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PROCESSING OF PRECIPITATION DATA

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ABSTRACT

Preliminary processing of the precipitation data is essential before it is put to further use in analysis. Processing of precipitation data has two major objectives. One is to evaluate the data for its accuracy and the other is to prepare the data in a form appropriate for subsequent analysis and other applications. While some errors are observational or instrumental, others occur while recording, transmitting and storing the data. With the volume of precipitation data to be handled increasing, manual quality control would be impossible and the advent of high speed digital computers has made possible computerised processing of precipitation data.

Precipitation data processing could be conceived of as a system through which the basic (raw) data could be transferred into freely accessible and readily usable form. Essentially, the system would consist of a number of manual and computerised processing procedures which include besides data collection,

i) preliminary processing,

ii) storage of data on computer compatible devices,

iii) quality control,

iv) editing,

v) data conversion

vi) further analysis and

vii) storage of analysed data into computer disc files

The system developed by users of precipitation data for its processing has to be adaptable both for climatological analysis as well as operation in real time. It has to be flexible enough to handle data from future precipitation data collection sources such as Radar and Satellites.

In this manual appropriate procedures for carrying out the various components of the processing system are described keeping in view the precipitation data collection and storage in India. Where necessary, the procedures are explained with examples. Two computer programmes, one for identifying missing data in daily rainfall data and the other for distribution of daily rainfall into hourly rainfall and computing the average hourly catchment rainfall are also provided.

1.0 INTRODUCTION

Precipitation is the most important factor among a variety of hydrometeorological parameters used as input in the hydrological models used for watershed simulation and estimation of stream flow. With the increased use of these models for flood forecasting, information on rainfall intensity at more frequent intervals at more number of locations is being collected. Accurate input data of precipitation intensities are essential for effective economical and integrated planning of water resources, their estimation and implementation of developmental schemes.

With the accent on automation through the use of telemetering precipitation gauges and gauges linked to micro-processor based data logging devices which can record data on computer compatible devices like floppy diskettes or cassette tape units, it has become possible to increase the frequency of observations and number of gauges. Inspite of the best efforts to maintain complete rainfall records of all observations in an area, often some data inconsistencies arising out of missing or wrongly recorded observations come to be noticed. Preliminary processing of the precipitation data is, therefore, essential to identify inconsistencies, detect missing and duplicate data, locate errors and remove all such inconsistencies and errors before the data could be put to further use by the analyst.

Processing of precipitation data has two major purposes. One purpose is to evaluate the observations which sample a precipitation event or a series of events. Evaluation includes checking of data for errors,inconsistencies and other aspects. The other purpose is to describe the event in a form appropriate for display,subsequent analysis such as depth-area-duration statistics, intensity-frequency relationships etc.

Besides observational and instrumental errors,some errors also occur while recording,transmitting and storing the data. Manual scrutiny for carrying out the preliminary processing has obvious limitations irrespective of howsoever experienced the person carrying out the scrutiny be. During manual scrutiny a large number of errors could be missed and besides introducing personal bias, would involve lot of time. Also, with the volume of precipitaton data coming from large number of sources increasing, manual scrutiny has become quite impracticable. With the advent of the computers and their availability at more number of centers, the accent has shifted to computerised quality control and processing. Computerised processing has several advantages over the manual scrutiny. Dewan (1984) has listed the following :

i) Objectivity,uniformity and accuracy

ii) Complicated processing

iii) Rapid achievement of results and

iv) Close supervision by experts at all stages

Experience has shown that a much greater number of questionable values are revealed by computerised quality control than those detected by manual scrutiny.

Several systems for data processing were developed the world over. This manual describes a system of precipitation processing suitable to the Indian system of data collection, recording, transmission, storage and retrieval.

2.0 THE SYSTEM

Data processing in general is conceived of as a system through which the basic information (precipitation data in this case) is transposed into more accessible and readily usable product. A designed system should provide a detailed description of what a system would accomplish. It would consist of

i) a statement of purpose ,

ii) flow chart of the system,

iii) design features of input and output layouts,

iv) datafile configuration and identification,

v) working procedures for operating and controlling the processing and

vi) summary of the computer programs designed for the system

The main features of the system besides observation and collection of the basic data are its transmission, storage, editing, organising and carrying out the necessary computations. The system further comprises of the manual pre-processing, necessary indexing, sorting,collecting and storing the data on computer compatible devices,quality control, data conversion, preparation of areal estimates and storing the processed data on disk files or tapes for further use.

