x + 2.4595	.5693
	Agra (u/s) to Agra (d/s)	y = 0.697x + 2.5708	.6624
	Agra (d/s) to Etawah (u/s)	y = 0.7669x + 1.926	.4052
	Etawah (u/s) to Etwah (d/s)	y = 1.005x + 0.2934	.8653
	Etawah (d/s) to Auriya	y = 0.0549x + 10.548	.0079
	Auriya to Hamirpur	y = 0.9234x + 2.0116	.4654
	Hamirpur to Praptapur(u/s)	y = 0.4756x + 5.8911	.2993
	Pratappur(u/s) to Pratappur (d/s)	y = 0.7637x + 3.4397	.6009

Fig.7: Inter-station correlation for Temperature

which fits the time series under study. Besides, as observed from the correlograms showing the persistence characteristics of the series, there exists seasonal components in addition to the non-seasonal aspects. To account for both these aspects the multiplicative type of ARIMA models seem to be adequate. In this study, for each parameter possible models have tentatively been identified. Subsequently, discrimination methods have been used for selecting the best model from the set of possible models.

The ACF and PACF correlograms have been used to identify the possible ARIMA models for each series. The ACF and PACF of the differenced series have been used to include the number of autoregressive (AR) and moving average (MA) parameters required in the model. As an example, the ACF and PACF correlograms for the temperature at station Kalanaur is shown in Figure 9. It has been observed from the analysis and ACF and PACF plots that the ARIMA $(1,0,1)*(0,0,0)_{12}$, $(1,1,1)*(0,0,0)_{12}$, $(1,0,1)*(1,0,0)_{12}$, $(1,0,1)*(0,0,1)_{12}$, $(1,1,1)*(1,0,0)_{12}$ and $(1,1,1)*(0,0,1)_{12}$. The results obtained using ARIMA $(1,0,1)*(0,1,0)_{12}$ for sample water quality variables temperature, chloride, sodium and electrical conductivity at Kalanaur, New Delhi (c/s), Agra(d/s) and Pratappur (d/s) are shown in Figures 10, 11, 12 and 13.

Fig. 8: Sequence plot of series for temperature

SEQUENCE PLOT OF SERIES

```
CASE   VALUE   12.000                          29.000
               +----+----+----+----+----+----+----+----+----+----+
  1   27.000   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
  2   23.000   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
  3   26.000   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
  4   26.000   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
  5   27.000   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
  6   20.000   XXXXXXXXXXXXXXXXXXXXXXXX
  7   19.000   XXXXXXXXXXXXXXXXXXXXX
  8   12.000   X
  9   15.000   XXXXXXXXX
 10   17.000   XXXXXXXXXXXXXXX
 11   22.000   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 12   23.000   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 13   25.000   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 14   25.000   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 15   26.000   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 16   25.000   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 17   22.000   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 18   20.000   XXXXXXXXXXXXXXXXXXXXXXXX
 19   18.000   XXXXXXXXXXXXXXXXXX
 20   13.000   XXX
 21   13.000   XXX
 22   20.000   XXXXXXXXXXXXXXXXXXXXXXXX
 23   23.000   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 24   25.000   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 25   27.000   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 26   28.000   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 27   27.000   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 28   27.000   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 29   24.000   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 30   20.000   XXXXXXXXXXXXXXXXXXXXXXXX
 31   18.000   XXXXXXXXXXXXXXXXXX
 32   15.000   XXXXXXXXX
 33   14.000   XXXXXX
 34   18.000   XXXXXXXXXXXXXXXXXX
 35   18.000   XXXXXXXXXXXXXXXXXX
 36   26.000   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 37   23.000   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 38   28.500   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 39   29.000   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 40   26.000   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 41   26.500   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 42   22.000   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 43   18.500   XXXXXXXXXXXXXXXXXXXX
 44   15.000   XXXXXXXXX
 45   13.000   XXX
 46   15.500   XXXXXXXXXXX
 47   19.500   XXXXXXXXXXXXXXXXXXXXXXX
 48   19.500   XXXXXXXXXXXXXXXXXXXXXXX
 49   28.000   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 50   27.000   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 51   27.000   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 52   26.500   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 53   25.500   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 54   24.000   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 55   20.000   XXXXXXXXXXXXXXXXXXXXXXXX
 56   14.500   XXXXXXXX
 57   14.000   XXXXXX
 58   18.000   XXXXXXXXXXXXXXXXXX
 59   23.000   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 60   27.000   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
```

