ANALYSIS AND INTERPRETATION OF HYDROMETEOROLOGICAL DATA

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in
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By
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Roorkee
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C E R T I F I C A T E

This is to certify that the dissertation entitled 'ANALYSIS AND INTERPRETATION OF HYDRO METEOROLOGICAL DATA' being submitted by Sri A.V.Khare in partial fulfilment of the requirement for award of the degree of Master of Hydrology of the University of Roorkee, is a record of the candidate's own work carried out by him under our supervision and guidance.

This is further certified that Sri A.V.Khare has worked for aperiod of $6\frac{1}{3}$ months from Ist October 1977 to 10th April 1978 in the preparation of this dissertation under our guidance at this University.

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CHAPTER - I

INTRODUCTION

1.1 GENERAL:

In the investigation and design stage of hydrological projects meteorological data plays an important role, and provides valuable information, therefore, the investigation of hydro-meteorological parameters is very important. In the investigation and design stage of water resources project, the hydro-meteorological data provides following information.

(i) Direct climatological data give valuable information such as (a) wind data for loading on structure, (b) temperature, radiation and humidity data for durability of materials.

(ii) Stastical analysis of meteorological data gives the information which has been required for the hydrological project, such as the information on the nature of stastical distribution of the element so that the frequency of occurence of certain events can be estimated as well as the probable extremes.

(iii) Estimate probable conditions when relevant hydrological data is not available. Knowledge of the physical relationships between elements with time and space enables interpolation to be done, and relationship can be established by stastical correlation.

Now-a-days engineering standards and recommended practices are specified on the basis of carefully collected and analysed data. These standards and practices are well documented and established.

1.2 STOCHASTIC NATURE OF HYDROLOGIC AND HYDROMETEOROLOGIC DATA:

The random phenomena which govern the evoluation of hydrologic and hydrometeorologic parameters in time are stochastic in nature and on the basis of information about present state the probability of future out come can be predicted. The hydrologic and hydrometeorologic phenomena are stochastic in nature, and these phenomenon change with time in accordance with law of probabilities and also the relationship with the antecedent conditions.

Hydrologic and hydrometeorologic data at a point in a space represents a sample from a population of all possible values of a phenomenon. The hydrometeorological and hydrologic variables represent the samples from different populations. These variable include data of rainfall, evaporation, temperature, humidity and sunshine hour etc.

1.3 INTER-RELATIONSHIP BETWEEN HYDROLOGIC AND HYDROMETEOROLOGIC DATA:

Hydrologic and hydrometeorologic parameters are inter-related to each other as they are the components of hydrologic cycle and are stochastic in nature.

The natural hydrologic time process defined as a time series of various hydrologic variables of a natural water resources system namely of input(rainfall), states of the system and output (Evaporation and Runoff). Hydrologic parameters of rainfall and runoff are connected to each other as well as to meteorological variables of evaporation. The evaporation process in turn depends on relative humidity, sunshine hours, temperature, wind velocity etc. The study of time series structure of these parameters will be of considerable use in water resources planning. In the present study monthly data will be analysed which is generally available.

1.4 TIME SERIES STRUCTURE OF MONTHLY SERIES:

The basic structure of monthly time series can be considered as consisting of the following three components.

(i) The secular or long term variation conceived as fluctuation of the basic. Characteristic of time series as function of time, either as the regular persistence of cyclicity and trends or as unspecified changes of nonstationary character.

(ii) The deterministic periodic component related to the astronomical cycle.

(iii) Stochastic component consisting of dependant and independent parts is the result of the probabilistic nature of the phenomenon.

1.5 PRESENT STUDY:

1.5.1 Objective:-

Structural analysis of monthly time series of different meteorological parameters viz. rainfall, eva poration, sunshine hours and temperature will be done. Monthly series are being considered for the analysis, since the monthly data is extensively used in engineering applications. This study has been taken upto gain better understanding of meteorological process and their comparison and developing stochastic models which can be used for data generation. The study will involve both stochastic and deterministic approaches.

The conventional deterministic method is used to study the evaporation process particularly its dependence on wind velocity.

1.5.2 Methodology:-

In this study the stationarity approach (Yevjevich 1972) will be used for analysis of time series structure. The given series will be tested for presence of trend. The non parametric approach will be used to standardise the monthly data to make it second order stationary series.

The parametric monthly means and standard deviations are periodic in nature. To separate periodic and stochastic component 12 values of monthly means and 12 values of monthly standard deviations are used for standardising the observed sequences and to obtain the stochastic component. This process will thus involve use of 24 parameter representing monthly means and monthly standard deviations. The correlogram analysis is used for finding the presence of stochastic dependent component in the standardised series; and suitable auto-regressive model will be fitted. The periodicity in monthly mean values will also be studied using Fourier series approach and proper tests will be used for finding significant harmonics.

The study of evaporation data will be done in order to evaluate parameters A and B in the following equation.

$$E = (e_s - e_a) \quad (A + BV)$$

where

e_s = saturation vapour pressure

e_a = actual vapour pressure

V = wind velocity at 2 mtr. height

A and B = constant

1.6 DATA:

The monthly data of rainfall, evaporation, sunshine hours, wind velocity, temperature and relative humidity are available for the period 1955-1976, for the hydro-meteorological station of IRI(U.P.) at Bahadarabad. This data will be used for the present study.

CHAPTER - II

REVIEW OF LITERATURE

2.1 INTRODUCTION:

For the planning of water resources project, study of the hydrological cycle and its components is very essential. Hydrological cycle represents the entire process of circulation of water. In circulation of water in its various phases the science of meteorology deals with the atmospheric portion of the cycle and meteorological parameters such as rainfall, evaporation, sunshine hours (Radiation), temperature and wind play an important role. For the planning of water resources development the investigation of these meteorological parameters is necessary in order to know their present and future behaviour in circulation of water.

2.2 IMPORTANCE OF METEOROLOGICAL PARAMETER IN HYDROLOGY:

For finding out the water yield, flood potential, infiltration characteristics and groundwater flow, meteorological parameters such as rainfall, evaporation, temperature give valuable information for use by hydrologist.

In India meteorological department Moghe (1958) studied the behaviour of Monsoon Current and found that this is characterised by periodic fluctuations of the elements which define its physical properties. These elements include mean precipitation, number of days of precipitation mean cloudiness, mean humidity and mean wind velocity. In 1958, Pant of I.M.D. studied the trends in annual rainfall by moving average. This study has been made for the frequent occurance of floods in different parts of country. To find water yield from the catchment Khosla (1951), used meteorological parameters. His forecast of the water yield was based on the concept that runoff is the residual after loss by evaporation was assumed by him to be a function of temperature. Khosla suggested a universal relationship between the mean monthly evaporation loss Lm in inches and mean monthly temperature Tm in ^{o}F.

$$Lm = \frac{Tm - 32}{9.5}$$

knowing monthly rainfall Pm and monthly loss Lm in inches. The monthly runoff Rm is calculated by the formula.

$$Rm = Pm - Lm$$

Hamon as quoted in Chow and Kareliotis (1970) proposed the relation to estimate evaporation using meteorological parameter of sunshine hours and absolute humidity. The relationship was as below:

$$E_p = .0055 \, D^2 \, P_t$$

where

D is possible sunshine hours in unit of 12 hours and P_t is absolute humidity in gms/ cubic meter. Thus it can be seen that meteorological parameters provide useful information for use in hydrological computation.

2.3 STOCHASTIC NATURE OF METEOROLOGICAL PARAMETERS:

Generally the meteorological phenomena are stochastic in nature, and on the basis of statistical information contained in available data, probable behaviour in future can be predicted.

The analysis of time series structure always is of value in studying the meteorological phenomena. Yevjevich (1972) in Colorado State University, Hydrology Paper No.56, stated that the series of monthly precipitation, monthly runoff as well as monthly series of many other hydrologic variables have periodic components of 12 months in both monthly mean and monthly standard deviation. When these periodic components are removed from a monthly series, the remaining part of component may be considered approximately as second order stationary process of monthly meteorologic series.

Roesner and Yevjevich (1966) in Colorado State University Hydrology paper No.15 suggested that the monthly series of meteorological parameters display a cycle of year and its eventual harmonics. The analysis of monthly data involves considerably less computation effort in comparison to that of daily data and it provides useful information about basic structure of meteorological phenomena. In view of this, in water resources planning and design the monthly data is generally used.

2.4 TIME SERIES ANALYSIS OF METEOROLOGICAL DATA:

Matalas (1966) points out that the tree ring growth expressed aswidth of annual rings, tends to vary about monotonically decreasing non linear trend line. This variation about trend line may be the result of variation in precipitation and temperature. Analysis of this type of long term data has thus shown presence of trend in meteorological parameters.

Study of monthly Rainfall and Runoff data of Lakshmanathirtha sub-basin of 38 years data by Murthy (1976) shows no trend in the series. While the trend is significant for annual flow series of Colorado river at Lee Ferry, Arizona for the period 1896-1959 (Yevjevich (1972)). It is seen from the above study that the short term data may not indicate trend as they are not statistically significant, Yevjevich (1972) pointed out that the trend may be linear or nonlinear. But the above quoted studies shows that linear trends have been found in case of runoff and rainfall sequences of monthly values. Roesner and Yevjevich (1966) studied the time series of monthly precipitation values of 219 precipitation stations, the series of monthly values were made stationary by them in two ways (i) By deducting from each calender month values its long term mean and dividing this difference by the standard deviation of month. (ii) By removing periodicity from the series after fitting 12-month period and its significant harmonics. The following mathematical models have been used in approximating the structure of stationary stochastic component of time series

(i) Dependent Stochastic Component represented by first order auto regressive Markov Model.

(ii) Independent Stochastic Component represented by appropriate probability distribution.

Chin and Yevjevich (1974) in Colorado State University Paper No.65, suggested the use of determination coefficient approach for selecting the order of auto-regressive model for stationary stochastic series. They further advice the use of correlogram with proper confidance limit in in addition to determination coefficient approach for deciding the order of a.r. model. In one case of Ice 50 series analysed by them, the determination coefficient criteria alone gave 3rd order model, however the study of correlogram showed a typical pattern of 1st order model which was then adopted.

In a study reported by Yevjevich (1976) of the precipitation series of seven coastal areas of United States, it was found that that the average monthly precipitation do not have any significant time dependence. This was clearly indicated by correlogram of the stationary stochastic components.

For the independent stochastic component of monthly meteorological series, Chin and Yevjevich (1974) suggest use of the following probability distribution functions to select best fit distributions.

(i) Normal Distribution

(ii) Double Branch Exponential Probability Function

(iii) Three Parametric Log Normal Probability Function

Chin and Yevjevich (1974) also remark the generation of new samples of the original process by experimental statistical methods of time series decomposition is best accomplished using data for the Independent Stochastic component obtained as a theoretical probability distribution function.

The best fit of the distribution can be choosen by using Chi Square Test.

Shen (1976) reports the study of monthly temperature series for 3 areas of Pacific Ocean close to U.S.Coast. The correlograms exhibit high dependence in stochastic component obtained after the periodicities in the mean and standard deviation were removed.

Torrelli (1974) studied the time series of monthly data of temperature, evaporation and precipitation. He proposed two different models for each monthly time series; one is the usual model based on the sample monthly average and standard deviation with eventual addition of auto-regression terms.

The second model was obtained by joint use of spectral and regression analysis and it gave better functional knowledge of the deterministic component of the monthly co-variance, resulting in reducing number of parameters required to represent the series.

2.5 INTER-RELATIONSHIP OF METEOROLOGICAL PARAMETERS:

Meteorological variables are related to each other, e.g. evaporation is related to wind velocity, radiation, humidity etc. Yevjevich (1972) studied the cross correlation for investigating the linear relation between the temperature, precipitation and water use time series. In this study the trend was removed from the mean and the standard deviation of water use series. This study has been made for Denver, Colorado and the Cross Correlation Function of independent components of water use and temperature and of water use and precipitation were studied to find the relation between the two series for different lags.

The purpose of investigating these relationships was to find mathematical models which could describe the functional relations between these processes.

Study of inter-relationship of rainfall, evaporation and storage in catchment was made by analysis of stochastic hydrologic system of watershed (Chow and Kareliotis 1970) by considering the rainfall as watershed input and evaporation as output. The hydrologic system model was formed on the basis of the principle of conservation of mass and composed of the components of stochastic process. In the analysis the stochastic process of precipitation, conceptual watershed storage, evapotranspiration were not treated independently of each other but were considered 3-dimensional vector or a multiple time series.

Roden (1968) in an extensive study of the inter-relationship between meteorological, oceanic and estuarial variable along the eastern pacific coast of United States and Canada found out the influence of stream flow on the salinity of coastal area.

2.6 DETERMINISTIC STUDY OF EVAPORATION:

For the evaporation study, wind velocity is generally assumed as varying logarithmically with height suggested by Brunt (1944) and the variation of wind velocity with height is expressed as $U \propto \log Z$ where Z is form of height above G.L.

By evaporation, water in liquid state is changed to vapour state, the rate of evaporation is proportional to the deficit in vapour pressure (Dalton 1802).

$$E = f(U) \ (e_s - e_a)$$

E = pan evaporation values

where wind factor $f(u) = A + BU$, A and B are constants.

Estimation of evaporation has been done by water balance method, Energy balance method and Mass transfer method; while estimating the evaporation from mass transfer method is also done assuming that the adiabatic atmospheric condition and logarithmic distribution of wind.

On the basis of Dalton's Formula equations have been proposed from time to time for estimating evaporation. Some of these are given below.

The equations below also indicate that the value A and B changes from the place to place in Wind Factor f (U).

Fitzgerald 1886 $E = f(u) \ (e_s - e_a)$

$f(u) = .4 + .199\ U$

Mayer 1915 $E = f(u) \ (e_s - e_a)\ C$

$f(u) = .1 + .1U$

Hortan 1917 $E = .4\ (f(u)(e_s - e_a))$

$f(u) = 2 - \bar{e}^{.2u}$

According to Wiesner these constant A and B are fixed according to height selected for calculating actual vapour pressure (e_a). They changes with height.

Many attempts have been made to find a correct equation for evaporation from surface of various kinds, in 1881, Stefan investigated evaporation from flush, circular and elliptical water surfaces at constant-temperature and in still air. According to Mumphrey (1940), Stefan was able to show that evaporation under restricted condition is proportional to the diameter of the evaporating surface but not to the evaporating area. Brown and Escombe (1940) reported later that diffusion of vapour through small openings is more mearly proportional to their diameter or perimeter than to their area. In India Meteorological Department, Raman and Santakopan (1934) developed evaporation formula on the above basis for monthly and annual evaporation at 80 stations in India.

2.7 REMARKS:

To investigate the meteorological process studies have been conducted by analysing meteorological data to make use of results for understanding the process and for future prediction. The information content of hydrologic and meteorologic observations can be presented in tabular or graphical form or in form of mathematical models. The better presentation is in the form of mathematical model. The information in a sample of 100 years of observation of monthly precipitation or monthly runoff, or of any other hydrologic or meteorologic parameters may be condensed into suitable mathematical models by proper estimation of parameters. Basically, the components of mathematical model for representing the structure of monthly time series are as follows.

(i) Trend Component

(ii) Periodic Component represented by appropriate main harmonic and its sub harmonics.

(iii) Dependent Stationary Stochastic component represented by appropriate auto-regressive model.

(iv) Independent stationary stochastic component represented by appropriate probability distribution.

The time series analysis data of rainfall evaporation temperature etc. has been done by different investigators. The evaporation process depends upon the radiation. The effect of radiation on evaporation can be studied indirectly by studying the effect of duration of sunshine. Thus study of time series of sunshine hours will also be of importance in investigating evaporation process and rainfall process (due to effect of cloud on sunshine). For evaporation study Dalton, vapour flow approach has been studied from time to time.

The evaporation is expressed as the rate over the period in which saturation deficit $(e_s - e_a)$ wind velocity U are measured. Wind factor f(u) of the form f(u) = A + BU, constant A and B can be derived. The constant A and B are fixed for height and place.

CHAPTER - III

METHODOLOGY FOR ANALYSIS

3.1 INTRODUCTION:

To investigate the structure of meteorological parameters stochastic methods have been used for the analysis of monthly data of Rainfall, Evaporation, Sunshine hour and Temperature.

The monthly data are very useful in water resources for planning and design of structure. The basic need for the analysis is to extract the information within the data for the above use and this can be done as below.

(i) Improved understanding and mathematical description of hydrologic stochastic process.

(ii) Developments of proper methods for generation of new samples of hydrologic time process.

As the series may contain trend and sudden changes in the basic parameter such as mean, the study of trend has been made. Further more the monthly meteorologic data generally contain the periodicity due to astronomical cycle. Therefore the periodicity has also been removed in order to make the monthly series as a second order stationary stochastic process. Monthly data of rainfall, evaporation, sunshine hour and temperature will be done to remove trend and periodicity by considering proper parameters and then the stochastic stationary series will be analysed for dependent and independent components. The study of monthly evaporation data will also be done on the basis of deterministic approach considering the adiabatic atmospheric condition, and logarithimic distribution of wind with height above ground.

3.2 ANALYSIS OF MONTHLY TIME SERIES:

Structural analysis of monthly time series has been done on the basis that the monthly time series is composed of stationary process combined with deterministic component.

Stationarity of time series means the non-varience except by a chance fluctuation of the statistical parameters, such as means, standard deviation, co-variance and other higher order moments of time series.

A hydrometeorologic or hydrologic time series may be composed of

(i) Trend or a long term movement with oscillation around the mean

(ii) Seasonal or cyclic component

(iii) Effect of serial correlation

(iv) Random i.e. unsymmetrical irregular component.

3.2.1 Components of Monthly Time Series:-

The components of time series can expressed mathematically as

$$X_t = T_t + P_t + \varepsilon_Z \qquad \ldots\ldots (3.1)$$

where X_t = observed monthly sequence

P_t = Periodic component

εt = Stochastic component consisting of dependent and independent components.

T_t the trend component is deterministic in the sense that its future values may be predicted more accurately, and P_t is deterministic on the assumption that oscilation have fixed phase and amplitudes.

In this analysis the trend component has to be removed, which makes the time series homogeneous and the removal of trend and periodic component makes the process stationary.