A schematic representation of a system of data storing and processing developed by the Lund Institute of Technology., University of Lund , Sweden (1984), is presented in figure 1. Two other schematic representations which were suggested by the Institut Royal Meteorologique de Belgique (1969) and the Institute of Hydrology, Wallingford (1981) are shown in figures 2 and 3 which broadly confirm to the methods of data processing recommended by WMO (1966). Part of such a system is also in operational use at the National Weather Service, USA for hydrological research and real time hydrologic forecasting. (National Weather Service, 1979).

2.2 System Design and Layout

While the system design and methodology described in this manual are generally suitable for any precipitation processing system, it may be advisable for the concerned organisation to develop a system specific to the requirements, keeping in view the type of data availablity, computer time and other aspects such that the manual and computerised means of processing could be mixed appropriately at the necessary levels of processing.

2.3 Special Considerations

Some of the points which need special consideration while designing the system are described below:

i) Since the procedures of data processing are nearly similar in case of real time operation and archiving for climatological purposes, at the time of developing the precipitation data processing system it needs to be ensured that the system is adaptable for both real time operation and archival use.

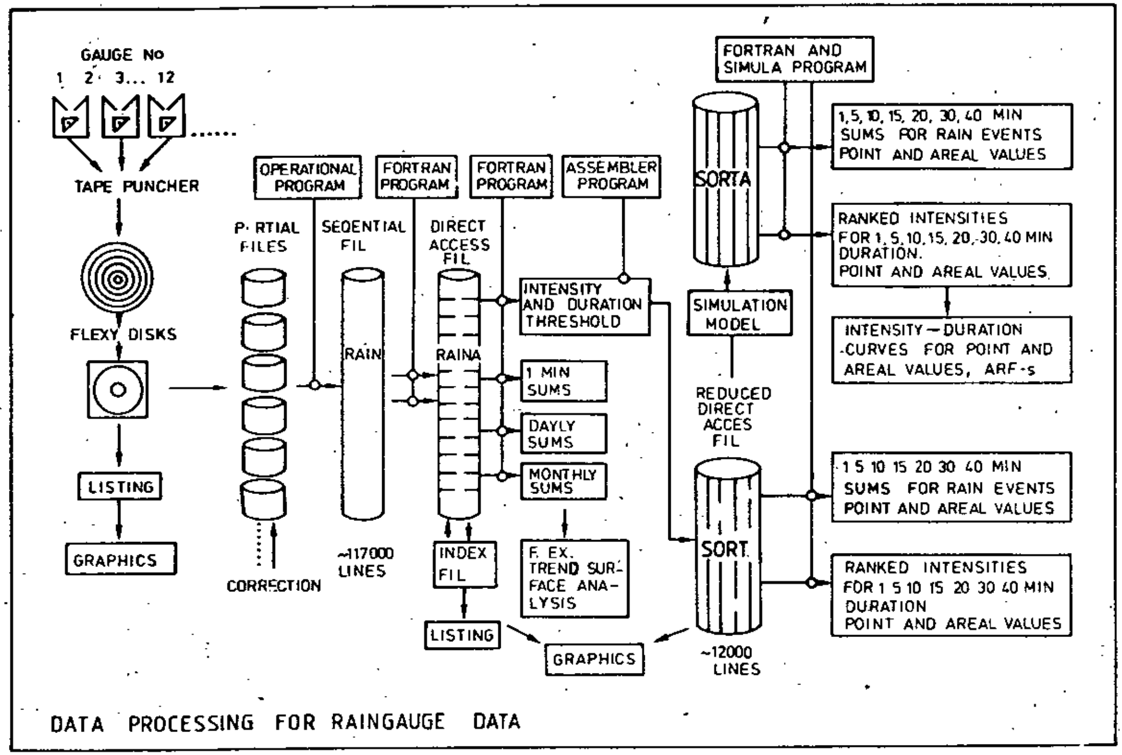
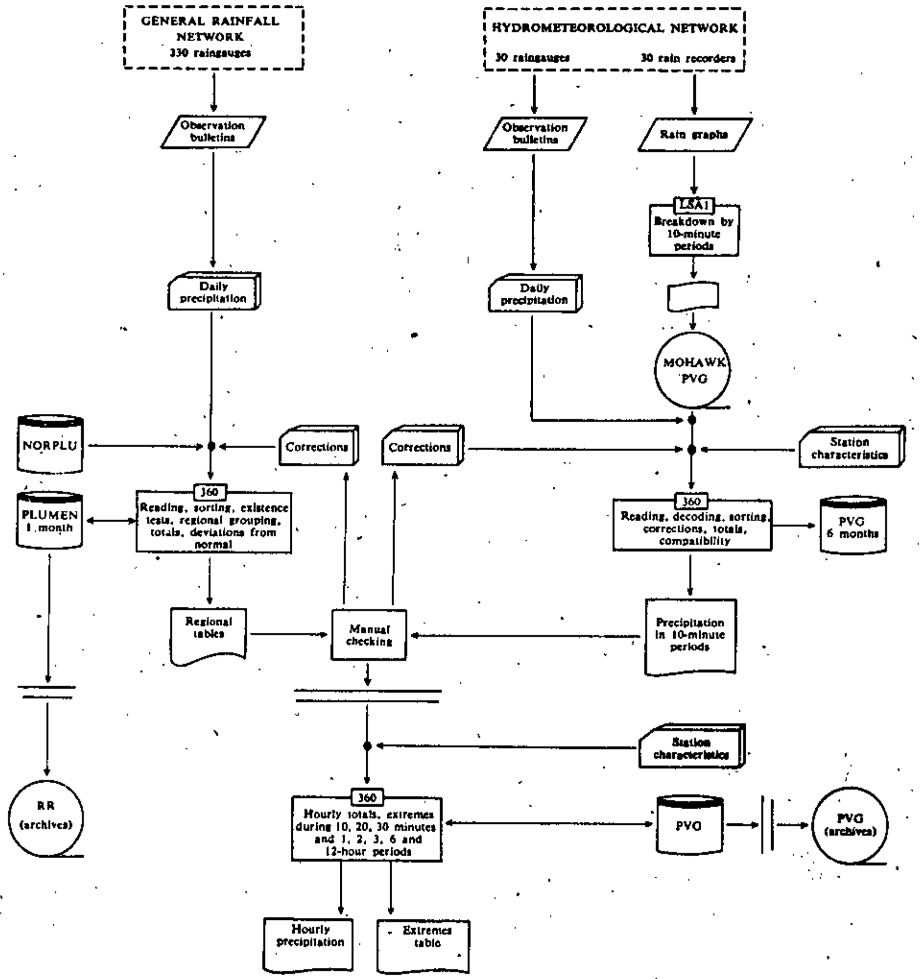