Fig. 9: Autocorrelation and partial auto-correlation functions for temperature

Station: Kalanaur

PLOT OF AUTOCORRELATIONS

```
LAG  CORR   SE -1.0 -.8 -.6 -.4 -.2  .0  .2  .4  .6  .8 1.0
                 +----+----+----+----+----+----+----+----+----+----+
 1  .734  .129              (    |XXXXX)XXXXXXXXXXXX
 2  .402  .186             (     |XXXXXXXX)X
 3 -.058  .200             (   X|    )
 4 -.424  .200           (XXXXXXXXX|     )
 5 -.671  .215        XXXXXX(XXXXXXXX|        )
 6 -.740  .247      XXXXXX(XXXXXXXXXX|          )
 7 -.667  .282       XX(XXXXXXXXXXXXX|         )
 8 -.388  .307         (   XXXXXXXXX|           )
 9 -.052  .315         (          X|          )
10  .332  .315         (           |XXXXXXXX     )
11  .614  .321         (           |XXXXXXXXXXXXXX)
12  .692  .340         (           |XXXXXXXXXXXXXXX)X
13  .617  .363        (            |XXXXXXXXXXXXXX )
14  .331  .380        (            |XXXXXXXX        )
15  .005  .384       (             |               )
16 -.299  .384       (       XXXXXXX|               )
17 -.496  .388       (   XXXXXXXXXXX|                )
18 -.568  .399       ( XXXXXXXXXXXXX|                 )
19 -.510  .412      (   XXXXXXXXXXX|                  )
20 -.352  .422      (       XXXXXXX|                 )
21 -.078  .427      (             X|              )
22  .178  .428      (              |XXXX           )
23  .399  .429      (              |XXXXXXXXX          )
24  .519  .435      (              |XXXXXXXXXXXX          )
25  .472  .445     (               |XXXXXXXXXXX          )
26  .302  .453     (               |XXXXXXX             )
27  .092  .457     (               |XX              )
28 -.157  .457     (            XXX|               )
29 -.312  .458     (        XXXXXXX|                  )
30 -.396  .461     (      XXXXXXXXX|                   )
31 -.354  .467     (       XXXXXXXX|                   )
32 -.268  .472     (         XXXXXX|                  )
33 -.103  .474     (             XX|               )
34  .079  .474     (               |X              )
35  .261  .475     (               |XXXXXX             )
36  .341  .477     (               |XXXXXXXX            )
37  .322  .481    (                |XXXXXXXX            )
38  .203  .485    (                |XXXXX             )
39  .020  .486    (                |               )
40 -.100  .486    (              XX|               )
41 -.201  .486    (           XXXXX|                )
42 -.214  .488    (           XXXXX|                )
43 -.199  .489    (            XXXX|               )
44 -.120  .491    (             XXX|              )
45 -.038  .491    (                |              )
46  .058  .491    (                |X             )
47  .122  .491    (                |XXX             )
48  .177  .492    (                |XXXX              )
49  .142  .493    (                |XXX              )
50  .061  .494    (                |X              )
51 -.021  .494    (                |              )
52 -.074  .494    (               X|              )
53 -.064  .494    (               X|              )
54 -.049  .494    (               X|              )
55 -.022  .494    (                |              )
56 -.012  .494    (                |              )
57  .003  .494    (                |              )
58  .009  .494    (                |              )
59  .020  .494    (                |              )
60  .000  .494    (                |              )
```