3.2.2 Trend Component:-

A trend is defined as systematic, and continuous change over an entire sample, in any parameter of a series, excluding periodic changes and produced by factors other than the expected sampling variation of stochastic process. Yevjevich (1975) states that the trends as deterministic component often occur in hydrologic series . Usually trend is assumed to be found in mean only.

If rainfall series contains trend, and if future samples are not likely to experience the same or similar trend, direct use of recorded data for further analysis of generation of equally likely future sequences may be highly biased and the elimination of trend is thus necessary to avoid this bias.

3.2.3 Test for the Significance of Trend:-

The trend in time series must be removed if it is not expected either to be repeated or if it will not occur at all in future. The removal of trend, if found significant makes the time series homogeneous.

Normally only linear trends are used because any non linear trend, though easy to fit, may have small justification because the difference between the non-linear and linear trends may be partly or fully the results of sampling variations (Yevjevich 1972).

Trend is generally removed from the time series by the method of least squares.

The method of least squares is used in this study and the same is briefly explained as follows:

Assuming a linear fit, the best straight line through the point (X_1 , Y_1) is by choosing the two parameters m and C of a straight line

$$Y = mX + C \qquad \ldots\ldots\ldots (3.2)$$

in such a way that the sum of the squares of the errors in Y is minimum. This is achieved by making

$$m = \frac{n\Sigma XY - \Sigma X\, \Sigma Y}{n\, \Sigma X^2 - (\Sigma X)^2} \qquad \ldots\ldots (3.3)$$

$$C = \frac{\Sigma X^2\, \Sigma Y - \Sigma X\, \Sigma XY}{n\, \Sigma X^2 - (\Sigma X)^2} \qquad \ldots\ldots (3.4)$$

where n is the number of paired observations, and X are prescribed values over monthly ranges and Y are the consequential observational values. It is assumed here that the observations Y are subjected to error. This line (equation 3.2) is called the Line of Regression of Y on X and one of its properties, is that it passes through the centroid $(\bar{X}, \bar{Y})$ of the observed points.

3.2.4 Confidance Limit of Mean Value and Slope of Regression Line:-

For the confidance limit calculation of the regression line, the errors or deviations must be calculated. At every observation point X_i, Y_i) which does not equally lie on the calculated line there is an e_i. The variance of Y estimated by the regression is then

$$S^2Y = \left(\left(\Sigma e_i^{\,2} \right) / \; u \right) \qquad \ldots\ldots (3.5)$$

where u is the degrees of freedom. Since calculation of m and C impose two restraints. The value of u is given by

$$U = (n-2)$$

The variance of the mean value $\bar{Y}$ is given by

$$(S\bar{Y})^2 = \frac{(SY)^2}{n} \qquad \ldots\ldots (3.6)$$

So that the confidance limits of $\bar{Y}$ are

$$Y \pm t(S\bar{Y}) \qquad \ldots\ldots (3.7)$$

where similar to sample mean, the value of t statistic is found from tables, using the appropriate number of degree of freedom.

The variance of the slope m is given by

$$(S_m)^2 = \frac{SY^2}{\Sigma\,(X-\bar{X})^2} \qquad \ldots\ldots (3.8)$$

and the confidence band for slope is given by

$$m \pm t\,(S_m) \qquad \ldots\ldots (3.9)$$

It is necessary to compare one regression line with another theoretical one, to see if there is any significant difference between the theoretical slope m_o , and the observed slope m. This test is performed by calculating t - stastic.

$$t = \frac{m - m_o}{S_m} \qquad \ldots\ldots (3.10)$$

and comparing with the tabulated value.

Therefore a straight line trend Y = mX + C fitted as regression line through Y, time series, is thus tested for m being significantly different from zero. This approach of trend detection and description is more reliable.

3.2.5 Correlogram Analysis:-

The auto-correlation analysis represented by correlogram is used in the analysis of description of hydrologic time series. The correlogram is a function between the serial correlation coefficients ρ_K as ordinate and lag K as abscissa with given by

$$\rho_K = \frac{\mathrm{Cov}(X_i,\ X_i + K)}{\left[(\mathrm{Var}\ X_i)\ (\mathrm{Var}\ X_i + K)\right]^{1/2}} \qquad \ldots\ldots (3.11)$$

Correlogram provides a general character of time series and a direct relation can be established between the shape of the correlogram and type of the time series.

Auto-correlation analysis is used to determine the linear dependance among the successive values of a series that are given lag apart. The measure of this depandence is given by the serial-correlation coefficient. If the value of X_t are linearly dependent upon the values of X_{t+K}, then the correlation between X_t and X_{t+K} may be taken as measure of dependence. This correlation is referred to as the K^{th} order serial correlation and is given by the open series approach as below.

$$rK = \frac{(N-K)\sum_{t=1}^{N-k} X_t\, X_{t+k} - \left(\sum_{t=1}^{N-k} X_t\right)\left(\sum_{t=1}^{N-k} X_{t+k}\right)}{\left[(N-K)\sum_{t=1}^{N-K} X_t^2 - \left(\sum_{t=1}^{N-K} X_t\right)^2\right]^{1/2}\left[(N-K)\sum_{t=1}^{N-K} X_{t+K}^2 - \left(\sum_{t=1}^{N-k} X_{t+K}\right)^2\right]^{1/2}} \quad \ldots\ldots (3.12)$$

The value of $r(K)$ for $K = 0$ gives no information about the time series, as $r(0)$ is always one and as the observed time series may be considered as two identical sequence each being the observed time series itself.

The value of $r(K)$ for $K = 0$ reflect the structure of time series, and they are dimensionless and oscilate between $+1$ and -1.

To facilitate the analysis of the structure, the values of r (K) as a function of K are depicted graphically with r (K) as the ordinate and K as the abscissa, which is called correlogram. In order to reveal the feature of the correlogram better, the plotted points are joined each to the next by a straight line.

The correlogram provides a theoretical basis to distinguish 3 types of oscillatory time series. It has been provéd analytically that if the time series is simulated by a moving average model for random elements of extent m. Then the correlogram will show a decreasing linear relationship and will vanish for all values of $K>m$, for sum harmonics model. The correlogram itself is harmonic with periods equal to those of the harmonic component of the model and will therefore show the same oscillations.

For an auto-regression model the correlogram will show damping oscillation of curve for a first order Markov process with a serial correlation coeff. r_1. The correlogram will oscillate with period unity above the abscissa with a decreasing but non-vanishing amplitude.

In fact, whether the cyclicity in the correlogram is damperred or not, may be used as the criteria for identifying the periodicity present in the time series.

If r_1 is negative when the time series is for short the computed correlogram may exhibit substantial sampling variation and thus conceal its actual form (Chow and Kareliotis 1970)

Selection of ~~Function~~ truncation Limit:-

The value K upto which correlogram is to be computed depends on what is to be accomplished by the correlogram. As the K value increases, (N-K) decreases and so the accuracy of estimate also decreases (Yevjevich 1972) usually $K \leq \frac{N}{3}$ selected and often $K = \frac{N}{10}$, $\frac{N}{6}$ or similar number is selected as ~~fu~~truncation limit, where N = sample size.

3.2.6 Periodicity in Hydrologic Parameters and Its Separation by Non-Parametric Method:-

Periodicisty of hydrologic time series may be present in one, two, several or all its parameters. Such parameters are the mean and standard deviation, the autocorrelation or autoregression coefficients, be higher order moments or the parameter which are the functions of these parameters and similar parameters. An independent stationary stochastic component is assumed to be always present in any hydrologic time series while the parameters of time series may or may not be periodic. The stationarity of the stochastic component after removal of periodicity is assumed either to be of the second order as weak stationary or of higher or less as strong stationary.

Non-Parametric Method of Separating Periodic and Stochastic Component:

The simple transformation of $X_{p\tau}$ series after removal of trend (if any) gives

$$e_p = \frac{X_{p,\tau} - m_\tau}{S_\tau} \quad \ldots\ldots (3.13)$$

where p = 1,2 . . . n represents year and = 1,2 . . . 12 represents month in case of monthly data.

m_τ and S are the sample means and sample standard deviation respectively at the position (representing particular month) in case of monthly series computed as below:

$$m_\tau = \frac{1}{n} \sum_{p=1}^{h} X_{p,\tau} \quad \ldots\ldots (3.14)$$

and

$$S_\tau = \left[\frac{1}{n} \Sigma \, (X_{p\tau} - m_\tau)^2 \right]^{1/2} \quad \ldots\ldots (3.15)$$

respectively, is the non parametric method of removing the two periodic parameters and of standardisation of the $X_{p,\tau}$ variable.

It requires the use 2ω statistics, W values of m_τ and W value of S_τ. For monthly value W = 12 and for daily values W = 365.

The non parametric method removes from the series periodicity in parameters but also removes all sampling variations association with the coefficients of the periodic functions of parameters.

3.2.7 Selection of Practical Mathematical Models of Stochastic Dependence:-

The variable $e_{p\tau}$, obtained by removing the periodicity in the mean and standard deviation is only approximately a second order stationary dependent or independent time series. The dependence can be often approximated by the first, second, third or higher order auto-regressive linear models. Generally hydrologic series rarely justify an investigation of higher order (more than 3rd order) auto-regressive linear models though they may indicated by physical processes, linear models seem sufficiently accurate for practical purpose. Though the real stochastic models may be non-linear. The general order auto-regressive linear model is

$$e_{p,\tau} = \sum_{j=1}^{m} \alpha_j, \quad e_{p,\tau-j} + \sigma \quad p,\tau \quad \ldots (3.16)$$

with α_j, the auto-regressive coefficient, either periodic as α_j, or non periodic as α_j and is a standard deviation, periodic or non periodic which enables to be a second order stationary and standard (o,1) random independent variable, if e_p is a standard random but dependent variable. The value of σ is

$$\sigma = \left[1 - \sum_{j=1}^{m} \alpha_j^2 - 2 \sum_{i>K} \alpha_i, \quad \alpha_K. \quad P_{i-K} \right]^{-1/2} \quad \ldots (3.17)$$

if $e_{p,\tau}$ is a standard variable (0.1) then σ is periodic as soon as any value

$\alpha_{j,\tau}$ j = 1,2 . . . m is periodic

The technique of statistical test for fitting the auto-regressive linear models is often best, by whitening the series or by assuming a model of the auto-regressive linear type by estimating its parameter and by computing the presumed independent $\epsilon_{p,\tau}$ component. Then $\xi_{p,\tau}$ is tested for independence. If this hypothesis is accepted, hypothesis of the model fitting well the time dependence is also accepted.

3.2.8 Determination Coefficient:

The measure of the goodness of fit of the auto-regressive linear model is judged by determination coefficient approach. R_j^2, j = 1, 2,3 . . proposed by Yevjevich (1974). The coefficient of determination tells what portion of the total variance of $\epsilon_{p,\tau}$, is explained by each term of the auto-regressive equation. The remaining portion of the variance of ϵ_p being explained by the term $\sigma[\xi_{p,\tau}]$. Because $R_m^2 > \ldots\ldots > R_3^2 > R_2^2 > R_1^2$.

A.R. Models of Order 1, 2 and 3

The determination coefficients are computed by:

$$R_1^2 = r_1^2 \qquad \ldots\ldots (3.18)$$

$$R_2^2 = \frac{r_1^2 + r_2^2 - 2\, r_1^2\, r_2}{1 - r_1^2} \qquad \ldots\ldots (3.19)$$

$$R_3^2 = \frac{r_1^2+r_2^2+r_3^2+2r_1^3r_3+2r_1^2+r_2^2+zr_1r_3^2-2r_1^2r_2-4r_1r_2r_3-r_1^4-r_2^4-r_1^2r^2}{1-2r_1^2-r_2^2+2r_1^2r_2} \quad \ldots\ldots (3.20)$$

where r_1, r_2, r_3 represent serial correlation coefficients conditions of lag 1,2 and 3 respectively.

(i) $(R_2^2 - R_1^2) \leq .01$ and $(R_3^2 - R_1^2) \leq .02$

First order model is selected.

(ii) $(R_2^2 - R_1^2) > 0.01$ and $(R_3^2 - R_2^2) \leq 0.01$

Second order model is selected.

(iii) $(R_2^2 - R_1^2) > 0.01$ and $(R_3^2 - R_2^2) > 0.01$

Third order model is selected.

For example if, 1st order model is selected, then the new series of $\xi_{p,z}$ is calculated, representing independent stochastic component.

$$\varepsilon_{p,z} = a_1 \varepsilon_{p,z-1} + (\sqrt{1-a^2})(\xi_{p,z})$$

$$\therefore \quad \xi_{p,z} = \frac{e_{p,z} - a_1 e_{p,z-1}}{(\sqrt{1-a_1^2})} \quad \ldots\ldots (3.21)$$

3.2.9 <u>Probability Distribution of Independent Stochastic Component:-</u>

The fitting of the probability function to the frequency distribution curve of $\xi_{p,z}$ is the approach followed in this study to structurally analyse, and mathematically describe independent stochastic component.

The transmission of $\chi_{p,z}$ to produce the standardized variable $e_{p\,z}$ and the treatment of $e_{p\,z}$ to produce the independent stochastic variable ξ_{pz} make the positively-valued variable χ_{pz} as a $\xi_{p,z}$ variable with both negetive and positive values. The auto-regressive linear models transform the variable e_{pz} which is bounded on the left side to a new variable $\xi_{p,z}$ which theoretically may be unbounded.

Owing to the fact that $\xi_{p,z}$ series include many negetive values, fits of normal, three parameter log normal, and three parameter gamma distribution have been considered in the present study.

In this study the $\xi_{p,z}$ series is checked for fit of normal distribution only by using chi square test.

3.2.10 Fitting Normal Distribution:-

The probability density function of the normal distribution used is

$$f(z) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left[-\frac{1}{2\sigma^2}(z-\mu)^2\right]$$

$$-\infty \leq z \leq +\infty \qquad \ldots\ldots (3.22)$$

In which μ is expected value of z_t and σ its standard deviation

The maximum likely hood estimators of the parameters of the normal density are

$$\hat{\mu} = \frac{1}{N}\sum_{i=1}^{N} z_{p,z} \qquad \ldots\ldots (3.23)$$

$$\hat{\sigma} = \left[\frac{1}{} \sum_{i=1}^{N} (z_{p,} - u)^2 \right]^{1/2} \quad \ldots\ldots (3.24)$$

p_j the probability of any class interval representing the area under the probability curve is known. K_j the class interval limits can be evaluated from the corresponding cummulative distribution obtained by integrating equation (3.22) by standardising the residuals of

$$f(x) = jP_j = \int_{\infty}^{uj} \frac{1}{\sqrt{2\pi}} e^{-u^2/2} du \quad \ldots .(3.25)$$

with j= 1,2 . . . (k-1) from the values of uj and estimates of population mean and standard deviation $\hat{\mu}$ and $\hat{\sigma}$

The equal probability class interval limit K_j of the variable $\xi p z$ are $K_j = \mu + uj\,\sigma$ . . . .(3.26)

In which uj are the class interval limits of the variable ut of the equation (3.25).

3.2.11 Chi-Square Test:-

The total range of sample ϕ observation is divided into K mutually exclusive class interval, each having the observed class frequency θ_j and corresponding expected class probability E_j (j = 1,2,3 . . . K) using the expected value E_j as the norm of any class interval, it is reasonable to choose the Quantity $(O_j - E_j)^2$ as a measure of departure from the norm. However, the magnitude of squared deviations (O_j-E_j) would not be comparable from one class to another.

Since the scale of each is nearly proportional to the expected value.

Therefore a suitable measure is expected by computing $[(O_j - E_j)^2 / E_j]$ and the measure of total discrepancy between observations and expectation, χ^2 (Chi Square) given as below:

$$\chi^2 = \sum_{j=1}^{K} \frac{(O_j - E_j)^2}{E_j} \qquad \text{. . . . . . (3.27)}$$

This stastistic is distributed asymptotically as Chi Square χ^2 with (K-1-) degrees of freedom, where is the number of parameters already estimated from the sample. The number of class intervals should be such that expected frequency is not below 5 in each class.

Knowing the class interval limit, the corresponding observed class frequencies are determined. Chi Square simplified for computational purposes in case of equal probability class intervals, is as below:

$$\chi^2 = \frac{K}{N} \left[\sum_{j=1}^{K} O_j^2 \right] - N \qquad \text{. . . . . (3.28)}$$

where N is the sample size, e.g. for 22 years monthly data, N = 12 x 22 = 264.

The Chi Square Test prescribes the critical values of χ_c^2 for a given confidence level (from χ^2 table) so that for $\chi^2 \leq \chi_c^2$ the null hypothesis of goodness of fit is accepted and for $\chi^2 \geq \chi_c^2$ it is rejected.

The above mentioned methodology has been used for analysis of time series of monthly rainfall, evaporation, sunshine hour and temperature data of Bhadarabad. The same has been checked for normal distribution.

3.2.12 Representing Periodicity in Mean: By Significant Harmonics:-

The general equation of the periodic function of any parameter using the Fourier series approach as given by Yevjevich (1972)

$$= \mu_v + \sum_{j=1}^{m} C_j \cos \left(\frac{2\pi j \tau}{W} + \theta_j \right) \quad \ldots\ldots (3.29)$$

in which μ_v = the mean of ν_τ over the W position of j = the sequential number of any harmonic out of the W/2 possible harmonics, m = the number of significant harmonics. For monthly data W = 12, m = 6.

For representing periodicity in the mean, above equation becomes

$$\mu = \mu x + \sum_{j=1}^{m} (A_j \cos \lambda_j \tau + B_j \sin \lambda_j \tau) \quad \ldots (3.30)$$

ux is the mean of 12 values of monthly means for monthly data.