FIGURE 1 - DATA PROCESSING SYSTEM FOR RAINFALL RECORDS

(Reproduced from Niemczynowicz 1984)



NORPLU : Monthly rainfall norms and station characteristics.
PLUMEN : Daily raingauge readings (1 month).
PVG : Results of rain-graph analysis.
RR : Daily raingauge readings (archives).

FIGURE 2 - DATA PROCESSING SYSTEM OF RAINFALL DATA
(Reproduced from Institut Royal Meteorologiqe de Belgique, 1969)

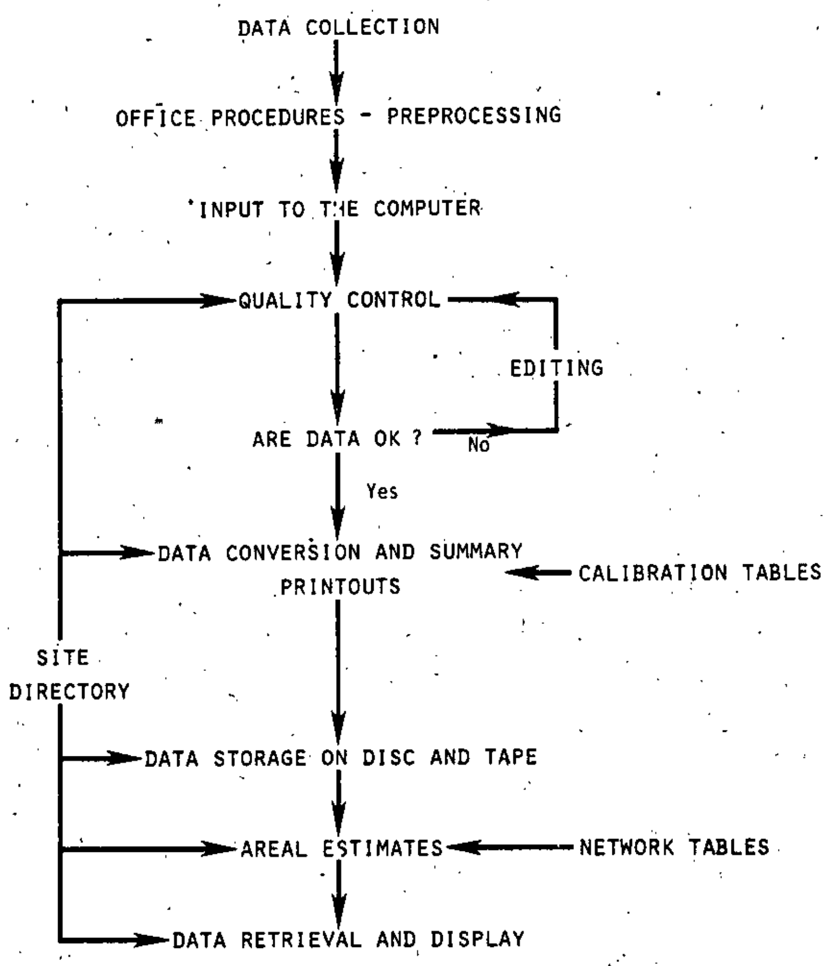


FIGURE 3 - FLOW CHART SHOWING THE GENERAL DATA PROCESSING FRAME WORK

(Reproduced from Institute of Hydrology, 1981)

ii) To facilitate better quality control of data some of the threshold values used as check values are to be readily available at the time of processing. For this purpose, such precipitation statistics such as mean, standard deviation, probable rainfall amounts for different durations shall be worked out in advance for all durations for each of the gauge locations.

iii) The system must be comprehensive enough to monitor data from all types of sources including future data sources such as Radar and Satellite.

iv) Since a comprehensive system comprises of various levels and degree of automation starting from data collection and use of microprocessors, data loggers, interfaces and mainframe computers, the flexibility of substitution has to be within levels of like capability.

v) Since the data are generally available on punched cards or magnetic tapes, for machine processing with microprocessors which are commonly and more readily available, the data needs to be stored on either floppy or cassette tapes as scratch input devices.

vi) The data retrieval should be arranged in such a way that the process is not complicated and is easily accessible.

v) The whole precipitation data processing system should be logically described so that it is clear to the user to facilitate introduction of manual processing (human interaction) where deemed necessary.

3.0 METHODOLOGY

The system mentioned earlier consists of a series of steps and procedures for editing, estimating and storing the information. These would include both manual and machine methods of processing the data. The efficiency, economy and speed of the system would depend on the type of storage devices, the quality of the machines used and the software (computer programmes) developed for this purpose. The methodology for executing the various steps involved in the processing system are briefly described here. The publications of WMO and Institute of Hydrology Wallingford (1981) listed under references may be referred to for further study.

3.1 Data Collection

Precipitation data (rainfall and snow fall) in India is collected by India Meteorological Department, State Irrigation Departments or some State organisations and other water resources organisations like Central Water Commission (CWC), Bhakra Beas Management Board (BBMB), Damodar Valley Corporation (DVC), Railway Design and Standards Organisation (RDSO), Snow and Avalanche Study Establishment (SASE) etc.

3.1.1 Methods of collection

Daily rainfall data is measured by Symon's type raingauge (figure 4). The rain gauges are being replaced by Fibreglass Reinforced plastic (FRP) Rainguages gradually.

Both the raingauges are similar in principle and contain a funnel with a circular cross section and collector(receiver)