PLOT OF PARTIAL AUTOCORRELATIONS

```
LAG  CORR   SE -1.0 -.8 -.6 -.4 -.2  .0  .2  .4  .6  .8 1.0
                 +----+----+----+----+----+----+----+----+----+----+
 1  .734  .129              (    |XXXXX)XXXXXXXXXXXX
 2 -.296  .129            X(XXXXX|   )
 3 -.528  .129        XXXXXXX(XXXXX|   )
 4 -.240  .129             (XXXXX|   )
 5 -.214  .129             (XXXXX|   )
 6 -.254  .129             (XXXXX|   )
 7 -.345  .129            XX(XXXXX|   )
 8 -.066  .129              (  X|   )
 9 -.115  .129              ( XX|   )
10  .013  .129              (   |   )
11  .083  .129              (   |XX )
12 -.132  .129              ( XXX|   )
13  .061  .129              (   |X  )
14 -.163  .129              (XXXX|   )
15 -.049  .129              (  X|   )
16  .045  .129              (   |X  )
17  .060  .129              (   |X  )
18  .008  .129              (   |   )
19 -.106  .129              ( XX|   )
20 -.080  .129              ( XX|   )
21 -.037  .129              (   |   )
22 -.119  .129              ( XX|   )
23 -.095  .129              ( XX|   )
24  .036  .129              (   |   )
25 -.078  .129              (  X|   )
26 -.184  .129              (XXXX|   )
27  .054  .129              (   |X  )
28 -.142  .129              ( XXX|   )
29 -.047  .129              (  X|   )
30  .012  .129              (   |   )
31  .090  .129              (   |XX )
32 -.117  .129              ( XX|   )
33  .003  .129              (   |   )
34  .053  .129              (   |X  )
35  .021  .129              (   |   )
36  .012  .129              (   |   )
37 -.126  .129              ( XXX|   )
38 -.039  .129              (   |   )
39 -.178  .129              (XXXX|   )
40  .066  .129              (   |X  )
41 -.036  .129              (   |   )
42 -.045  .129              (  X|   )
43  .014  .129              (   |   )
44 -.008  .129              (   |   )
45 -.040  .129              (   |   )
46 -.117  .129              ( XX|   )
47  .058  .129              (   |X  )
48 -.022  .129              (   |   )
49 -.036  .129              (   |   )
50 -.058  .129              (  X|   )
51 -.038  .129              (   |   )
52  .052  .129              (   |X  )
53  .057  .129              (   |X  )
54 -.016  .129              (   |   )
55 -.051  .129              (  X|   )
56  .028  .129              (   |   )
57  .010  .129              (   |   )
58 -.079  .129              (  X|   )
59 -.003  .129              (   |   )
60 -.026  .129              (   |   )
```