The coefficient A_j and B_j, j = 1,2 . . . 6 are estimated from W values of m obtained from sample by

$$A_j = \frac{2}{W} * \sum_{j=1}^{m} (m_2 - \mu x) \cos \left(\frac{2\pi j \tau}{W} \right) \quad \ldots\ldots (3.31)$$

$$B_j = \frac{2}{W} * \sum_{j=1}^{m} (m_2 - \mu x) \sin \left(\frac{2\pi j \tau}{W} \right) \quad \ldots\ldots (3.32)$$

3.1.13 Testing Significance of Harmonics:-

For choosing significant harmonics in equation (3.29) an approximate procedure may be used. Let $S^2(m_\tau)$ be the variance of m_2

$$S^2_{(m\tau)} = \frac{1}{n}\sum_1^n (m_2 - \mu x)^2 \qquad \ldots\ldots (3.33)$$

Then $\quad \mathrm{Var}\, h_j = (A_j^2 + B_j^2)/2 \qquad \ldots\ldots (3.34)$

is the variance corresponding to the harmonic j.

$$\Delta P_j = \frac{\mathrm{Var}\, h_j}{S^2(m\tau)} \qquad \ldots\ldots (3.35)$$

As the part of explained variance by the harmonic j with respect to the total variance of $m\tau$. The relation ΔP_j are ordered in decreasing sequence and added as

$$P_j = \sum_{i=1}^{j} (\Delta P)_i \quad \text{for } j = 1,2 \ldots 6. \qquad \ldots (3.36)$$

where m = W/2 = 6 for monthly values.

Two critical values for the sequence P_j are given by

$$P_{min} = a\sqrt{\frac{W}{NC}} \qquad \ldots\ldots (3.37)$$

C = 1 for periodicity in mean

a = .033 (recommended by Yevjevich)

and N = sample length

W = 12

$$P_{max} = (1 - P_{min}) \qquad \ldots\ldots (3.38)$$

The following criteria are used for determining significant harmonics if $.P_6 < P_{min}$. There is no significant harmonics.

If $P_6 > P_{max}$ the first j harmonics whose P_j value first exceeds P_{max} are selected as significant harmonics.

If $P_{min} < P_6 \leq P_{max}$, all six harmonics are significant.

3.3 METHODOLOGY FOR STUDY OF VERTICAL DISTRIBUTION OF WIND VELOCITY:

3.3.1 Effect of height on wind speed:

It is a well known fact that wind speed varies with height above ground level. Therefore, it is a greatest decrepancy of wind records of adjacent stations is due to the differences in the height of anemometers above the surfaces; but the little effort has been made to standardise the height of anemometer installation. Actual wind records show a gradual reduction of speed to be associated with the growth of the city.

3.3.2 The Variation of Wind With Height:

In the surface layers, the roughness and variations of the earth's surface and the stability of the air create physical and tharmal barriars to the free movement of air and modify its trajectory. These effects cause the wind velocities in the boundary layer vary in direction and magnitude with height above the earth's surface.

Wind velocity is generally accepted as varying logarithimically with height and formula of the form

$$U = a \log Z + b \qquad \ldots\ldots (3.39)$$

and

$$U = a \log (Z + C) + b \qquad \ldots\ldots (3.40)$$

where a, b, c are constants can be established for set of observation in particular site where roughness is constant and when the atmosphere has a given stability. If the constants of these equation are evaluated from the experimental data, winds at different heights may be estimated. The basic data is plotted as velocity against the logarithim of height and a straight line is drawn.

The variation of wind with height can also be represented by a power profile of the form

$$\frac{U_1}{U_2} = \left(\frac{Z_1}{Z_2}\right)^K \qquad \ldots\ldots (3.41)$$

or

$$U = C\, Z^K \qquad \ldots\ldots (3.42)$$

where C and K are constants for set conditions. K is constant which is about 1/5 for average condition, about 1/7 for winds over 35 mph.

U_1 is wind speed at height Z_1 above the surface and U_2 is wind speed at height Z_2. In present study U v/s log Z approach will be used.

3.2.3 Wind Speed and Evaporation:-

As the evaporation depends on the wind speed, in the Dalton's vapour flow approach transfer coefficient is the function of wind speed only. $E = f(u)\ (e_s - e_d)$

$$\text{where} \quad f(u) = (A + BU) \qquad \ldots\ldots (3.43)$$

And the wind speed varies with height. Therefore, it is essential to know the vertical distribution of wind speed while calculating the evaporation. So that wind speed at standard height could be computed and used for estimation of evaporation.

3.4 METHODOLOGY FOR EVAPORATION STUDIES:

3.4.1 General:-

Evaporation plays an important role in hydrologic cycle, a great deal of effort has been expanded in attempts to find a means of measuring it directly. As the measurement of evaporation has been restricted to use of instrument which measures evaporative power of the air and not the actual evaporation.

The evaporative power is a measure of the degree to which a region is favourable or unfavourable to evaporation. Thus the evaporative power is greater over a hot dessert than near humid coast line. Thus the evaporation changes from place to place and a study has been made for monthly evaporation of this area.

3.4.2 Nature of Process:-

By evaporation water in liquid state is changed to vapour state. This change occurs when some molecule in the water mass have attained enough Kinetic energy to eject themselves from the water surface.

The motion of the molecules through the water surface produces a pressure. The pressure is called Vapour pressure.

Escaping molecules collide with those in the air, some of the former will drop back into the water which number of molecules thus escaping equals the number of those that fall back into the water an equilibrium is reached between the pressure exerted by the escaping molecules and the pressure of surrounding atmosphere. This equilibrium condition known as saturation.

3.4.3 Vapour Flow Approach:-

It was early realised by Dalton and others, that the transfer of vapour must occur along a gradient of moisture concentration at a rate dependent on turbulent mixing, and a measure of the transfer coefficient might be a function of wind speed.

$$E = f(u) \quad (e_s - e_d) \qquad \ldots\ldots (3.44)$$

where f(u) is function of wind speed which can be empirically derived. It is commonly of the form $f(u) = (A+BU)$. The evaporation is expressed as a rate over the period in which $(e_s - e_a)$ and U are measured. e_s is saturation vapour pressure and e_a actual vapour pressure. e_s is measured at the evaporating surface and e_a in the free air usually at 2 m height and U is an average wind speed at suitable height. The constant A and B are fixed according to heights related for e_a and U and the nature of evaporation surface.

In this study the rate of evaporation will be determined by the difference between the vapour pressure of the body of water and that of the air above the water surface under given conditions and the expression derived on the above principle as below:

$$E = (e_s - e_a) \quad (A + BU) \qquad \ldots\ldots (3.45)$$

where E = evaporation in mm

e_s = saturation vapour pressure

e_a = actual vapour pressure

A, B = constant

U = wind velocity at 2 mtr. height.

As the evaporation depends upon the temperature (saturation vapour pressure) and atmospheric pressure therefore the rate of evaporation can be expressed in the following equation.

$$E = e_a \left(1 - \frac{R}{100} \right) \quad (A + BU) \qquad \ldots\ldots (3.46)$$

where E = evaporation in mm

U = wind velocity in km./hr. at 2 m. height

e_s = saturation vapour pressure

$\left.\begin{matrix} A \\ B \end{matrix}\right\}$ = constants to be estimated.

Data used in this case study is the monthly data for rainfall and monthly average value for evaporation, temperature and sunshine hour. In this study the monthly average values have been used for the analysis.

CHAPTER - IV

THE DATA

4.1 INTRODUCTION:

The analysis and interpretation of hydrometeorological data by stochastic or deterministic methods, is done to extract the information within the data, the information contained in the data can be presented in concase form by representing the particular process by a mathematical model (stochastic or deterministic).

4.2 DESCRIPTION OF STATION AND DATA AVAILABILITY:

Data needed for the analysis in this study has been taken from the hydraulic research station of Bahadarabad. This research station has been maintained by the Irrigation Research Institute, Roorkee (U.P. Irrigation Department). The Bahadarabad Research Station is 16 km. from Roorkee and situated on Roorkee Hardwar Road.

Bahadarabad Research Station is having a meteorological observation station, and all sorts of meteorological observations are taken here since 1955.

4.3 DATA:

For analysis of time series of rainfall, evaporation, sunshine hour and temperature monthly average values of these parameters has been used.

For the study of rainfall, time series analysis has been done from the monthly sequences of 22 years (1955-1976), consisting of total rainfall in calender months in mm. (Table No.4.1)

For the study of evaporation, the evaporation data is taken from U.S. Class A Pan. The data used in the analysis is total monthly pan evaporation in mm for the calender month for the period of 18 years (1955-1972) (Table No.4.2).

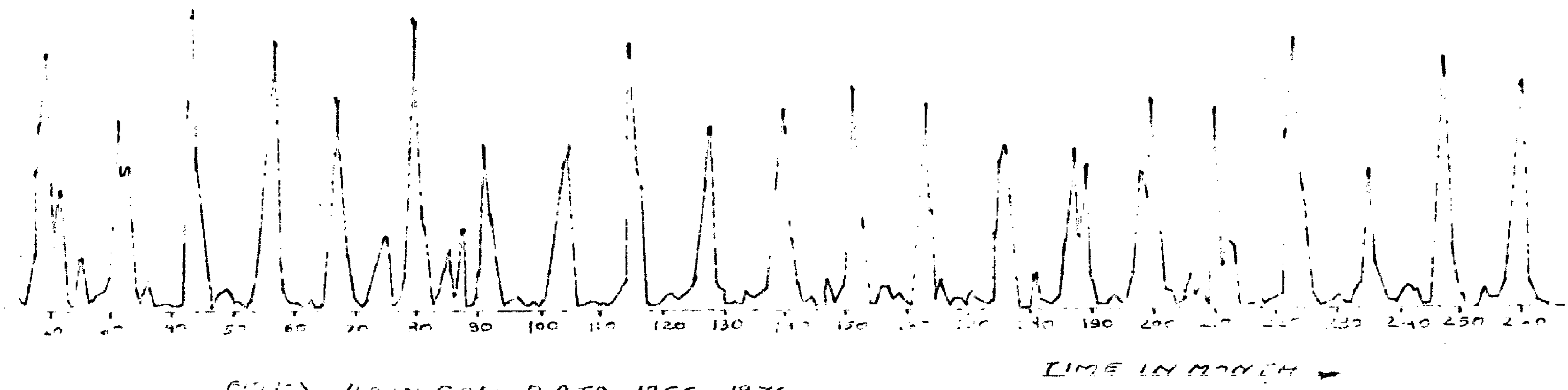
In the case of sunshine hour the total sunshine for the month is the average sunshine hour, in one day for the month. The monthly data of these is available for the period of 21 years (1956-1976) (Table No.4.3).

Temperature data is available for 18 years (1955-1972) (Table No.4.3). The monthly average values in one day of the month has been used for the analysis.

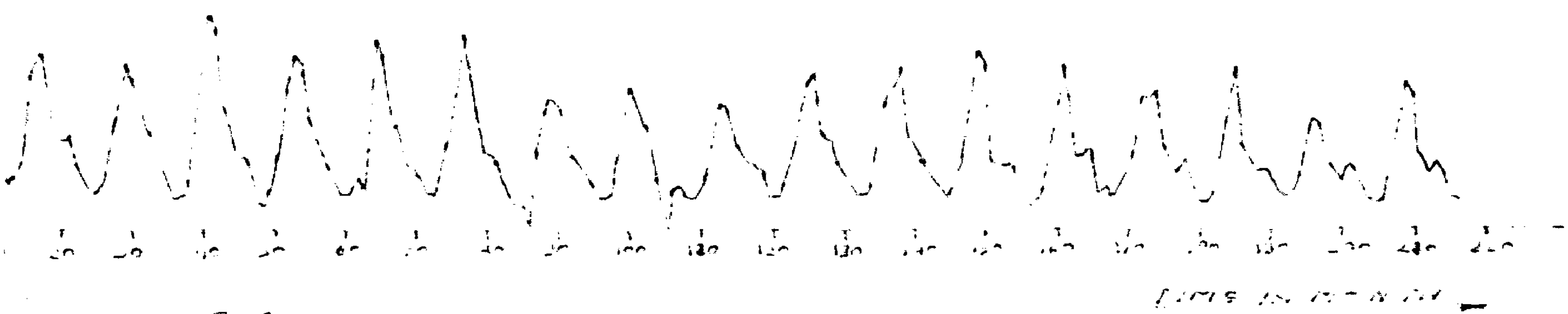
For the deterministic study of evaporation the Class A Pan data of 17 years has been used (1956-1972), and the monthly average wind velocity at 16 ft. height has been used (1956-1972) (Table No.4.4), For this analysis monthly averages of the relative humidity (Table No.4.5) and temperature data have also been used for the period of 17 years (1956-1972). Saturation deficit in mm has been calculated by using this. The data used for the study is given (Table No.4.6).

To study the vertical distribution of wind speed the monthly data of 7 years have been used (1970-1976). The wind data has been used for this period are the wind speed at different heights, 2 ft. 10 ft., 16 ft. and 30 ft. respectively and given (Table No.4.7 to 4.10). These wind speeds are the monthly average values in Kmph.

The data of rainfall, evaporation, sunshine hour and temperature has been indicate graphically from figure 1-a to Fig. 1-d.



RAIN FALL DATA 1955 – 1976



EVAPORATION DATA 1955-1976

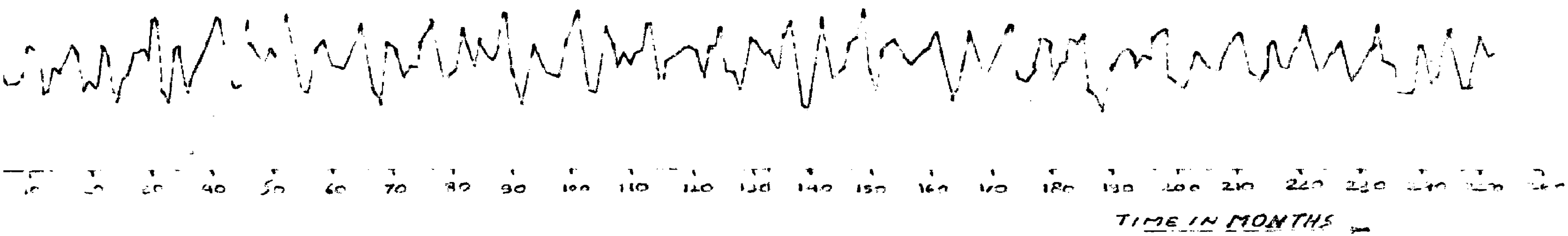


FIG. [illegible] SUNSHINE HOUR DATA 1956-1976

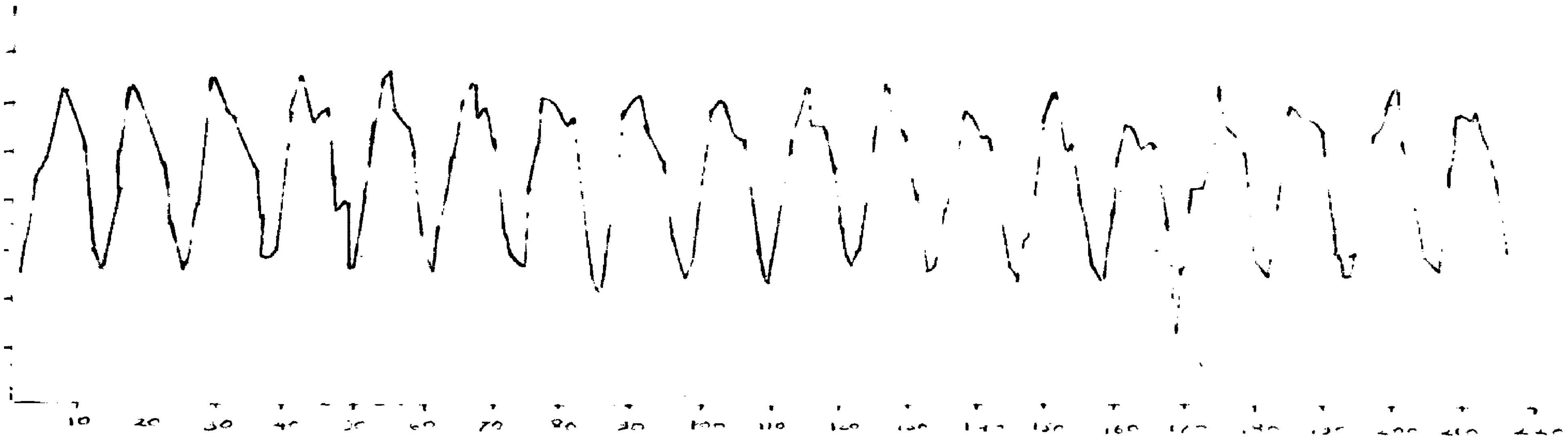


FIG 1-D TEMPERATURE [illegible] 1953-MIL

TABLE NO. 4.1

MONTHLY RAINFALL IN MM. (1955-1976)

Year	Jan.	Feb.	March	April	May	June	July	August	Sept.	Oct.	Novem.	December
1955	98.29	6.6	105	20	2.03	100	283.71	354.58	386.58	179.07	0.0	1.77
1956	9.39	21.33	34.54	1.52	73.15	120.14	407.67	559.05	162.56	265.17	21.08	0.0
1957	113.53	.762	25.91	33.78	1.77	81.28	415	288.8	316.2	39.9	10.0	68
1958	4.5	7.6	13.7	4.1	2.3	39.2	655.1	311.2	234.4	58.6	.5	38.2
1959	45.2	16.3	19.8	0	19.6	73.4	295.1	588	111.8	56.1	15.5	0.0
1960	2.14	0.0	20.6	1.3	.8	169	457.2	233.4	113.9	24 .4	0.0	12.33
1961	70.9	160	.5	3.1	11.2	65.5	635.3	484.1	182.6	120.4	3.81	49
1962	120.7	21.1	173.5	0	3.1	70.9	356.4	207.5	144.8	0	15.2	29.4
1963	11.9	8.1	10.5	1.3	19.1	85.9	192.3	319.5	355	0	1.8	7.4
1964	12.4	.3	7.1	3	30.2	63.7	571.7	300.2	260.5	0	0	17.6
1965	21.7	28.1	19.6	26.2	57.4	.03	268	392.5	46	25	0	2.6
1966	1.5	35.6	17	25.9	34.6	158.1	376.1	438.1	156.6	51.4	2.5	23.2
1967	0	.8	61.5	9.1	5.9	62.5	483	474.8	185	0	4	44
1968	41.7	19.6	24.6	16.2	0	120.2	448.4	217.3	14.9	60	.4	13.7
1969	15	1.8	32	18.6	2.1	3	312	352	182	0	0	0
1970	71.7	15.5	7.5	0	20.6	134.3	340.1	142	303.5	56	0	0
1971	15.5	23.4	0	33.1	87.7	294	235	451.7	168.2	37.3	33	0
1972	16.1	72.5	25.4	42.4	0	429	84	143.6	139.2	.5	3.7	1
1973	18.8	4	10.2	0	26	388.64	582.4	263.7	169.6	32.9	0	8.7
1974	.5	23.4	5	1	35.1	56 .1	296.1	98.8	61	19.3	0	29.8
1975	45.5	36.5	34.7	0	3.1	148.6	534.7	349.6	136.2	26.4	0	0
1976	8.5	36	11.4	14.3	49.6	101	398.4	489.1	57	12	0	0