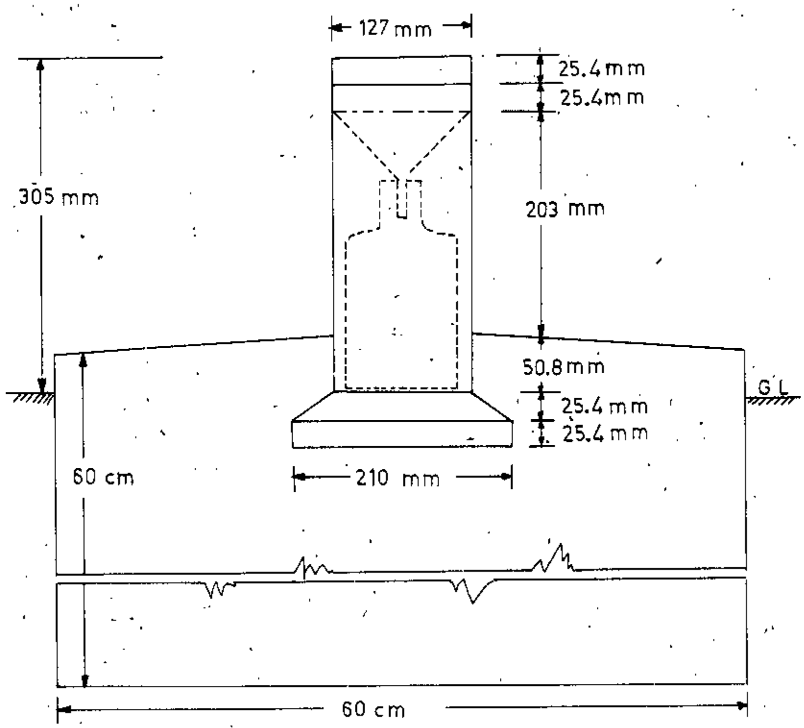


FIGURE 4 - SYMON'S RAINGAUGE

at the bottom from which the water is transferred to a measure glass for determining the rainfall depths. The snow fall is measured by either using snow poles or snow gauge. The snow gauge is generally guarded by a Alter wind shield (Figure 5) to reduce the drifting of snow due to wind.

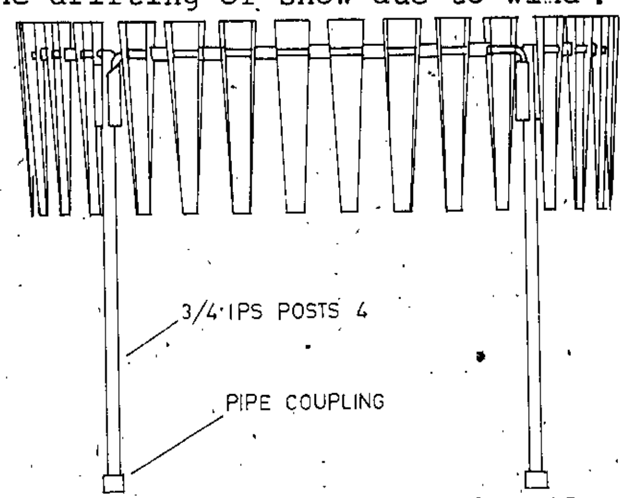


FIGURE 5 - ALTER WIND SHIELD

The rainfall is recorded by a syphon type self recording raingauge (Figure 6) which contains a clock drum with a chart recorded by a pen attached to a float operated by the rain water. The rain water syphons out generally after every 10 mm of catch .