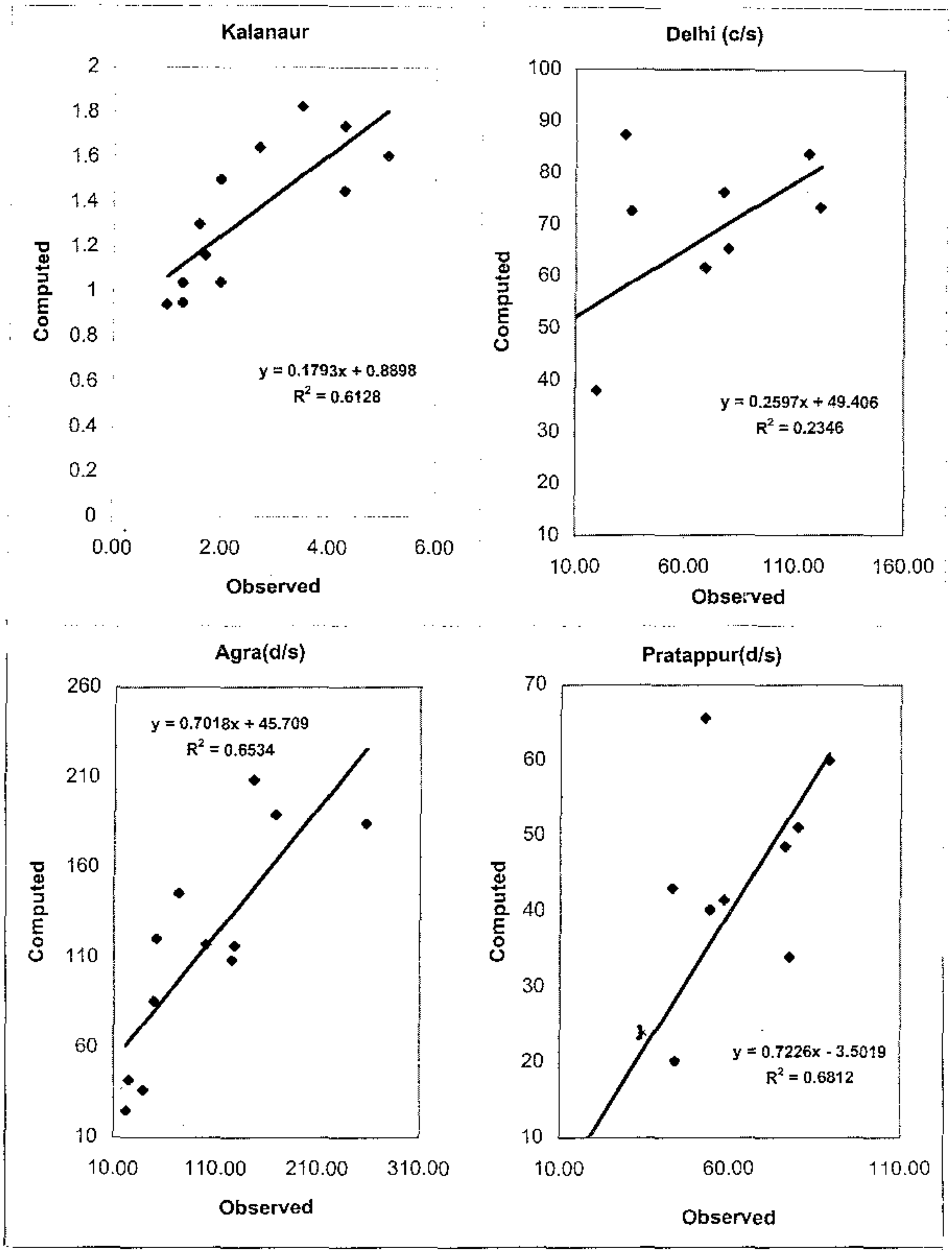


Fig. 10: Comparison between observed and computed values of Sodium