TABLE NO. 4.2

MONTHLY EVAPORATION IN MM (1955-1972)

Year	Jan.	Feb.	March	April	May	June	July	August	Septem.	October	November	December
1955	86.49	103.05	185.69	261.30	346.27	284.27	217.31	161.2	173.7	118.73	96.6	73.16
1956	76.88	121.52	177.00	300.00	333.56	241.50	169.26	167.71	178.80	120.28	94.50	68.20
1957	64.48	108.08	171.00	273.30	316.20	281.10	236.22	179.50	166.80	136.40	81.00	53.63
1958	62.99	101.64	218.86	236.20	406.00	377.00	230.64	161.2	137.7	135.16	90.60	43.40
1959	48.05	86.80	158.10	267.00	337.59	292.50	200.47	160.58	126.30	118.11	82.20	68.20
1960	62.00	98.84	171.60	278.00	355.00	328.20	195.00	173.00	125.00	119.00	81.00	67.00
1961	62.00	98.84	172.00	255.30	305.00	295.50	183.00	147.25	138.00	109.12	78.30	43.09
1962	47.12	7.00	140.74	220.80	241.00	234.60	182.59	132.06	120.00	103.23	84.30	53.32
1963	53.01	91.84	154.07	219.66	270.00	200.70	164.38	103.85	111.30	3.47	75.60	57.66
1964	53.01	91.00	185.38	239.70	213.59	153.30	127.72	122.40	102.00	103.54	72.00	51.46
1965	52.70	95.76	142.60	202.20	272.49	294.00	170.50	161.20	129.00	105.40	81.00	61.69
1966	68.20	81.20	161.20	243.00	269.70	309.9	164.30	136.40	120.00	105.40	89.00	65.10
1967	55.80	100.80	136.40	258.00	331.70	306.00	114.70	122.14	114.00	117.8	69.00	40.30
1968	49.60	67.20	139.50	198.00	300.70	207.00	139.50	147.98	147.00	108.50	69.00	71.30
1969	55.80	86.80	130.20	249.00	248.00	255.0	155.0	120.90	105.00	120.9	78.00	49.60
1970	43.40	61.60	130.00	213.00	300.70	153.00	120.90	108.10	110.00	109.00	69.00	55.80
1971	65.10	98.0	158.10	195.00	195.30	114.00	108.5	80.60	114.00	102.30	60.00	49.60
1972	49.60	70.00	139.50	198.00	272.80	258.0	139.50	105.50	115.00	100.00	59.00	50.00

TABLE NO. 4.3

10°C

JAN.	FEB.	MARCH	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
12.95	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	24.75	[illegible]	[illegible]
13.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
13.1	[illegible]	[illegible]	[illegible]	[illegible]	32.4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	27.50	24.04	[illegible]	14.60
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	19.40	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7.55
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	13.60
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	26.15	24.10	[illegible]	[illegible]
13.95	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	26.65	[illegible]	[illegible]	15.55

SUNSHI[illegible]TA(1950-1970)

IN HOUR

JAN.	FEB.	MARCH	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
[illegible]	246.4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	173.6
178.6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	170.7	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	254.2
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	237.0	[illegible]	[illegible]	235.6
[illegible]	[illegible]	[illegible]	[illegible]	322.4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	207.7
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	177.4	177.4	[illegible]	[illegible]	[illegible]	[illegible]
260.4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	269.7	[illegible]	[illegible]
269.7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	291.4	[illegible]	254.2
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	135.4	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	233.2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	297.6	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	201.0	[illegible]	[illegible]	[illegible]
[illegible]	232.4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	246.4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	127.1	[illegible]	269.7	270.0	264.6
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	264.6	261.0	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	264.6
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

TABLE NO. 4.4

WIND VELOCITY AT 16FT HEIGHT KMPH /Hr.(1956-1972)

Year	Jan.	Feb.	March	April	May	June	July	August	September	October	November	Decembe
1956	4.67	4.46	6.38	6.10	6.10	4.85	3.93	3.52	3.25	2.72	2.46	3.84
1957	4.03	5.4	8.53	6.88	6.82	5.6	5.28	4.42	3.37	4.32	4.35	3.34
1958	6.25	7.84	9.36	9.18	11.16	10.38	6.11	5.36	5.44	4.48	4	4.38
1959	2.94	4.86	5.22	5.12	5.6	5.81	4.56	3.22	3.33	3.14	2.54	2.89
1960	3.42	3.7	4.72	5.8	5.65	5.91	4.1	3.22	3.2	4.78	2.61	2.56
1961	3.52	4.67	2.35	5.02	5.81	5.84	3.62	3.00	2.8	2.56	2.45	2.42
1962	3.12	3.49	4.69	5.57	5.38	3.93	3.44	3.58	3.58	2.65	3.69	3.37
1963	3.16	3.62	6.3	3	5.64	5.21	4.1	3.75	2.84	3.4	4.06	4.0
1964	4.14	6.00	6.99	6.86	7.67	6.27	4.65	3.8	4.25	2.85	2.88	4.9
1965	4.7	5.05	4.9	5.6	6.4	6.16	4.38	3.67	3.05	3.49	3.44	2.93
1966	3.35	4.51	4.6	5.52	5.5	5.81	3.62	3.56	3.54	3.45	2.9	3.20
1967	3.24	5.08	5.26	6.64	6.05	5.56	3.6	3.4	2.96	3.37	2.85	2.96
1968	3.5	4.4	4.86	4.9	5.8	5.23	3.66	3.9	3.5	3.36	2.74	2.80
1969	3.13	4.5	3.70	6.2	5.04	5.04	2.88	2.52	2.5	3.17	2.8	2.37
1970	2.9	3.3	4.10	2.6	2.2	3.98	3.22	2.9	2.78	2.5	2.04	2.07
1971	2.56	4.04	3.85	4.5	3.05	3.14	2.55	1.99	2.53	2.73	2.7	2.3
1972	2.4	4.0	4.60	4.8	5.14	4.72	3.94	2.95	2.5	2.6	2.34	2.93

TABLE NO. 4.5

RELATIVE HUMIDITY IN PERCENTAGE (1956-1972)

Year	January	February	March	April	May	June	July	August	September	October	November	Decemb
1956	80	78.5	72	54.5	63	77.5	87.5	88.75	87	89.5	88.5	72.5
1957	88.5	79	71.83	85	42	55	85.64	73.7	85	76	57.6	90.13
1958	88.4	50	36	28	16	32	85.67	78	84.6	84.61	56	70
1959	82	60	42	27	28	40	71	80	71	67	62	59
1960	86	84	44	44	23	53	77	87	82	73	77	81
1961	77	87.5	64.09	44.4	38.2	60.8	75	89.74	84	78.3	80.9	88.7
1962	87.4	80.05	71	43	35.8	50	81	89.60	83.3	70.2	77	81.3
1963	85.6	79	63.40	40.6	46.35	73.1	78.2	87.50	81.5	73.82	74.3	80.2
1964	85.4	44	52.20	40.16	39.6	52.9	85	85.0	84	75.20	70.2	82.35
1965	88	75	64	50	34	48	77.5	83.0	78	69	72	71.8
1966	75	72	57	37	42	60	71	82.0	75	67	68	76
1967	79	68	64	43	34	52	88	96	83	62	69	80
1968	83	79	67	45	35	62	83	84	79	66	69	78
1969	83	73	68	38	38.6	46	78	66	86	75	78	86
1970	87	88	75	54	52	77	84	87	90	86	85	92
1971	89	80	76.80	64	66	88	90	91	90	86	88	91
1972	91	82	76.0	60	50	60	83	88	87	79	88	88

Year	gust		September		October		November		December	
	Y	X	Y	X	Y	X	Y	X	Y	X
1956	3[illegible].9	2.39	48.06	2.21	52.1	1.85	51.92	1.67	19.43	2.61
1957	5[illegible].31	3.00	45.69	2.29	27.39	2.94	12.33	2.96	44.32	2.27
1958	4[illegible].17	3.65	28.63	3.70	37.75	3.05	12.29	2.72	8. 15	2.98
1959	2[illegible].42	2.19	19.14	2.26	15.16	2.14	13.11	1.73	12.79	1.96
1960	3[illegible].93	2.19	24.80	2.17	19.80	3.29	23.42	1.78	27.57	1.74
1961	2[illegible].22	2.04	30.53	1.90	22.36	1.75	27.36	1.67	35.81	1.65
1962	3[illegible].24	2.44	29.92	2.44	15.31	1.80	23.03	2.51	22.94	2.29
1963	3[illegible].28	2.55	23.48	1.93	17.89	2.31	19.29	2.76	22.70	2.72
1964	3[illegible].60	2.58	22.81	2.89	19.42	1.94	15.85	1.96	23.18	3.33
1965	3[illegible].52	2.50	21.46	2.07	17.22	2.37	15.35	2.34	18.98	1.99
1966	2[illegible].12	2.42	18.66	2.41	15.03	2.35	15.58	1.97	23.08	2.17
1967	2[illegible].23	1.64	24.84	2.01	14.93	2.29	17.42	1.94	16.12	2.01
1968	2[illegible].46	2.65	28	2.38	16.79	2.28	13.71	1.86	19.42	1.9
1969	2[illegible].93	1.71	28.84	1.7	20.77	2.15	20.36	1.9	28.83	1.61
1970	3[illegible].64	1.97	39.59	1.89	33.33	1.70	30.13	1.38	59.36	1.41
1971	3[illegible].58	1.35	46.34	1.72	32.78	1.86	30.76	1.84	43.13	1.56
1972	4[illegible].84	2.0	34.63	1.7	22.12	1.77	30.25	1.6	32.05	1.99

TABLE NO. 4.6

DATA FOR EVAPORATION STUDY (1956 - 1972)

Year	January		February		March		April		May		June		July		August		September		October		November		December	
	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X
1956	33.47	3.17	41.75	4.46	33.71	4.34	26.38	4.15	27.47	4.61	37.58	3.30	48.36	2.67	52.9	2.39	38.06	2.21	52.1	1.85	51.92	1.67	19.43	2.61
1957	50.97	2.74	42.09	5.40	35.18	5.80	76.77	4.68	15.25	4.64	18.92	3.81	54.80	3.59	23.31	3.00	45.69	2.29	27.39	2.94	12.33	2.96	44.32	2.27
1958	45.55	4.25	16.26	7.84	18.48	6.37	11.51	6.25	14.65	7.59	14.98	7.06	56.95	4.16	26.17	3.65	28.63	3.70	37.75	3.05	12.29	2.72	8. 15	2.98
1959	23.21	2.00	17.71	4.86	14.93	3.55	14.56	3.48	14.65	3.81	13.44	3.95	23.15	3.10	28.42	2.19	19.14	2.26	15.16	2.14	13.11	1.73	12.79	1.96
1960	39.89	2.32	42.24	3.70	17.26	3.21	20.90	3.95	14.29	3.84	19.81	4.02	28.63	2.79	42.93	2.19	24.80	2.17	19.80	3.29	23.42	1.78	27.57	1.74
1961	22.55	2.12	35.81	4.67	26.10	1.59	18.53	3.42	18.0	3.95	23.52	3.97	24.73	2.46	62.22	2.04	30.53	1.90	22.36	1.75	27.36	1.67	35.81	1.65
1962	38.34	2.12	2.54	3.49	29.38	3.19	14.01	3.79	11.73	3.66	13.90	2.67	30.43	2.34	11.24	2.44	29.92	2.44	15.31	1.80	23.03	2.51	22.94	2.29
1963	34.09	2.15	36.44	3.62	22.38	4.28	16.57	2.04	16.23	3.84	22.90	3.54	22.47	2.79	31.28	2.55	23.48	1.93	17.89	2.31	19.29	2.76	22.70	2.72
1964	33.94	2.82	12.26	6.00	19.57	4.75	15.26	4.67	12.03	5.22	9.23	4.27	30.70	3.17	28.60	2.58	22.81	2.89	19.42	1.94	15.85	1.96	23.18	3.33
1965	36.59	3.19	29.02	5.05	23.30	3.33	17.81	3.82	13.76	4.35	15.70	4.20	27.28	2.98	34.52	2.50	21.46	2.07	17.22	2.37	15.35	2.34	18.98	1.99
1966	22.54	2.28	20.0	4.51	21.49	3.13	15.54	3.76	15.27	3.74	24.59	3.95	20.04	2.46	28.12	2.42	18.66	2.41	15.03	2.35	15.58	1.97	23.08	2.17
1967	24.60	2.20	22.10	5.08	24.84	3.58	19.68	4.52	16.58	4.12	18.61	3.78	34.14	2.45	127.23	1.64	24.84	2.01	14.93	2.29	17.42	1.94	16.12	2.01
1968	27.26	2.38	27.21	4.40	24.30	3.30	15.12	3.33	15.42	3.95	19.45	3.56	32.44	2.49	34.46	2.65	28	2.38	16.79	2.28	13.71	1.86	19.42	1.9
1969	29.41	2.13	23.33	4.50	20.60	2.51	20.08	4.22	14.82	3.43	13.39	3.43	23.48	1.96	12.93	1.71	28.84	1.7	20.77	2.15	20.36	1.9	28.83	1.61
1970	30.07	1.97	38.74	3.30	28.44	2.79	17.99	1.77	19.82	1.50	21.79	2.71	25.08	2.19	28.64	1.97	39.59	1.89	33.33	1.70	30.13	1.38	59.36	1.41
1971	37.83	1.74	35.76	4.04	38.37	2.62	21.66	3.06	21.06	2.76	32.76	2.14	37.80	1.73	25.58	1.35	46.34	1.72	32.78	1.86	30.76	1.84	43.13	1.56
1972	47.10	1.63	33.02	4.0	31.35	3.13	21.06	3.26	18.03	3.49	21.32	3.22	27.08	2.68	30.84	2.0	34.63	1.7	22.12	1.77	30.25	1.6	32.05	1.99

Where $Y = \frac{E}{e_a - e_s}$

E = Evaporation in mm

$e_s - e_a$ = Saturation Deficit in mm.

X = Wind speed at 2m height in Kmph/hr

TABLE NO. 4.7

MONTHLY WIND VELOCITY AT 2 FT. HEIGHT IN KMPH / HOUR
(1970-1976)

Year	January	February	March	April	May	June	July	August	Sept.	Oct.	Nov.	December
1970	1.365	1.354	1.416	1.880	2.890	1.590	1.028	.923	0.87	0.903	.867	1.009
1971	1.100	2.200	2.000	2.50	2.0	1.40	1.30	.90	0.7	0.90	1	0.75
1972	0.900	1.700	1.500	1.800	2.50	2.30	1.30	1.0	0.8	1.4	1.5	1.70
1973	1.600	1.900	2.400	2.70	2.90	1.50	.50	0.50	0.8	0.9	.9	1.40
1974	1.700	1.900	2.500	2.70	2.90	2.40	1.40	1.20	1.2	1.1	1.09	1.00
1975	0.900	1.900	3.100	2.60	4.20	2.70	1.70	1.20	1	1	1.1	1.30
1976	1.300	2.300	2.400	3.30	3.10	2.40	2.20	1.90	1	1.7	1.2	1.50

TABLE NO. 4.8

WIND VELOCITY AT 10 FEET HEIGHT IN KMPH /HOUR

(1970 - 1976)

Year	Month											
	Jan.	Feb.	March	April	May	June	July	August	Sept.	Oct.	Nov.	December
1970	3.30	3.50	4.40	4.60	6.50	4.20	3.60	3.50	3.50	2.90	2.60	2.70
1971	2.90	4.50	4.60	5.30	5.10	3.90	3.30	3.10	3.0	2.80	2.90	2.40
1972	3.00	4.60	4.80	5.70	6.10	5.40	4.60	3.60	3.10	3.30	3.00	3.60
1973	4.00	2.80	4.70	5.60	5.70	4.10	3.60	3.70	3.10	2.50	2.70	3.50
1974	3.90	4.40	5.0	5.60	5.70	5.00	4.10	3.20	3.30	3.0	3.0	3.1
1975	3.10	4.10	5.80	5.30	7.20	5.20	3.90	3.0	2.90	2.64	2.50	2.7
1976	3.00	4.00	5.2	6.0	5.80	4.50	4.07	3.90	3.10	2.90	2.6	3.1

TABLE NO. 4.9

WIND VELOCITY AT 10 FEET HEIGHT IN KMPH /HOURS

(1970-1976)

Year	Month											
	Jan.	Feb.	March	April	May	June	July	August	Sept.	Oct.	Nov.	Dec.
1970	2.90	3.3	4.1	2.6	6.2	3.98	3.22	2.90	2.78	2.50	2.04	2.07
1971	2.56	4.01	3.85	4.5	4.05	3.14	2.55	1.99	2.53	2.73	2.70	2.30
1972	2.40	4	4.6	4.8	5.14	4.72	3.94	2.95	2.5	2.6	2.34	2.93
1973	3.30	3.4	4.4	5.3	5.3	3.4	2.4	2.7	2.4	2.7	2.4	3.2
1974	3.60	4.30	4.9	5.5	5.4	4.7	3.4	2.4	2.8	2.3	1.9	2.2
1975	2.20	3.0	4.9	4.4	6.1	4.1	3.7	2.8	2.9	2.3	2.1	2.5
1976	2.30	4.0	4.4	5.2	5.3	4.1	3.8	3.8	2.7	2.3	2.2	2.4

TABLE NO. 4.10

WIND VELOCITY AT 30 FEET HEIGHT IN KMPH / HOUR

(1970-1976)

Year	Month											
	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1970	3.3	4.1	5.0	5.8	7.3	5.8	3.3	3.2	3	2.7	2.7	2.6
1971	3	5.3	5.2	6	5.7	3.8	2.7	2.5	3	3.1	3.3	2.8
1972	3.4	5.4	6	6.3	6.6	5.7	4.5	2.6	1.8	3.0	3.1	3.8
1973	4.5	4.3	5.6	6.9	6.8	3.7	2.5	2.7	2.9	2.7	2.6	4.1
1974	4.1	4.7	5.6	6.6	6.8	5.2	4.2	2.6	3.0	2.4	2.3	2.5
1975	2.9	4.0	6.2	5.7	7.50	5.40	3.10	2.10	1.70	1.70	1.70	2.40
1976	2.6	3.9	4.6	5.9	6.1	4.7	3.90	3.70	1.90	1.50	1.50	2.90

CHAPTER- V

ANALYSIS OF DATA

5.1 INTRODUCTION:

As it has been discussed in earlier Chapters, the meteorological and hydrological data constitute sample values obtained from the population of phenomena which are stochastic in nature. The information provided by such data particularly monthly data is of considerable importance and used in the planning, design and operations of water resources project. The structural analysis of time series of monthly data and its representation by means of parameters of stochastic model, provides a very suitable technique for presentation of the information contained in the data in concise manner. This also facilitates comparison of different meteorological and hydrological processes at a particular place. In this Chapter the results of analysis of time series structure of available monthly data of rainfall, pan evaporation, sunshine hours and temperature of Bahadarabad Hydraulic Station of Irrigation Research Institute, Roorkee, are discussed.