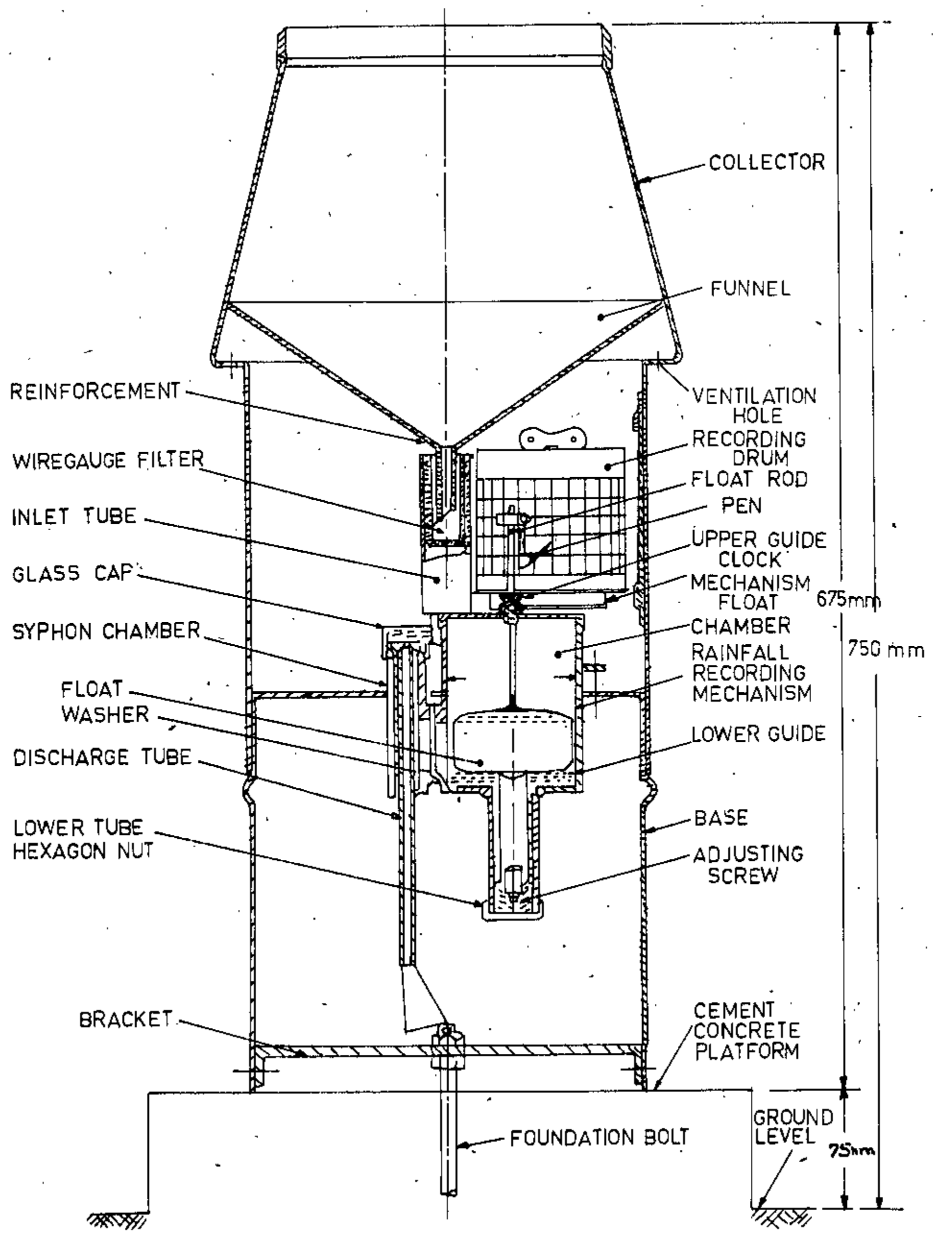


FIGURE 6 - SELF RECORDING RAIN GAUGE

For telemetering, the tipping bucket type rain gauge is used which is as shown in figure 7. These are normally designed to tip after every 0.1 mm of catch.