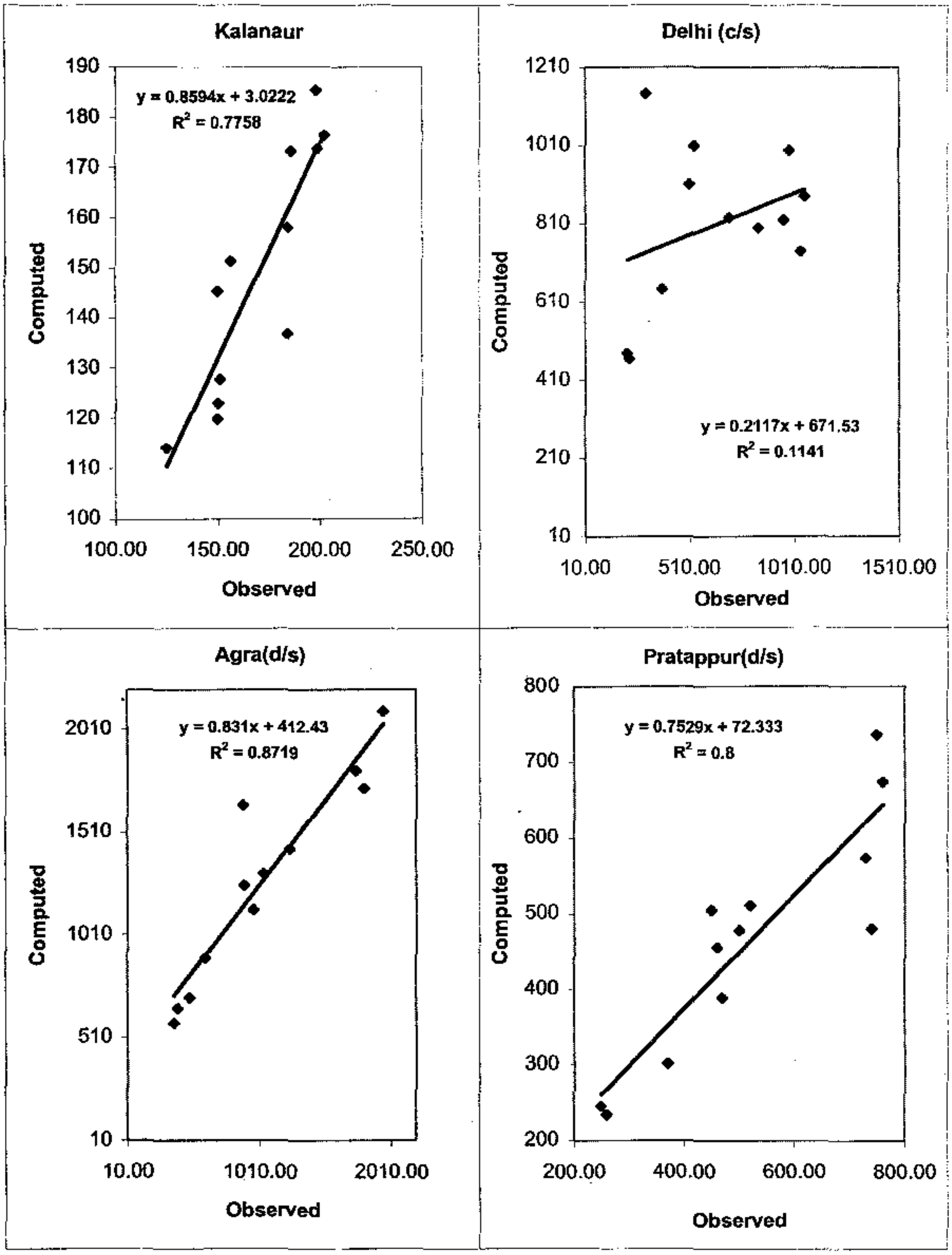


Fig. 11: Comparison between observed and computed values of Electrical conductivity