The results of deterministic study of relationship between average monthly pan evaporation and wind velocity and variation of wind velocity with height above ground level are also presented.

5.2 ANALYSIS OF RAINFALL DATA:

5.2.1 Statistical Parameters:-

The study of monthly statistical parameters of rainfall (Table 5.1) shows that monthly mean values vary from as low as 5.06 mm in November to as high as 392.16 mm in July. Generally mean values are higher for monsoon months June to September. Pattern of standard deviation is also nearly similar. The pattern of both these parameters is indicated in a combined form by the value of coefficient of variation which are in the range of 35 percent to 85 percent, for monsoon months and 108 percent and above for other months. The values of coefficient of skewness C_s for all the 12 months are greater than zero indicating that the distribution is skewed to the right, however the values of coefficient of skewness for July and August are nearly equal to zero, indicating almost normal distribution.

The values of statistical parameters calculated on the yearly basis (Table 5.2) show an interesting pattern. The mean values range from 5.87 mm in 1965 to 332.4 mm in 1961. The pattern of standard deviation is nearly similar, lowest value being 7.22 mm in 1965. The year 1961 with highest mean rainfall has lowest coefficient of variation of 61.8 percent and this is the only year indicating negetive values of coefficient of skewness as -0.44. Thus distribution for 1961 is nearly normal. For the rest of years from 1955 to 1975 the distribution is skewed to the right.

Statistical parameter are calculated by using the computer programme No.1 and the rainfall data used in this analysis has been plotted in Figure 1-a in Chapter-IV.

5.2.2 Analysis of Trend:-

The method of least squares was used in the present study for fitting a regression line to monthly rainfall data,

$Y = mX + C$, and the equation for this line was obtained as below.

$$Y = 117.7830200 - .1185957\ X$$

where Y represents the monthly rainfall in mm, slope of this regression line was compared with horizontal line, by a 't'-statistic equation (3.10) and value of 't'-statistic was found to be -0.986338 which is less than the tabulated value 1.96 at 95 percent confidence level (computer programme No.3). It was inferred that the trend in the data is statistically not significant, it is only due to chance fluctuations or sampling bias rather than non-homoginity in the data. The confidence limits for above regression line were found to be 120.02929 and 84.108890 from equation (3.7) and the regression line for the data period lies within these confidence limits further confirming that the trend in the data is not significant and hence time series of monthly rainfall data as such was used for further analysis.

5.2.3 Correlogram of Original Series:-

A correlogram study of the original series of rainfall has been made using (computer programme No.2) and equation (3.12).

Asthe lag K should be between $\frac{N}{10}$ to $\frac{N}{3}$ where N is sample size, therefore r_K values were computed upto K = 44. The 95 percent confidence limits of r_K values in the correlogram have been computed using following equation (Yevjevich 1972).

$$r_K \ (\alpha) = \frac{-1 \pm n\alpha \sqrt{N - K - 1}}{N-K} \quad \ldots\ldots (5.1)$$

For 95 percent confidence level $n\alpha$ is 1.96.

The correlogram of original series has been plotted and 95 percent confidence limits marked in Fig. 5.2-a. This shows that the periodicity is present in the series with predominant period of 12 months. Also 6,4 and 3 months cycles are indicated in correlogram.

5.2.4 Periodic and Stochastic Component:-

The composition model of periodic and stochastic components of the time series is

$$X_{p\tau} = \mu_\tau + \sigma_\tau e_{p,\tau} \quad \ldots\ldots (5.2)$$

where both μ_τ and σ_τ have periodic component for separating periodic and stochastic components following transformation is done and standardized stochastic component is obtained

$$e_{p\tau} = \frac{X_{p,\tau} - m_{\tau}}{S_{\tau}} \quad \ldots\ldots (5.3)$$

where m_{τ} and S_{τ} are the monthly mean and standard deviation calculated by equation (3.14, 3.15) for given data as given in Table 5.1. Thus the variable $e_{p,\tau}$ obtained by removing the periodicity in the mean and standard deviation is a second order stationary time series which will be tested further for dependent and independent components.

5.2.4.1 Correlogram Analysis of $e_{p,\tau}$ series:-

Correlogram study of the standardised series $e_{p,\tau}$ has been made using the computer programme No.2, and using equation (3.12). The 95 percent confidence limits of r_K values in the correlogram have been computed. The correlogram (Fig. 5-2-b) shows that the r_K values are within the 95 percent confidence limits. This indicates that the periodic component has been removed and $e_{p,\tau}$ series can be considered as second order stationary stochastic component.

5.2.5 Selection of Mathematical Model:-

To identify the order of linear auto-regressive model the determination coefficient approach was adopted using the serial correlation coefficient r_1 = .0496293, r_2 = .0420756 and r_3 = .1020739 for $e_{p\tau}$ series. The values of determination coefficients R_1^2, R_2^2 and R_3^2 were found using equation (3.18) to (3.20) respectively; and their values were obtained as .0026, .004152, .01065 respectively. Since $(R_2^2 - R_1^2) = .001552 \leq .01$ and $(R_3^2 - R_2^2) = .0065 \leq .02$, this approach indicates first order auto-regressive model for representing dependent stochastic component of $e_{p\tau}$ series. However the correlogram of $e_{p\tau}$ as discussed in 5.2.4.1 indicates that $e_{p\tau}$ series is independent. Hence, $e_{p\tau}$ series was considered as independent series $\varsigma_{p\tau}$ and tested further for fit of normal distribution using Chi Square test.

5.2.6 Fit of Normal Distribution:-

For testing goodness of fit of $\varsigma_{p\tau}$ series it was arranged in descending order using computer programme No.5 and 26A values were divided into 30 classes of equal probability interval, such that for each class interval expected frequency is more than five. Using the standardised normal variate (Normal Frequency Distribution) class interval limits were calculated since two parameters are calculated and using data no. of degrees of ν = n-K-1 = 30.2.1 and 27. For 27 degrees of freedom at 5 percent level $\chi^2 0.05$ is 40.11. The calculated χ^2 as given in Table 5.3 is 128.27. Thus $\chi^2 > \chi^2_c$ and hence normal distribution does not fir calculation given in Table (5.3).

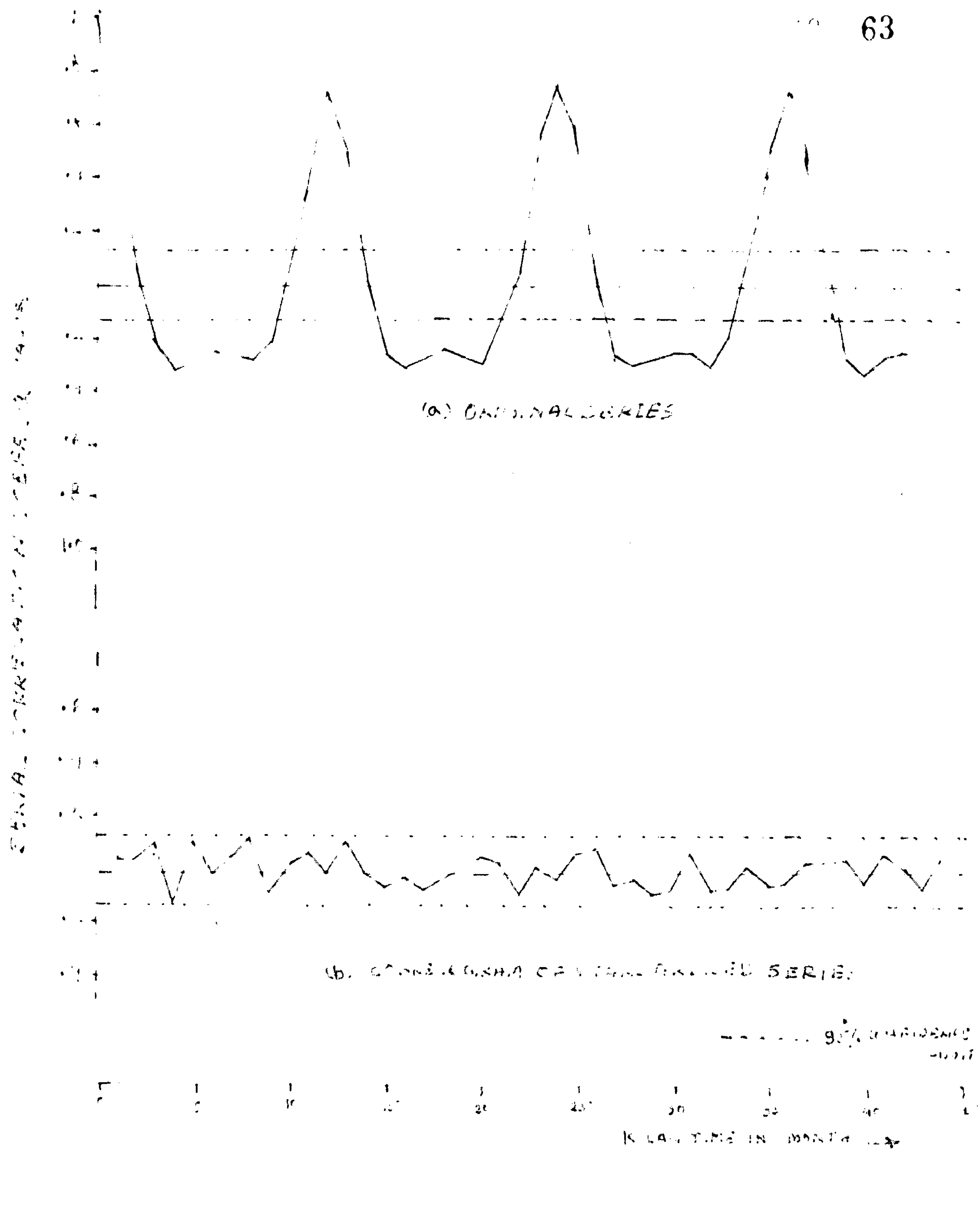

(a) ORIGINAL SERIES
95% CONFIDENCE LIMIT

TABLE NO. 5.1

MONTHLY STATISTICAL PARAMETERS OF MONTHLY RAINFALL

Sl.No.	Month	Meam in MMS	Standard Deviation in MMs.	Coefficient of Variation C_v in %	Coefficient of C_s skewness
1.	January	33.88409	36.87286	108.8206	1.35013
2.	February	24.51327	33.97495	138.5982	3.35216
3.	March	30.00227	38.49596	128.3102	3.01615
4.	April	11.58182	13.10486	113.1503	1.01099
5.	May	22.06136	24.75081	112.1907	1.39436
6.	June	125.65863	108.3429	86.2201	1.85308
7.	July	392.16727	142.94744	36.4506	.04492
8.	August	339.04681	132.68925	39.1360	.05894
9.	September	176.70636	96.71547	54.7323	.58059
10.	October	48.38364	63.18615	130.5941	2.49279
11.	November	5.06773	8.51139	167.9528	2.26295
12.	December	15.75591	19.11685	121.3313	1.36662

TABLE NO. 5.2

YEARLY STATISTICAL PARAMETERS OF MONTHLY RAINFALL DATA

1955-1975 On Year basis

Sl No	Year	Mean (mms)	Standard Deviation (mms)	Coefficient of Variance C_v %	Coefficient of Skewness C_s
1.	1955	128.13000	135.97102	106.1196	1.02084
2.	1956	139.40083	174.21353	124.9731	1.70804
3.	1957	118.34833	133.69523	112.9676	1.52014
4.	1958	116.57500	188.38427	161.5992	2.55492
5.	1959	103.22916	166.32668	161.1237	2.73498
6.	1960	118.68750	120.66226	101.6638	2.23923
7.	1961	332.41583	205.42493	61.7976	- .04406
8.	1962	268.00250	195.00034	72.7606	.25201
9.	1963	108.08666	128.33011	76.3476	.34370
10	1964	63.43667	80.44933	126.8183	1.83335
11.	1965	5.87417	7.22468	122.9908	1.21836
12.	1966	20.78583	20.87438	100.4217	1.19566
13.	1967	110.88333	172.03838	155.1526	1.97328
14.	1968	81.4166	125.89226	154.6271	2.70893
15.	1969	76.54167	124.39188	162.5153	1.81589
16.	1970	90.93333	113.9269	125.2862	1.59541
17.	1971	114.90833	137.71742	119.8498	1.64815
18.	1972	79.7416	116.41155	145.9859	2.81200
19.	1973	125.41166	183.05355	145.9621	1.85972
20.	1974	52.17500	78.90102	151.2238	3.1139
21.	1975	109.60833	160.70210	146.6149	2.20556

TABLE NO. 5.3

CHI SQUARE TEST FOR GOODNESS OF - FIT

(Independent Stochastic component - Rainfall Series)

Sl. No.	P(X x)	K	X = y + k	O_j	O_j^2
1.	2.	3.	4.	5.	6.
1				4	16
2	.0333	- 1.83426	- 1.834673	1	1
3	.0666	- 1.501538	- 1.501827	2	4
4	.0999	- 1,282222	- 1.2825286	5	25
5	.1332	- 1.111429	- 1.1117138	2	4
6	.1665	- .968000	- .96826	6	36
7	.1998	- .842500	- .84275	15	225
8	.2331	- .728710	- .72894	26	676
9	.2664	- .623636	- .62385	19	361
10	.2997	- .525294	- .52550	22	484
11	.3330	- .431667	- .43186	12	144
12	.3663	- .341622	- .34180	13	169
13	.3996	- .254359	- .25453	12	144
14	.4329	- .168974	- .16899	13	169
15	.4662	- .084750	- .084903	9	81
16	.4995	- .001250	- .0013928	10	100
17	.5328	.082250	0.082117	9	81
18	.5661	.166410	0.16628	11	121
19.	.5994	.251795	0.25168	5	25
20	.6327	.338947	0.33884	3	9
21	.6666	.428889	0.4288	7	49
22	.6993	.522355	0.52227	4	16

Continued........

Table No. 5.3 Continued

1.	2.	3.	4.	5.	6
23	.7326	.620606	0.62054	5	25
24	.7659	.725484	0.72543	2	4
25	.7992	.838929	0.83889	2	4
26	.8658	1.106818	1.1068168	13	169
27	.8991	1.276471	1.2764915	4	16
28	.9324	1.493846	1.4938943	7	49
29	.9657	1.829352	1.8294432	7	49
30	.999	3.100	3.1002537	14	196
		Total		264	3452

$$Y^2 \text{ Calculated} = \frac{30}{264} * 3452 - 264$$

$$= 128.27$$

$$Y^2_{0.05} \text{ for } 27 \text{ d.f.} = 40.11$$

$\therefore X^2$ calculated X^2_c

Hence Normal distribution does not fit.

5.3 ANALYSIS OF EVAPORATION DATA

5.3.1 Statistical Parameters:-

The study of statistical parameters on monthly and yearly basis was done using 18 years of evaporation data given in the Table (4.2) Chapter-IV. The monthly evaporation data has also been plotted in Fig. No.4.1-b of Chapter IV.

The study of monthly statistical parameters of evaporation (Table No.5.4)) shows that monthly mean values vary from 54.417 mm in December to 29.8.644 in May. Generally mean values are higher in the summer months of April, May, June and July.

The monthly mean values indicate a decreasing pattern from the month of May to Month of Dec.

The standard deviations do not follow the pattern of means. The maximum value of standard deviation 210.34 mm is in the month of July, where as the maximum mean evaporation 298.644 mm is in the month of May.

The pattern of both these parameters is indicated in combined form by the values of coefficient of variation which are in range of 13.38 percent to 136.99 percent, the highest coefficient of variation is in the month of November. The coefficient of skewness is nearly equal to zero in the month of April and May, indicating almost normal distribution. The month of May also has the maximum mean evaporation, thus indicating that the distribution becomes nearly normal when monthly evaporation is maximum.

It is seen that in the month of January, February and March coefficient of ~~a~~ skewness is greater than zero, indicates that distribution is skewed to right (Autumn Season), however for August, October and December (Winter Month) is less than zero indicating that the distribution is skewed to left for these months. However, for drawing definite conclusions, further study will be needed.

The values of statistical parameters calculated on the yearly basis (Table No.5.5) shows that in the year 1959, mean evaporation is maximum i.e. 232.33 mm and this also indicates the lowest value of coefficient of skewness i.e. - .08625, thus indicating nearly normal distribution. The mean values range from 81.56 mm in 1965 to 233.33 mm in 1959, and standard deviation ranges from 9.20 mm to 188.48 mm. The pattern of standard deviation is not similar to that of mean, lowest value of standard deviation is 9.20 mm in 1965. The coefficient of variation ranges from 11.28 percent to 96.074 percent.

In the year 1959 and 1960 coefficient of skewness is nearly zero while in the year 1961-1966 coefficient of skewness is less than zero indicating that the distribution is skewed to the left. While in the remaining years coefficient of skewness is greater than zero, indicating that distribution is skewed to the right.

5.3.2 Analysis of Trend:-

The method of least square was used in the present study for fitting a regression line, to monthly evaporation data,

$Y = mX + C$ and the equation for this line was obtained

$$Y = 176.750910 - .1706087\ x$$

where Y represents the monthly evaporation in mm, the slope of this line was compared with horizontal line, by a 't' - statistic and value of 't' statistic was found to be -1.329425 which is less than the tabulated value 1.96 at 95 percent confidence level. It was inferred that the trend in the data is statistically not significant.