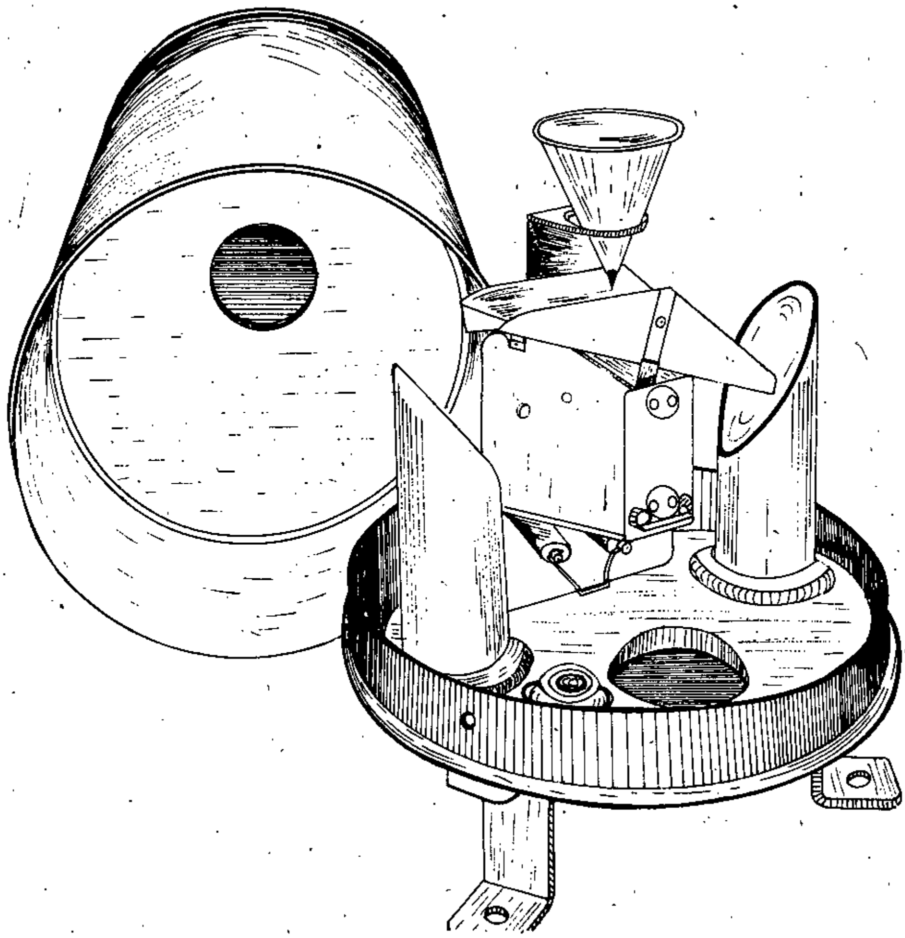


FIGURE 7 - TIPPING BUCKET RAINGAUGE

In case of inaccessible areas like seas, forested and hilly areas, raingauges forming part of the data collection platforms broadcast rainfall data to geostationary satellites like INSAT1B every hour and received at the DCP data processing unit.

Though weighing type raingauges are capable of recording and transmitting, they are not generally used in India.

3.1.2. Hours of measurement

Rainfall measurements are made twice daily at 0830 hrs IST (0300) GMT and 1730 hr. IST (1200 GMT) at IMD observatories and once daily at 0830 hr. IST at raingauges maintained by State organisations and other agencies. Some organisations like RDSO, however, make hourly or 3 hourly manual measurements.

In case of the self recording raingauges, the chart is set and removed daily at 0830 hrs. IST at observatories maintained by India Meteorological Department and other organisations. At some gauges located in forested and hilly areas weekly or fortnightly charts are used. In case of data collection platforms, however, data is recorded at the time of satellite interrogation.

3.2 Preliminary Processing and Scrutiny

Before the precipitation data is stored on computer compatible devices for machine processing by computer it becomes obligatory to carry out preliminary checks,enquiries and manual scrutiny of the data.

The preliminary processing includes ensuring the completeness of data for the period under consideration in respect of relevant details like station identification,date, time and other visible errors. The reasonableness of the report is checked by using appropriate verification and validation techniques.

Measurement errors have been classified into various groups (WMO/WWW,1968). These can be generalised as:

a. errors built into instruments
b. errors involved in reading,
c. errors due to improper instrument exposure or to the lack of representativeness of the instrument site to the area for which it is to be used as an index and
d. errors occuring during the processing of the data

Zero reports can be received from automated basic or synoptic network stations. Because zero precipitation is an acceptable report, care has to be taken such that the zero reports are not caused by instrumental mal-function.

Positive but likely reports are the most difficult to detect. These reports could be in error because of transpose digits in the report, misreading by observer and spurious pulses occuring in recording and transmitting in the case of automated gauges.

3.2.1 Verification

The reports received from manually observed stations by telephone or other communication channels like wireless need to be checked by a repeat back system. In case of data received from telemetering raingauges (Tipping bucket type) or automated weather stations, the parity check or some other checking process has to be devised and carried out.

3.2.2 Valid status

The station reporting should have a valid status. That is the station should have been equipped with standard instrument with proper identification with respect to its location, latitude,longitude,elevation,district and state to which it belongs etc. It should be part of a recognised network, and should have some historical record.

3.2.3 Reasonable report

Improper registering of data includes entering against wrong time and date, alteration of figures etc. Transmitting errors occur while sending the data either through telegram, wireless by observer or Telemetering by automatic raingauges. The official at the receiving station could check the reasonableness of the report by judging the report based on past experience and other precipitation statistics for the region to which the reporting station belongs.

One of the primary tests to check the reasonableness of a report before other tests are carried out is to check the data against its own past record (internal consistency). A preliminary check could be against the pentad normal rainfall or monthly normal rainfall at the station or of stations in the region. By considering the possible physical,meteorological and climatological constraints, limits of precipitation for the region of interest could be set and the values of precipitation checked against these limits. Any value outside these limits is suspect and should be screened more carefully after flagging. The precipitation limits which could be used for checking are:

i) Regional parameters like Probable Maximum Precipitation or return period (25,50 or 100 yr) values and

ii) Other locally determined record precipitation values.

The WMO/World Weather Watch Report (1968) listed some of the values which could be used as checking standards:

i) Forecast value for the actual period.

ii) Polynomial of second or third degree.

iii) Local statistical parameters such as mean or mean ± some multiple of standard deviation.