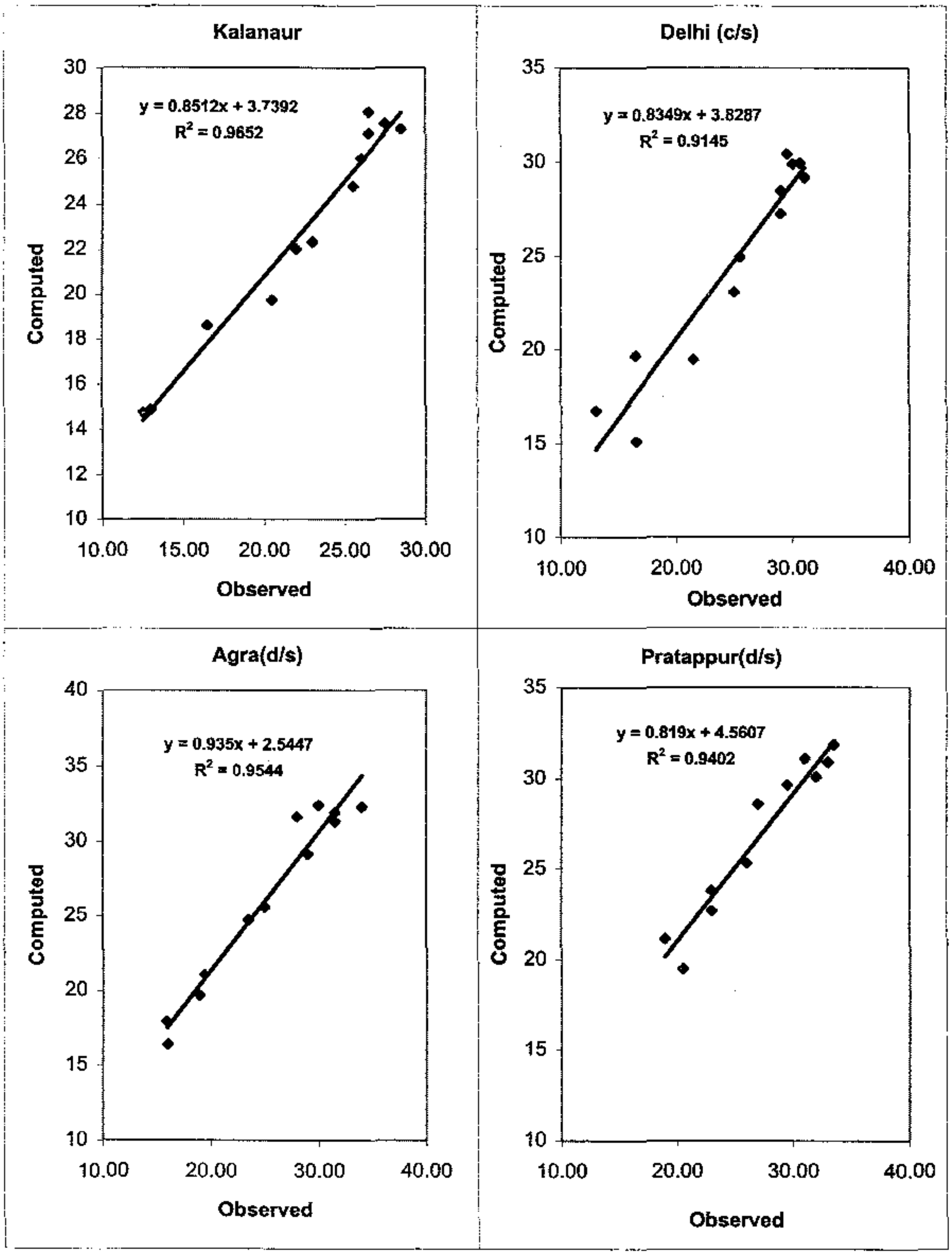


Fig. 12: Comparison between observed and computed values of Temperature

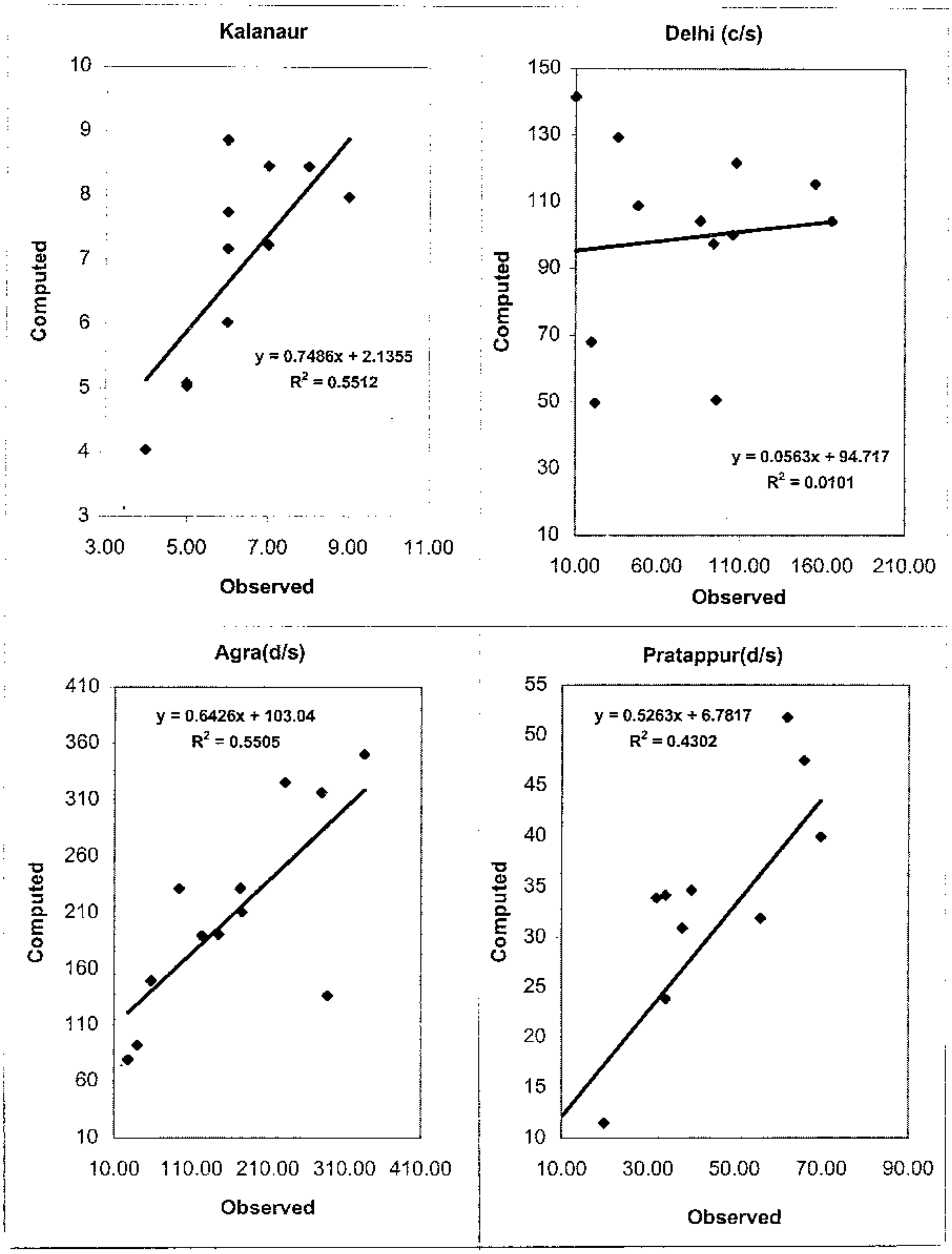


Fig. 13: Comparison between observed and computed values of Chloride

Chapter 5

SUMMARY AND CONCLUSIONS

The following conclusions can be drawn:

1. The twenty two water quality variables are non-normally distributed in some of the cases as the coefficient of skewness is not equal to zero in these cases.

2. Most of the time series plots did not show any definite trend. However seasonal affect has been observed in all the cases for the data sets. This pattern in water quality may be due to the influence of annual cyclic pattern of the hydrologic inputs to the river water environment.

3. The cross-correlation developed between the stations are not significant in all the cases. However, the regression equations developed in Table 3 can be used for approximate estimate of the water quality variables.

4. Analysis of these data using ARIMA model framework such as correlogram structure, minimisation for sum of squares of the residuals indicated that the models having both non-seasonal and seasonal components were, in general, appropriate for modelling the water quality time series at all the stations.

5.1 Scope for Future Work

1. The ARIMA models developed in the present work have the limitation of sufficient data sets. The model performance can be improved further with the increase in data sets.

2. The cross-correlation should be developed between water quality data of different stations, which is not attempted in the present work.