The confidence limits for the above regression line were found to be 173.92364 and 142.55610 from equation (3.7). The regression line for the data period lies within these confidence limits further confirming that the trend in the data is not significant and hence original time series of monthly evaporation data as such was used for further study.

5.3.3 Correlogram of Original Series:-

Correlogram of original series of monthly evaporation data has been made using computer programme No.2 and equation (3.12). The funcation limit of K equal to 44 has been choosen for correlogram. The 95 percent confidence limit of r_K values in the correlogram have been computed using equation (5.1).

The correlogram of original series (Fig. No.5.3-a) shows that the periodicity is present in the series with predominent period of 12 months.

5.3.4 Periodic and Stochastic Component:-

The composition model of periodic and stochastic component of the time series is expressed in equation (5.2) in which both μ_τ and s_τ have periodic components. For separating periodic and stochastic components following transformation is done and standardized stochastic component is obtained.

$$e_{p,\tau} = \frac{X_{p,\tau} - m_\tau}{S_\tau} \quad \ldots\ldots (5.4)$$

where m and S are the monthly mean and standard deviation calculated by equation (3.14, 3.15) for the given monthly evaporation data as in (Table No.5.4). Thus the variable $e_{p\tau}$ obtained by removing the periodicity in the mean and standard deviation is a second order stationary time series which was tested further for dependent and independent components.

5.3.4.1 Correlogram Analysis of $e_{p\tau}$ Series:-

Correlogram study of the standardised series e_p has been made using the computer programme No.2, and using equation (3.12). The 95 percent confidence limit of r_K values in the correlogram (Fig. 5.3-b) shows that the r_1 value is outside the 95 percent confidence limit. This indicates that the periodic component has been removed and

e_{pz} series can be considered as a dependent stochastic process for which suitable a.r. model is to be found.

5.3.5 Selection Mathematical Model:-

To identify the order of linear auto-regressive model the determination coefficient approach was adopted using the serial correlation coefficients $r_1 = .2807672$, $r_2 = .1498699$ and $r_3 = .26850$ for e_{pz} series. The values of determination coefficients R_1^2, R_2^2 and R_3^2 were found using equation (3.18, 3.19 and 3.20) respectively; and their values were obtained as 0.078827, 0.08431 and -0.36675 respectively. Since, $(R_2^2 - R_1^2) = .005483 \leq .01$ and $(R_3^2 - R_2^2) = -.44506 \leq .02$. This approach indicates first order auto regressive model for representing dependent stochastic component of e_{pz} series.

5.3.6 Independent Stochastic Component:-

As indicated earlier, the application of determination coefficient method indicates first order auto-regressive model. Hence the stochastic independent component can be expressed as below:

$$e_p = r_1 \; e_{pz-1} + (\sqrt{1-r_1^2}) \; \xi_{pz} \qquad \ldots . (5.5)$$

where r_1 is first serial correlation coefficient. Substituting the value of r_1 in (5.5) and rearranging,

$$\xi_{pz} = \frac{e_{pz} - .2807672 \; e_{pz-1}}{(\sqrt{1 - .078827})} \qquad \ldots . (5.6)$$

independent stochastic component ξ_{p2} thus calculated has mean as -.0001977 and standard deviation as 1.0062035 which are slightly different from 0 and 1 respectively due to run off errors. To have 0 mean and 1 standard deviation of the series, the same has been standardised, and arranged in descending order using computer programme No.5.

5.3.7 Correlogram Analysis of ξ_{p2} Series:-

Correlogram study of the series ξ_{p2} has been made using the computer programme No.2, and using equation (3.12). The 95 percent confidence limit of r_K values in the correlogram have been computed. The correlogram (Fig. No.5.3-6) that the r_K values are within the 95 percent confidence limit. This indicates that the periodicity has been removed and ξ_{p2} series can be considered as second order stationary, independent stochastic component with 0 mean and 1 standard deviation.

5.3.8 Fit of Normal Distribution:-

For Chi Square test ξ_{p2} series arranged in descending order using computer programme No.5, and 216 values have been divided into 30 classes of equal probability intervals, such that for each class interval expected frequency is more than five. Using the standardised normal variate (Normal Frequency Distribution) the class interval limits were computed and observed frequency was calculated for each class.

For 27 degrees of freedom (30-1-2) as in case of rainfall data Chisquare calculated was χ^2 = 78.6. From tabulated values of Chi Square for 27 degrees of freedom at 5 percent level, $\chi^2_{c_1} = 40.11$.

Thus, χ^2 calculated $> \chi^2_c$

It indicates that normal distribution does not fit. The χ^2 calculations are given in Table No.56.

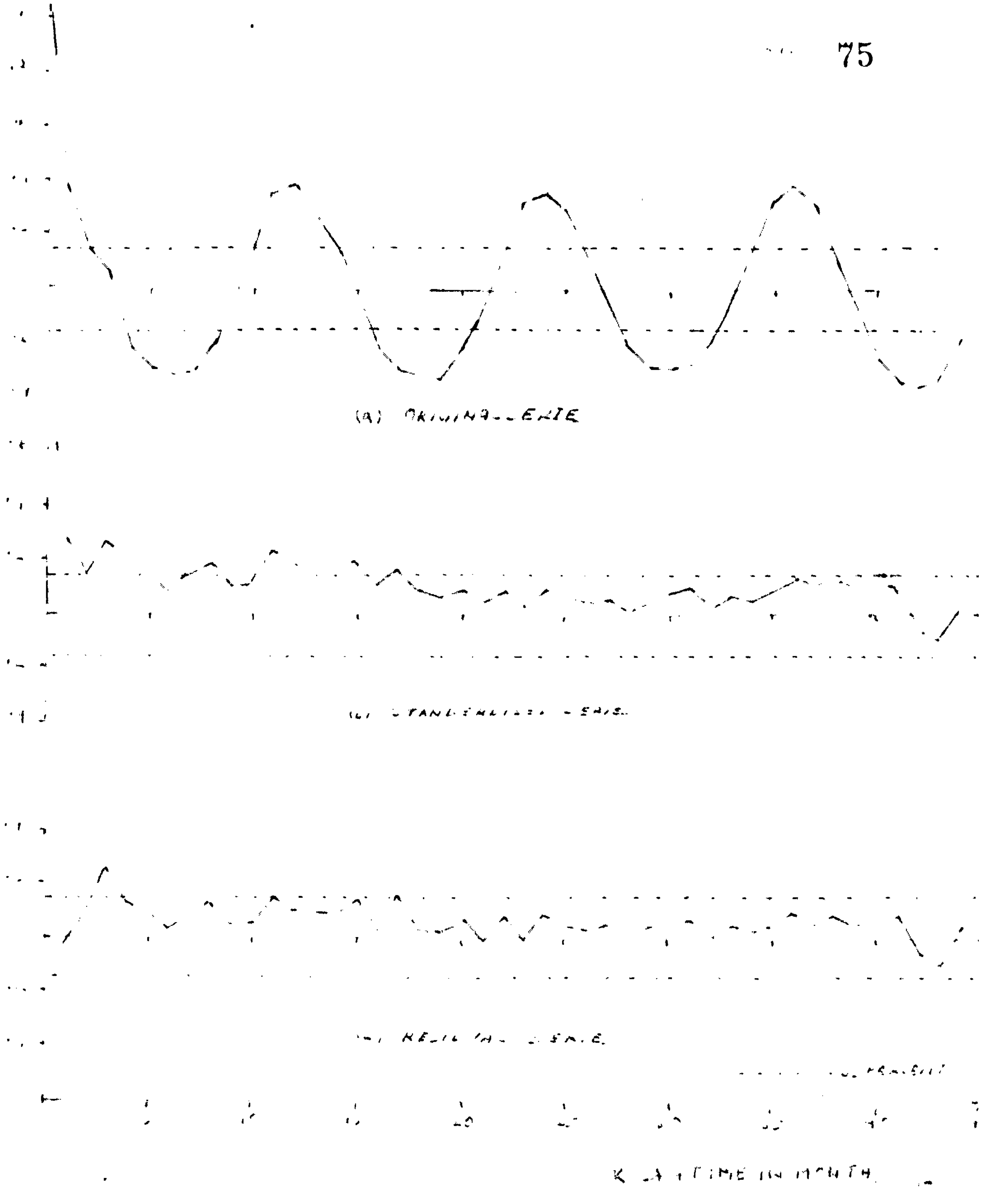


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TABLE NO. 5.4

MONTHLY STATISTICAL PARAMETER EVAPORATION

Sl.No.	Month	Mean in mm	Standard Deviation	Coefficient of variation in %	Coefficient of of skewness
1.	January	58.70444	10.70572	18.2366	1.10940
2.	February	118.02055	123.02907	104.2438	4.32431
3.	March	159.55222	22.79938	14.2896	0.90933
4.	April	242.07777	32.39187	13.3808	0.04574
5.	May	298.64444	53.91835	18.0544	-0.06896
6.	June	260.30944	72.18691	27.7312	-0.32231
7.	July	217.19388	210.34256	96.8455	4.37728
8.	August	135.19277	27.98825	20.7025	-0.16423
9.	September	129.96111	22.50968	17.3203	1.10937
10.	October	107.57444	27.25828	25.3390	-3.51097
11.	November	117.230165	160.59786	136.9936	4.58968
12.	December	54 .41722	16.16346	29.7028	-2.26553

TABLE NO. 5.5

YEARLY STATISTICAL PARAMETER OF MONTHLY EVAPORATION DATA ON YEARLY BASIS (1955-1972)

Sl. No.	Year	Mean	Standard Deviation	Coefficient of Variation C_v	Coefficient of Skewness C_s
1	1955	183.98083	97.63828	53.0698	1.05863
2	1956	172.94833	78.61310	45.4547	0.95667
3	1957	188.15333	75.17076	39.9519	-0.04865
4	1958	216.04166	110.45199	51.1253	.18329
5	1959	232.3316	113.67159	48.9264	- .08625
6	1960	222.0475	107.05617	48.2132	.09506
7	1961	158.72525	66.46828	41.8763	-1.28891
8	1962	131.94583	38.18883	28.9428	- .73278
9	1963	117.83583	48.90044	41.4988	-1.16998
10	1964	99.20833	37.15849	37.4550	-1.8630
11	1965	81.56942	9.20283	11.2822	- .37301
12	1966	55.24250	18.57933	33.6323	-2.66237
13	1967	147.22000	92.80427	63.0378	1.22323
14	1968	137.27333	69.49960	50.6286	1.06706
15	1969	196.18333	188.48142	96.0741	3.06699
16	1970	169.06666	150.71277	89.1440	2.75248
17	1971	111.70833	46.58842	41.7054	.80823
18	1972	129.74166	73.49035	56.6436	1.02376

TABLE NO. 5.6 Continued

1	2	3	4	5	6
24	.7659	.725484	.73014	2	4
25	.7992	.838929	.84393	10	100
26	.8658	1.106818	1.1134864	10	100
27	.8991	1.276471	1.2841918	7	49
28	.9324	1.493846	1.5029153	2	4
29	.9657	1.829352	1.8405026	4	16
30	.9999	3.1000	3.1190331	7	46
				216	2118

$$Y^2 \text{ calculated} = \frac{30}{216} \times 2118 - 216$$

$$= 78.6$$

$X^2_{0.05}$ for 27 d.f. = 40.11

$\therefore$ X^2 calculated X^2_c

Hence normal distribution does not fit.

TABLE NO. 5.6

CHISQUARE TEST FOR GOODNESS OF FIT

(Independent Stockastic component - Evaporation series)

Sl No	P(X x)	K	X = y + k	O_j	O_j^2
1	2	3	4	5	6
1				1	1
2	.0333	- 1.83426	- 1.8458	7	49
3	.0666	- 1.501538	- 1.5100504	5	25
4	.0999	- 1.28222	- 1.2903719	3	9
5	.1332	- 1.1112129	- 1.1185254	6	36
6	.1665	- .968000	- .9742	7	49
7	.1998	- .842500	- .84792	6	36
8	.2331	- .728710	- .73342	6	36
9	.2664	- .623636	- .6277	5	25
10	.2997	- .525294	- .52875	10	100
11	.3330	- .431667	- .43454	8	64
12	.3663	- .341622	- .34393	12	144
13	.3996	- .254359	- .25613	7	49
14	.4329	- .168974	- .17022	14	196
15	.4662	- .084750	- .085473	19	361
16	.4995	- .001250	- .0014555	17	289
17	.5328	.082250	.082562	8	64
18	.5661	.166410	.16724	3	9
19	.5994	.251795	.25315	9	81
20	.6327	.338947	.34085	4	16
21	.666	.428889	.43135	3	9
22	.6993	.5223553	.52339	2	4
23	.7320	.620606	.62425	12	144

Continued....

TABLE NO. 5.6 Continued

1	2	3	4	5	6
24	.7659	.725484	.73014	2	4
25	.7992	.838929	.84393	10	100
26	.8658	1.106818	1.1134864	10	100
27	.8991	1.276471	1.2841918	7	49
28	.9324	1.493846	1.5029153	2	4
29	.9657	1.829352	1.8405026	4	16
30	.9999	3.1000	3.1190331	7	46
				216	2118

$$Y^2 \text{ calculated} = \frac{30}{216} \times 2118 - 216$$

$$= 78.6$$

$X^2_{0.05}$ for 27 d.f. $= 40.11$

$\therefore$ X^2 calculated X^2_c

Hence normal distribution does not fit.

5.4 MONTHLY SUNSHINE HOURS DATA:

5.4.1 Statistical Parameters:-

The monthly sunshine hours data of 21 years (Chapter IV, Table 4.3) has been used here to find statistical parameters; such as mean, standard deviation coefficient of variation, coefficient of skewness. The study of monthly statistical parameters of sunshine hours (Table No.57) shows that monthly mean value vary from as low as 181.971 in the month of August to as high as 320.22 hrs. in the month of May. Only in the monsoon period the mean values are low. The pattern of standard deviation is not similar to mean. The highest value is in the month of October, and lowest value is in the month of November. Further, it shows that the value of standard deviation are lower from January to April, and in the remaining period the values are higher, except in the month of November.

The values of coefficient of variation ranges from 4.86 to 23.5377. The pattern is nearly similar to standard deviation.

The values of coefficient of Skewness C_s are less than zero for non-monsoon months indicating that the distribution is skewed to the left. While in the monsoon months it is greater than one indicating that the distribution is skewed to the right. The value of statistical parameters calculated on the yearly basis (Table No.5.8) shows an interesting pattern that the mean values are of nearly same order of magnitude for the entire period (1956-1976), ranging from 201.31 to 270.43. The year 1965 shows the maximum value of standard deviation i.e. 82.96 and generally it follows the pattern of mean.

The values of coefficient of variation ranges from 4.39 to 35.17.

Nearly half values of the coefficient of skewness are less than zero indicating that distribution is skewed to the left and remaining half values indicate that the distribution is skewed to the right.

5.4.2 Analysis of Trend:-

The method of least squares was used in the present study for fitting a regression line. The equation of the trend line was obtained as

$$Y = 240.892 + .027564\ X$$

where Y represents the monthly sunshine hour and X represents month number. The slope of trend line was compared with horizontal line by 't' statistics (3.10) and value of 't' statistic was found to be 0.69033 which is less than the tabulated value of 1.96 at 95 percent confidence limit. Thus it was inferred that the trend in the data is statistically not significant. The confidence limit for regression line were found to be 250.80221 and 238.570.147. The regression line for the data period lies within these confidence limits, further confirming that the trend in the data is not significant.

5.4.3 Correlogram of Original Series:-

The correlogram of original series (Fig.No.5.4) shows that the periodicity is present in the series with predominant period of 12 months also 6 months and 3 months cycles are indicated in correlogram.

5.4.4 Periodic and Stochastic Component:-

The composition model of periodic and stochastic components of the time series expressed as per equation (5.2) For separating periodic and stochastic component following transformation is done and standardized stochastic component is obtained.

$$e_{p,\tau} = \frac{X_{p\tau} - m_{\tau}}{S_{\tau}} \quad \ldots\ldots (5.7)$$

where m_{τ} and S_{τ} are the monthly means and standard deviations calculated by equation (3.14, 3.15) for a given data as in (Table No.5.7). Thus the variable e_p obtained by removing the periodicity in the mean and standard deviation is a second order stationary time series which was tested further for dependent and independent components.

5.4.4.1 Correlogram Analysis of $e_{p,\tau}$ Series:-

Correlogram study of the standardised series $e_{p,\tau}$ has been made. The 95 percent confidence limit of r_K values in the correlogram (Fig.No.5.4-b) shows that the r_1 value is outside the 95 percent confidence limit. This indicates that the periodic component has been removed and $e_{p,\tau}$ series has to be considered as dependent stochastic component for which the order of a.r. model was selected as in next para.

5.4.5 Selection of Mathematical Model:-

To identify the order of linear auto-regressive model the determination coefficient approach was adopted using the serial correlation coefficients r_1 = .1987078, r_2 = 0.0076637 and r_3 = 0.0766531, For $e_{p,\tau}$ series. The values of determination coefficients R_1^2, R_2^2 R_3^2 were found using equation (3.18 to 3.20 respectively and their values were obtained as 0.03941, 0.0405 and 0.04748 respectively, since $(R_2^2 - R_1^2)$ = .00110 $\leq$ .01 and $(R_3^2 - R_2^2)$ = 0.006947 $\leq$ .02. This approach indicates first order auto-regressive model for representing dependent stochastic component of $e_{p,\tau}$ series.

5.4.6 Independent Stochastic Component:-

As discussed earlier that the determination coefficient method indicates the first order auto-regressive model,hence the stochastic independence component can be expressed as below

$$e_{p,\tau} = r_1\, e_{p,\tau-1} + (\sqrt{1-r_1^2})\, \xi_{p,\tau} \qquad \ldots \text{ (5.8)}$$

where r_1 = first serial correlation coefficient substituting value of r_1 and rearranging

$$\xi_{p,\tau} = \frac{e_{p,\tau} - (.1987078)\,(e_{p,\tau-1})}{(\sqrt{1 - 0.0394})}$$

Independent Stochastic Component $\xi_{p,\tau}$ thus calculated has mean .000920 and standard deviation 0.9990, which are nearly 0 and 1 respectively.

To have exactly 0 mean and 1 standard deviation of the series the same has been standardised and arranged in descending order using computer programme No.5.

5.4.7 Correlogram Analysis of Series:-

Correlogram study of the series has been made using the equation (3.12). The 95 percent confidence limit of r_K values in the correlogram have been computed and plotted.

The correlogram (Fig. No. 5.4-c) shows that the r_K values are within the 95 percent confidence limit. This indicates that the periodicity has been removed and , series can be considered as a second order stationary independent stochastic component with 0 mean and 1 standard deviation.

5.4.8 Fit of Normal Distribution:-

For Chi Square test series arranged in descending order using computer programme No.5 and 252 values were divided into 30 classes of equal probability intervals such that in each class interval expected frequency is more than five. Using the standardised normal variate the class interval limits were calculated and observed frequency calculated and for 27 degree of freedom, Chi Square is obtained and compared with tabulated value at 10 percent level.

$$\chi^2 \text{ calculated} = 44.00$$

$$\chi^2\ 0.01 = 46.99$$

as $\chi_{\text{calculater}} \leq \chi^2\ 0.01$

Thus normal distribution fits at 10 percent level.

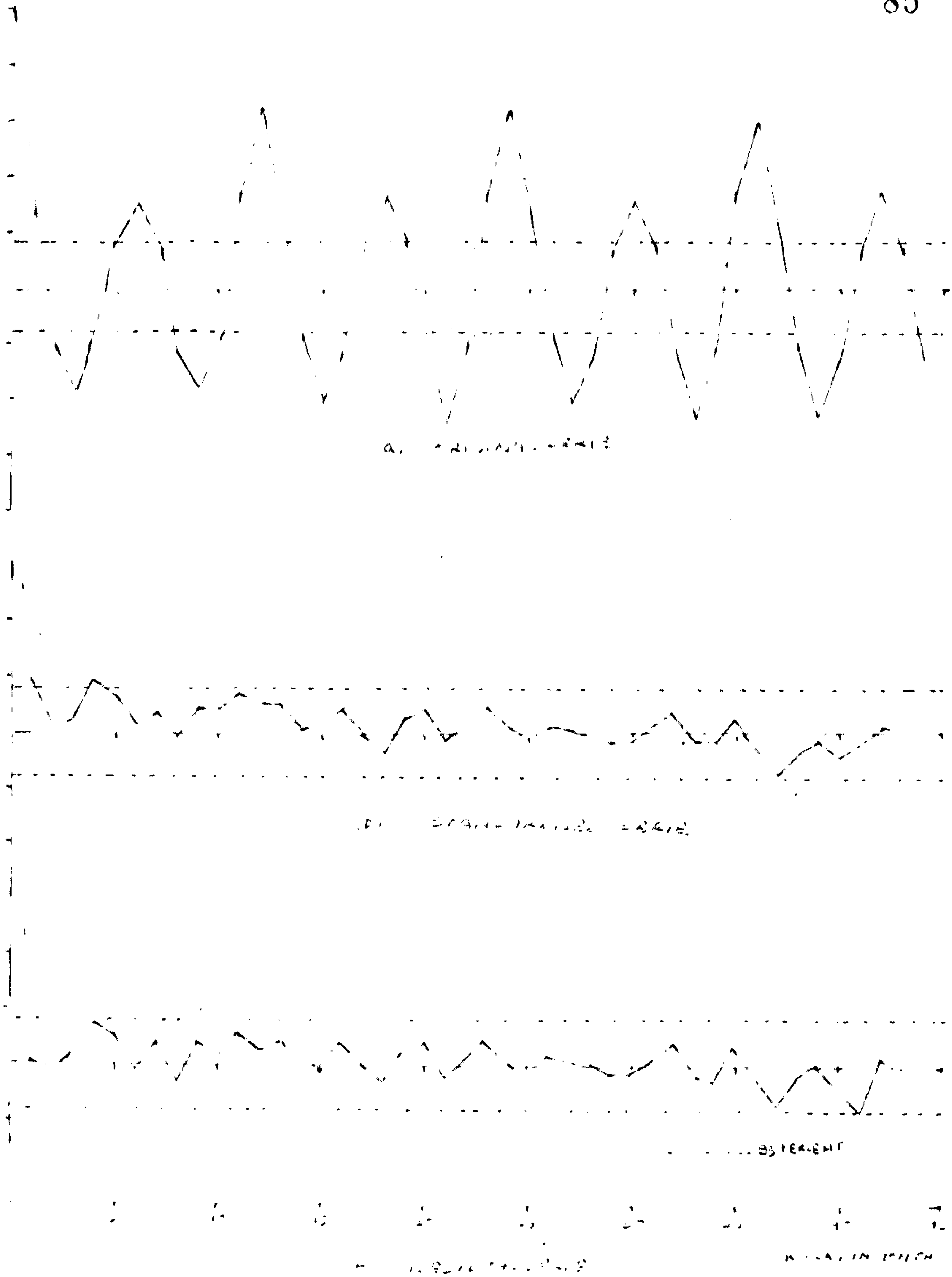

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TABLE NO. 5.7

MONTHLY STATISTICAL PARAMETER MONTHLY SUNSHINE HOUR

(1956-1976)

Sl.No.	Month	Average in Hours	Standard Deviation in Hours	Coefficient of variation in Ft.	Coefficient of skewness
1.	January	225.86666	28.94889	12.8168	.66782
2.	February	233.09523	19.46438	8.3504	- .77008
3.	March	254.86666	24.78863	9.7261	- .97295
4.	April	284.00000	15.02379	5.2901	- 1.13978
5.	May	320.22857	23.05315	7.1990	- .34146
6.	June	239.71428	40.66261	16.9629	- .79077
7.	July	196.78095	36.57166	18.5850	2.99721
8.	August	181.97142	30.20691	16.5998	.26941
9.	September	221.39523	29.34029	13.2524	- .32496
10.	October	277.08571	65.21952	23.5377	- 4.01410
11.	November	272.42857	13.24351	4.8613	- .74968
12.	December	228.44285	32.38143	14.1748	- .61614

TABLE NO. 5.8

YEARLY STATISTICAL PARAMETER OF MONTHLY SUNSHINE HOUR DATA (1956-1976)

Sl. No.	Year	Average in Hours	Standard deviation in Hours	Coefficient of variation %	Coefficient of skewness
1	2	3	4	5	6
1	1956	202.60833	71.26400	35.1733	- 2.00433
2	1957	229.69166	40.35891	17.5709	- .39102
3	1958	237.71666	51.93579	21.8474	.39102
4	1959	266.60833	48.62363	18.2379	- .18355
5	1960	266.41666	51.23183	19.2300	- .25745
6	1961	238.90000	43.99387	18.4152	- .76294
7	1962	226.11666	51.46019	22.7582	1. 42936
8	1963	201.30833	39.07738	19.4117	.70565
9	1964	225.41666	42.00411	18.6340	1.17218
10	1965	266.51666	82.96454	31.1292	-3.39047
11	1966	270.43333	11.88988	4.3966	- .17004
12	1967	216.52500	33.09178	15.2831	- .45373
13	1968	261.93333	44.61634	17.0335	.25017
14	1969	247.75833	43.76202	17.6632	- .81940
15	1970	249.29166	45.19888	18.1309	.10973
16	1971	239.34166	53.41830	22.3188	-1.07631
17	1972	240.22500	39.14972	16.2971	.29754
18	1973	236.71666	46.43092	19.6146	- .54979
19	1974	251.90000	33.05261	13.1213	.41776
20	1975	237.63333	44.22586	18.6110	- .30246
21	1976	237.85000	48.43691	20.645	.10876

TABLE NO. 5.9

CHISQUARE TEST FOR GOODNESS OF FIT

(Independent Stochastic component Sunshine Hour)

Sl. No.	P(X x)	K	X = y + k	Oj	Oj^2
1	2	3	4	5	6
1					
2	0.0333	-1.83426	- 1.81573	9	81
3	0.0666	-1.501538	- 1.48620	8	64
4	0.0999	-1.282222	- 1.26899	8	64
5	.1332	-1.111429	- 1.09984	5	25
6	.1665	- .968000	- 0.95778	7	49
7	.1998	- .842500	- 0.83349	7	49
8	.2331	- .728710	- 0.72263	5	25
9	.2664	- .623636	- 0.61672	11	121
10	.2997	- .525294	- 0.51933	5	25
11	.3330	- .431667	- 0.4266	7	49
12	.3663	- .341622	- 0.33742	6	36
13	.3996	- .254359	- 0.25099	6	36
14	.4329	- .168974	- 0.16643	12	146
15	.4662	- .084750	- 0.083016	9	81
16	.4995	- .001250	- 0.000318	10	100
17	.5328	.082250	0.08238	12	144
18	.5661	.166410	0.16573	9	81
19	.5994	.251795	0.25029	4	16
20	.6327	.338947	0.33661	16	256
21	.666	.428899	0.42569	9	81

Continued .....

1.	2.	3.	4.	5.	6.
22	.6993	.522353	0.51825	8	64
23	.7326	.620606	0.61556	9	81
24	.7659	.725484	0.71943	13	169
25	.7992	.838929	0.83179	10	100
26	.8656	1.106818	1.097113	15	225
27	.8991	1.276471	1.265137	9	81
28	.9324	1.493846	1.480425	13	169
29	.9657	1.329352	1.81271	3	9
30	.999	3.100	3.07116	5	25
			Total	250	2450

$$X^2 = \left(\frac{K}{N}\, oj^2 - -N \right)$$

$$X^2_{\text{calculated}} = \frac{30}{250} \times 2450 - 250 = 44$$

X^2 0.05 for 27 degree of freedom 40.11

X^2 0.01 for 27 degree of freedom 46.99

$X^2_{\text{calculated}}$ X^2 0.01

Hence normal distribution fits.

5.5 MONTHLY TEMPERATURE DATA

5.5.1 Statistical Parameters:-

The monthly average temperature data of 18 years (Table No.4.3) has been used here to find statistical parameters such as mean, standard deviation coefficient of variation, coefficient of skewness.

The study of monthly statistical parameters of temperature (Table No.510) shows that the mean value ranges from 13.5 °C to 29.8°C and the standard deviation follows the pattern of mean. The values of coefficient of variation ranges from 2.27 percent to 15.73 percent. The coefficient of skewness shows that in the winter months distribution is skewed to the left and in summer months it is skewed to the right.

The values of statistical parameters of calculated on the yearly basis (Table No.511) show an interesting result. The coefficient of skewness is less than zero for all the year thus indicating that distribution is skewed to the left. The values of coefficient of variation range from 8.57 percent to 31.78 percent.

5.5.2 Analysis of Trend:-

The method of least squares was used in the present study for fitting a regression line, the equation of this was obtained as

$$Y = 23.3725 - .00241311 X$$

where Y represents monthly temperature and X represents month number.

The 't' statistic of equation (3.10) was found to be -.035336, which is less than the tabulated value of 1.96 at 95% confidence level. It was inferred that the trend in the data is statistically not significant.

The confidence limits for regression line were found to be 23.945 and 22.276. The regression line lies within these confidence limits, thus further confirming that the trend in the data is not significant.

5.5.3 Correlogram of Original Series:-

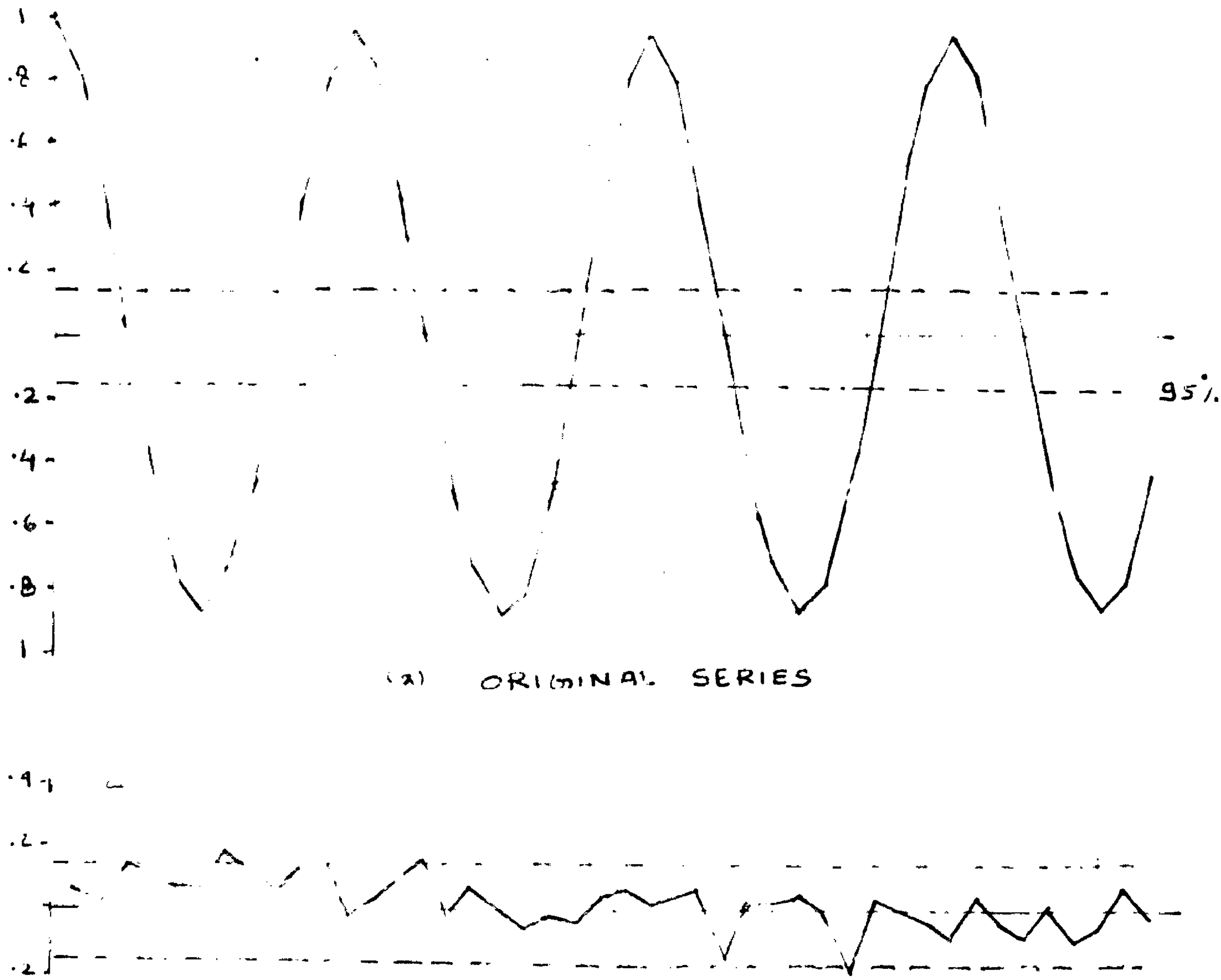
The correlogram of original series (Fig. 5.5-a) shows that the periodicity is present in the series with predominent period of 12 months, also 6 month cycle is indicated in correlogram.

5.5.4 Periodic and Stochastic Component:-

The composition model of periodic and stochastic component of the time series is as per equation (5.2). For separating periodic and stochastic component following transformation is done and standardized stochastic component is obtained.

$$\varepsilon_{p,\tau} = \frac{X_{p\tau} - m_{\tau}}{S_{\tau}} \quad \ldots\ldots$$

where m and S are the monthly means and standard deviations calculated by equation (3.14, 3.15) for a given data as in Table No.5.10. Thus the variable ε_p obtained by removing the periodicity in the mean and standard deviation is a second order stationary time series. This will be tested further



(b) STANDARDISED SERIES

FIG. 5.5 CORRELOGRAM ANALYSIS OF TEMPERATURE SERIES

TABLE NO. 5.10

MONTHLY STATISTICAL PARAMETER OF MONTHLY TEMPERATURE DATA (1955-1972)

Sl. No.	Month	Average in ^oC	Standard Deviation in C^o	Coefficient variation in Pct	Coefficient pf skewness
1.	2.	3.	4.	5.	6.
1	January	13.50722	1.57736	11.6779	2.67721
2	February	15.40056	1.61103	7.5389	-.02791
3	March	20.56611	1.18956	5.7897	-.58656
4	April	25.72722	1.41431	5.4973	-.46106
5	May	29.80167	1.29812	4.3559	.33520
6	June	30.98500	1.48264	4.7850	-.26193
7	July	28.94222	.65836	2.2748	.34090
8	August	28.13278	1.34261	4.7724	1.48091
9	September	27.39222	1.09919	4.0128	.64579
10	October	23.80111	.85589	3.5960	-1.00691
11	November	18.65167	.67895	3.6402	- .02833
12	December	14.44056	2.2774	15.7386	- .72064

TABLE NO. 5.11

YEARLY STATISTICAL PARAMETER OF MONTHLY TEMPERATURE DATA YEAR 1955 - 1972

Sl. No.	Year	Average (°c)	Standard Deviation in c°	Coefficient of Variance Pct	Coefficient of skewness
1	2	3	4	5	6
1	1955	22.77917	5.91335	25.9595	- .52084
2	1956	23.60833	5.89392	24.9654	- .33431
3	1957	24.40833	5.33244	21.8468	- .24322
4	1958	26.67083	3.95672	14.8354	- .40308
5	1959	27.69167	5.25043	18.9603	- 1.63662
6	1960	27.91250	5.67506	20.3316	- 1.61370
7	1961	26.20417	5.22006	19.9207	- 2.29399
8	1962	25.63333	4.57796	17.8594	- 2.00611
9	1963	25.62083	4.01510	15.6712	- 1.96438
10	1964	22.87500	2.95909	12.9359	- 2.52925
11	1965	18.21083	1.56132	8.5736	- 2.81147
12	1966	14.91083	1.83291	12.2925	2.48241
13	1967	22.45417	6.05843	26.9813	- .16133
14	1968	21.56667	6.85457	31.7832	- .89626
15	1969	23.14167	5.98167	25.8481	- .38579
16	1970	23.09583	6.29797	27.2688	- .53450
17	1971	23.62500	5.34616	22.6293	- .20220
18	1972	22.97500	5.94557	25.8784	- .47989

for dependent and independent components.