REFERENCES

1. ADSORBS/2/1980-81. Basin sub-basin inventory of water pollution: The Ganga basin- Yamuna sub-basin. Central Board for prevention and control of water pollution, New Delhi.
2. ADSORBS/2/1982-83. Basin sub-basin inventory of water pollution: The Ganga basin. Central Board for prevention and control of water pollution, New Delhi.
3. Bender, M. and Simonovic, S.. (1994). Time series modelling for long range stream flow forecasting. Journal of Water Resources Planning and Management, ASCE, Vol. 120, No.6, pp. 857-870.
4. Box, G. E. P. and Tiao, G. C.. (1975). Intervention analysis with applications to economic and environmental problems. Journal of American Statistical Association. Vol. 70, No. 30, pp. 70-79.
5. Central Board for the Prevention and Control of Water Pollution. (1982). Quality and trend of River Yamuna (1978-82). Report, New Delhi.
6. Central Water Commission. (1990). Water quality studies- Yamuna system (1978-90). Status Report, New Delhi.
7. Ellis, G. W., and Grasso, D. (1990). ARIMA process and reliability based design of water treatment facilities. Journal of Environmental Engineering, ASCE. Vol. 119, No. 3, pp.463-477.
8. Fox, P., Monga, T. R. and Miller, W. J.. (1991). Long term annual and seasonal trends in surface salinity in San Franscisco Bay. Journal of Hydrology, 122, pp. 93-117.
9. Hipel, K. W. and McLeod, A. I.. (1994). Time series modelling of water resources and environmental systems. Development in Water Science 45, Elsevier, Amsterdam, The Netherlands.
10. Hipel, K. W.. (1985). Time series analysis in perspective. Water Resources Bulletin. Vol. 21, No.4, pp. 609-624.
11. Hirsch, R. M. and Slack, J. R.. (1984). A non-parametric test for seasonal data with serial dependence. Water Resources Research. Vol. 20, No.6, pp. 727-732.
12. Hirsch, R. M., Slack, J. R. and Smith, R. A.. (1982). Techniques of trend analysis for monthly water quality data. Water Resources Research, Vol. 18, No. 1, pp. 107-121.
13. Kendall, M. G.. (1975). Rank correlation methods, Charles Griffin, London, Fourth edition.
14. Lettenmaier, D. P.. (1977). Detection of trends in stream quality: Monitoring network design and data analysis. Technical Report 51, Harris Hydraul. Lab., Dept. of Civil Engg., University of Washington, Seattle.
15. Liebetrau, A. M.. (1979). Water quality sampling: Some statistical considerations. Water Resources Research. Vol. 15(6), pp. 1717-1725.
16. Loftis, J. C., McBridge, G. B. and Ellis, J. C.. (1991). Considerations of scale in water quality monitoring and data analysis. Water Resources Bulletin. Vol. 27, No. 2, pp. 255-263.
17. Lucas, J. M. (1985). Control data cusums. Technometrics. Vol. 27, pp. 129-144.
18. Lungu, E. M. and Sefe, F. T. K.. (1991). Stochastic analysis of monthly streamflow. Journal of Hydrology, 126, pp. 171-183.

19. Makridakis, S. and Wheelright, S. C.. (1983). Forecasting methods and application. Wiley, New York.
20. Mattikalli, N. M. and Devereux, B. J. and Richards, K. S.. (1996). Prediction of river discharge and surface water quality using an integrated geographical information system approach. International Journal of Remote Sensing. Vol. 17, No.4, pp. 683-701.
21. McLeod, A. I., Hipel, K. W. and Comacho, F.. (1983). Trend assessment of water quality time series. Water Resources Bulletin. Vol. 19, No. 4, pp.537-547.
22. MINARS/1/1986-87. Status of water quality of some rivers of India monitored under global environmental monitoring series. Control Board for the Prevention and Control of Water Pollution, New Delhi.
23. MINARS/1/1986-87. Status of water quality of river Ganga Central Pollution Control Board, New Delhi.
24. Salas, J. D., Delleur, J. W., Yevjevich, V. and Lane, W. L.. (1980). Applied modelling of hydrologic series. Water Resources Publication, Littleton, Colorado.
25. Steele, T. D., Gilroy, E. J. and Hawkinson, R. O.. (1974). An assessment of areal and temporal variations in streamflow quality using selected data from the National Stream Quality Accounting Network. Open File Report 74-217. U. S. Geological Survey, Reston., Va. 1974.
26. Vandaele, W.. (1983). Applied time series and Box-Jenkins Models. Academic Press, Inc. New York.
27. Ward, R. C. and Loftis, J. C.. (1986). Establishing statistical design criteria foı water quality monitoring systems: Review and synthesis. Water Resources Bulletin. Vol. 22, No. 5, pp. 759-766.
28. Wolman, M. G.. (1971). The Nation's tivers. Science. Vol 174 (4012), pp. 905-918.
29. Zetterqvist, L.. (1991). Statistical estimation and interpreting of trends in water quality time series. Water Resources Research. Vol. 27, No. 7, pp- 1837-1648.

STUDY GROUP

DIRECTOR	:	DR.K.S.RAMASASTRI
CO-ORDINATOR:		DR.K.K.S.BHATIA
HEAD	:	DR.C.K.JAIN

SCIENTISTS INVOLVED:

1. DR. K.K.S. BHATIA
2. DR.C.K.JAIN
3. DR. RAMAKAR JHA