5.5.4.1 Correlogram Analysis of $\varepsilon_{p,\tau}$ Series:-

The correlogram study of the standardised series has been made. The 95% confidence limit of r_K values in the correlogram (Fig. No.5.5-b) shows that the r_1 value is within the confidence limit. This indicates that the periodic component has been removed and $\varepsilon_{p,\tau}$ series can be considered as second order stationary in stochastic component.

5.5.5. Selection of Mathematical Model:-

To identify the order of linear auto-regressive model the determination coefficient approach was adopted using the serial correlation coefficients $r_1 = 0.0618116$, $r_2 = 0.0259649$ and $r_3 = 0.1545668$ for $\varepsilon_{p,\tau}$ series the values of determination coefficients R_1^2, R_2^2 and R_3^2 were found using equation (3.18 to 3.20) respectively and their values were obtained as 0.0038205, 0.004312 and 0.002754 respectively. Since $(R_2^2 - R_1^2) = 0.00049235 \leq .01$, and $(R_3^2 - R_1^2) = 0.0232281 > .02$. Hence, no model fits here.

5.6 PERIODICITY IN THE MEAN

5.6.1 Periodicity in the Mean Monthly Rainfall:-

Periodicity in the mean rainfall was studied (Fig. No.5.6) and study of the significance of harmonics was done. Fourier coefficients have been calculated using equation

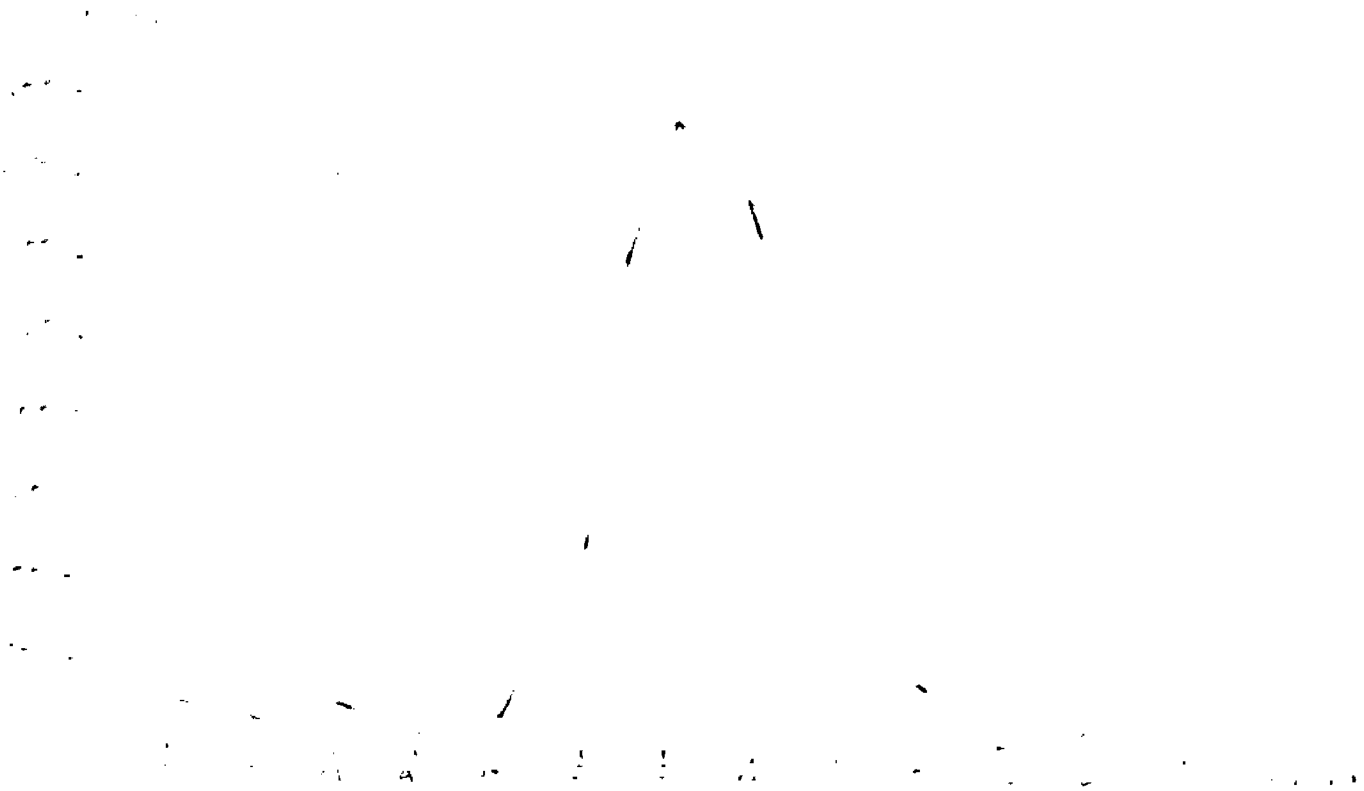
(3.30) and (3.31) for 12 month main harmonic and its sub harmonics of 6, 4, 3, 2.4 and 2 months. The significance of harmonics was tested using equation (3.32) to 3.37). Variance explained by each of the harmonics is given in the (Table No.5.12). For testing significance of harmonics P_{min} & P_{max} were calculated using equations (3.37) and (3.38). P_{min} = 0.02436 (for W = 12, C = 1 and n = 22) and P_{max} = 0.97536 were obtained for the test. As recommended by Yejvcvich (1972) if $P_{min} < P \leqslant P_{max}$, all six harmonics are significant.

If $P > P_{max}$, only some of the six harmonics are significant. For this case on applying this test to values of variance P (= 68.13%) explained by all six harmonics, (Table No.5.12) it was found that all six harmonics are significant.

5.6.2 Periodicity in the Mean Monthly Evaporation:-

The evaporation mean has been related (Fig. No.57) and variance explained by each of the harmonic has been given in the (Table No.5.13) and using 3rd approach suggested by Yejevich (1972), P_{min} = 0.0273748 for1= 18, C = 1, W = 12 and P_{max} = 0.972625.

If $P_{min} < P \leqslant P_{max}$, all six harmonics are significant. In this case on applying the test to value of variance explained by all the six harminocs i.e. P = 38.6466%, it was found that all six harminics are significant.



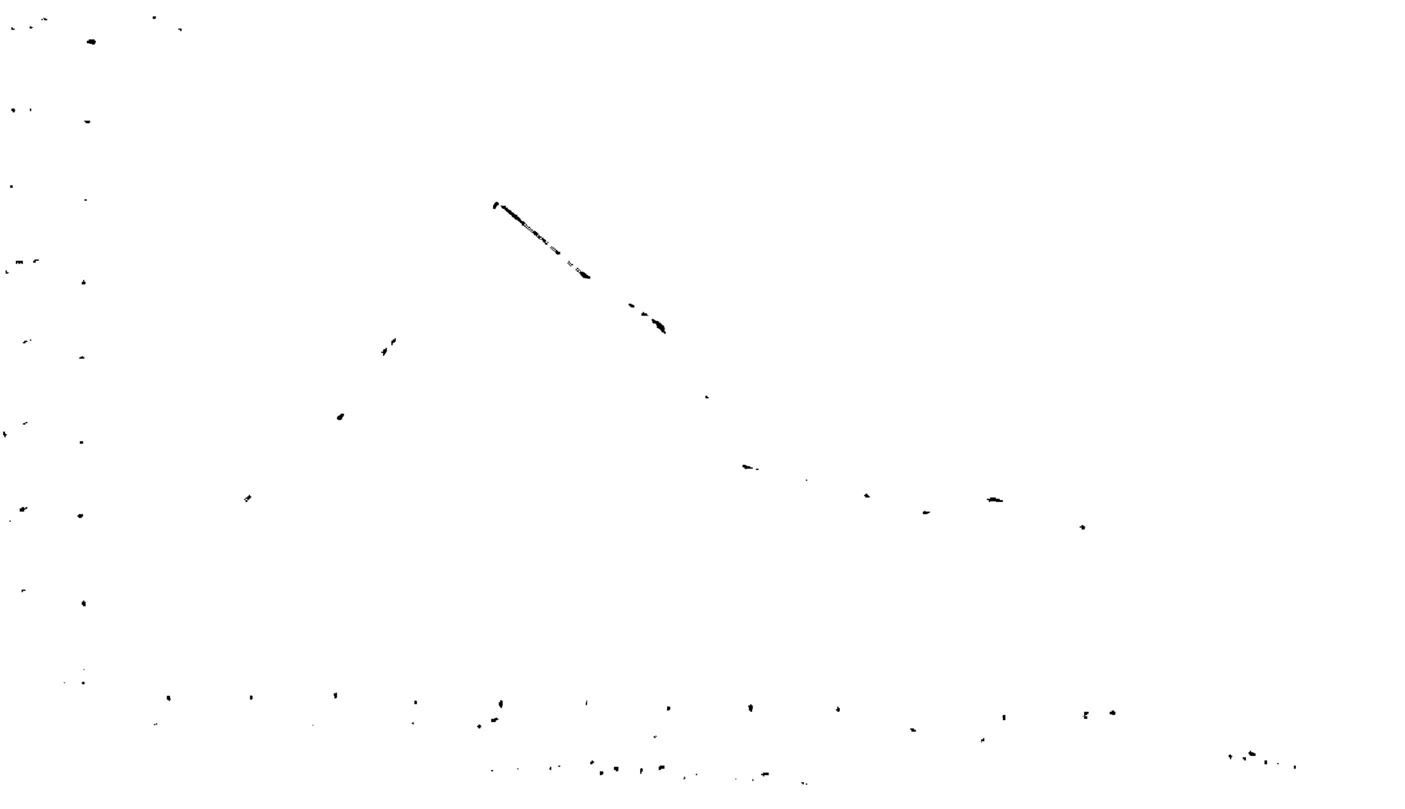


TABLE NO. 5.12

VARIANCE EXPLAINED BY EACH OF THE HARMONKS RAINFALL MEAN

Sl.No	Particulars	Fourier Coefficient		Explained Variance $(A_j^2 + B_j^2)/2$	Percentage of Explained Variance
		A_j	B_j		
1.	12 Months Period	57.530	89.264	5639.003	31.42
2.	6 Months Period	8.350	101.237	5159.375	28.74
3.	4 Months Period	27.971	-32.580	921.990	5.14
4.	3 Months Period	-15.113	13.599	206.660	1.15
5.	24 Months Period	13.169	10.167	138.645	0.77
6.	2 Months Period	15.990	0	127.867	0.71
					68.7355

TABLE NO. 5.13

VARIANCE EXPIAINED BY EACH OF THE HARMONICS EVAPORATION MEAN

Sl. No.	Particulars	FOURIER COEFFICIENT		Explained Variance $(A_j^2 + B_j^2)/2$	Percentage of Explained Variance
		A_j	B_j		
1.	12 Months period	-65.912	6.864	2194.82	34.776
2.	6 Months period	4.792	69.956	46.462	0.736
3.	4 Months period	9.035	-10.156	92.396	1.463
4.	3 Months period	7.491	- 5.715	44.389	0.730
5.	2.4 Months period	8.753	3.955	46.129	0.730
6.	2 Months Period	5.159	0	13.310	0.210

5.7 DETERMINISTIC APPROACH:

5.7.1 Evaporation Study:-

Evaporation study was carried out using 17 years of pan evaporation data, wind velocity data and relative humidity data and monthly temperature data collected at Bahadarabad (Table No.4.6) using this data the value of A & B in the following relation were obtained using linear regression between

$E / (e_s - e_a)\ (A + BU)$

where, A & B are regression coefficient representing intercept and slope respectively of regression line.

U = Wind velocity in kmph/hr at 2 mtr. height.

$(e_s - e_a)$ = saturation deficit (obtained by using monthly relative humidity temperature). The (Table No.5.14) show the monthwise value of A & B and correlation coefficient for the regression relation.

It is seen from the table that the July month indicates the maximum value of correlation coefficient as 0.5578 but in December month negetive maximum value of correlation was obtained as -.52975.

Verticial wind velocity U were plotted on ordinary scale as abscissa against height above ground level Y on log scale as ordinate the values of Y at which observations were available are .6096 mtrs. 3.048 m, 4.8768 and 9.144 mtr. and straight line were fitted graphically. Slopes of these straight lines are tabulated in Table No.5.15 different months January to December for 1970-1976.

It is seen from this table that values of slope (log/V) vary from .387 to .591 on the yearly basis, and on the monthly basis log Y/U vary from .196 to .726. The maximum slope occur in the month of December, while the lowest value of in is the month of February.

TABLE NO. 5.14

MONTHLY EVOPORATION STUDIES FOR THE BAHADRABAD FOR THE PERIOD 1956-1972

Sl. No.	Month	A	B	R	$E = e_s (1 - \frac{Y}{100}) (A + BX)$
1	2	3	4	5	6
1	January	23.66393	4.248318	0.3139522	$E = e_s(1 + y/100)(23.66393 + 4.248318 X)$
2	February	44.62704	- 3.578050	-0.3337743	$E = e_s(1 - y/100)(44.62704 - 3.578050 X)$
3	March	25.93060	- 0.1887137	-0.0338373	$E = e_s(1 - Y/100)(25.93060 - .188713 X)$
4	April	12.24191	2.421654	0.1691635	$E = e_s(1 - Y/100)(12.24191 + 2.421654 X)$
5	May	19.48316	- 0.7613682	-0.2478839	$E = e_s(1 - Y/100)(19.48316 - 0.7613682 X)$
6	June	30.30765	- 2.726329	-0.3976778	$E = e_s(1 - Y/100)(30.30765 - 2.726329 X)$
7	July	3.455264	10.62422	0.5598029	$E = e_s(1 - Y/100)(3.455264 + 10.62422 X)$
8	August	6.937843	-14.26135	-0.2966257	$E = e_s(1 - Y/100)(6.937843 - 14.26135 X)$
9	September	40.30454	- 4.506430	-0.2360146	$E = e_s(1 - Y/100)(40.30454 - 4.506430 X)$
10	October	26.77771	- 1.456908	-0.06742599	$E = e_s(1 - Y/100)(26.77771 - 1.456908 X)$
11	November	44.74617	-11.23229	-0.5071274	$E = e_s(1 - Y/100)(44.74617 - 11.23229 X)$
12	December	54.45975	-12.93219	-0.5297575	$E = e_s(1 - Y/100)(54.45975 - 12.93219 X)$

Where, E = Evaporation in mm

X = Wind velocity in kmph/hr at 2 mtr height.

TABLE NO. 5.15

VERTICAL WIND VELOCITY DISTRIBUTION $\frac{\text{Log } Y}{U}$

Month	YEARS							Average month wise
	1970	1971	1972	1973	1974	1975	1976	
January	.255	.318	.175	.200	.241	.220	.425	.262
February	.212	.194	.159	.154	.200	.140	-	.176
March	.163	.185	.171	.175	.175	.259	.250	.196
April	.200	.166	.167	.133	.333	.333	.500	.262
May	.286	.333	.286	.286	.286	.333	.364	.310
June	.25	.500	.333	.500	.500	.54	.467	.455
July	.437	.660	.350	.635	.400	.666	.666	.317
August	.540	.900	.450	.500	.666	.500	.366	.560
September	.50	.666	.660	.666	.666	.666	.660	.642
October	.660	.410	.584	.540	.770	.500	1.100	.651
November	.700	.500	.780	.646	1.000	.700	.700	.718
December	.816	.636	.537	.437	.660	1.000	1.000	.726
Average Yearly	.417	.456	.387	.406	.491	.486	.591	

CHAPTER - VI

CONCLUSIONS

(i) The statistical parameters (Mean, Standard deviation Coefficient of variation, coefficient of skewness) of monthly data of rainfall, evaporation, sunshine hour and temperature, calculated for calender months as well as on yearly basis indicate the statistical information in concise manner.

The range of variation of monthly mean is larger in case of rainfall and evaporation data in comparison to that for sunshine hours and temperature. Similar pattern is indicated for coefficient of variation (Fig. No.6.1). For rainfall coefficient of variation varies from 36% to 168%, where as for temperature it varies from 2.3% to 15.7%. The values of coefficient of skewness for calender month for x rainfall data indicate nearly normal distribution (C_s=0) for May and June months which also have maximum mean monthly value of rainfall.

The mean values found for yearly basis indicate a vide variation in case of rainfall andsome what lesser variation in case of evaporation. However for both sunshine hour and temperature the variation in yearly mean value is relatively small. The coefficient of variation for rainfall data varies from 61% to 162% from year to year; however corresponding limit for evaporation data range from 11% to 80 %. The coefficient of variation values for both temperature and sunshine hour data have comparatively smaller range from year to year. The skewness coefficient for different years for rainfall data also indicates near normal distribution (C_s=0) for years having maximum value of mean evaporation.

(ii) The trend component has not found to be significant for monthly data of rainfall, evaporation, sunshine hour, temperature.

(iii) The periodicity in the monthly mean values for both rainfall and evaporation requires all the six harmonics viz. 12, 6, 4, 3, 2.4, 2 months for its representation.

(iv) Dependent stochastic component of second order stationary stochastic series obtained after standardising the series, was inferred using determination coefficient approach as well as correlogram analysis. The first order model was indicated for evaporation and sunshine hour while for rainfall and temperature data model was indicated.

(a) The fit normal distribution is indicated at 10% level by Chi Square test only for stochastic independent component in case of sunshine hour data. However for rainfall and Evaporation data notmal distribution does not fit stochastic independent component.

(b) The Deterministic study of evaporation and wind velocity data gives only approximate relationship.

Scope of Further Study:-

There is need for further study on the lines used in the present study using data from number of meteorological regions.

The fit of stochastic independent component should be checked for best fit using other suitable probability distribution. The study is also needed for establishing inter-relationship between time series components of different hydrometeorological process.

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      Y(1)=Y(1)/A
      Y(I)=(Y(I)-A*Y(I-1))/A
      SUM=SUM+Y(I)
      SUM2=SUM2+Y(I)*Y(I)
      Y(I)=(Y(I)-    )/
      Y(I)=Y(I+1)
      Y(I+1)=
```

```
      IJ=1,
      I=1,
      Y=SU  X + (I)*Y(I)
      R=R1/R2
      PUNCH3,IJ,A, ,R
      FORMAT(5X,1  SERIES.NO=,I2/5X,2HA=,E16.7,15X,2HB=,E16.7,5X,2HR=,
     1E16.7//)
   1  CONTINUE
      STOP
      END
```