Other kinds of test which could be applied include

a) A test to see that the hourly report of precipitation is within the reported maximum and minimum values of the daily record

b) a check for occurrence or non-occurrence of precipitation based on the weather reports.

Where data of other meteorological parameters are also observed, the precipitation values could be checked by examining dew point, cloud amount, type of cloud etc.

In case of precipitation data reported for shorter durations such as 1 hour or 3 hour, the totals of three 1 hour amounts could be compared with the 3 hour total precipitation reported, total of two 3 hour amounts compared with 6 hour total precipitation reported etc.

3.3 Storage of Precipitation Data

World Meteorological Organisation(1977) advised that to the extent possible, all data be stored in digital form on technical carriers. Where such storage was not possible, the data could be stored in the possible convenient form temporarily and transferred to the digital carrier as soon as possible.

World Meteorological Organisation(1983) also recommended the maintenance and upgrading of national climatic data archives in a form which enables computer processing. Magnetic tapes, diskettes (floppys) and computer disks are the most durable and convenient storage media generally recommended and increasingly being used by different National data archieves the world over.

Dewan (1984) reported that India Meteorological Department has been punching the Climatological data including precipitation data (some of it dating back to more than 100 years) for the last about 40 years and storing it on punch cards.

The data can be stored on a magnetic tape in various forms namely card image (character) form,binary form,under format control,unformatted,blocked mode,unblocked mode and so on. The use of binary form or the blocked mode allows the storage of data in a very condensed form thus allowing a large amount of data to be loaded on each magnetic tape. For example if the data are loaded on magnetic tape in card image form in an unblocked mode about 40,000 cards could be accomodated on a 2400 ft. length tape (800 bpi density), whereas the same tape could hold approximately two lakh cards if the data is stored in blocked mode. Dewan (1984) recommended use of 20 to 50 cards per block (i.e. between 1600 to 4000 per block) for efficient processing. Magnetic tapes, however, can be accidentally over written during use. Great care has, therefore, to be excercised in their use.

Precipitation data collected by state organisations is normally stored only in the form of printed records published by the respective state organisations in the form of either Gazette or other form. The data are, however, transferred by the office of Additional Director General of Meteorology (Research), Pune into computer compatible storage devices after necessary indexing with station code, latitutde, longitude. In earlier years, the data were punched on cards which were subsequently transferred on to tapes. With the acquisition of key to tape punch units at the Meteorological office, Poona, the data is now being directly put on the magnetic tapes in 80 column card images.

Due attention also needs to be paid for devising suitable formats in which various types of data are to be digitised and stored. Basically, the formats should be simple so that it is easy to retrieve the data, and adequate enough to take care of even extreme values. The formats in which the data are punched by I.M.D. are described below:

3.3.1 Daily rainfall data format

The daily rainfall data were being punched in a 31 card format as shown in figure 3 until 1970 and was switched over to a 24 card format as shown in figure 9 since 1971.

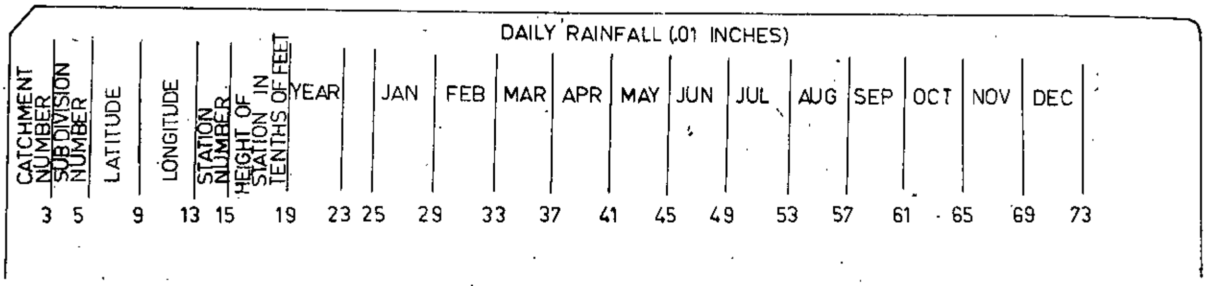


FIGURE 8 - DAILY RAINFALL - 31 CARD FORMAT

In the 31 card format, the data of 12 months for each day are punched on each card together with other station related statistics, year and date. Thus the cards corresponding to 31st date would contain blanks in columns of those months with less than 31 days. In case of February, for a normal year, the cards corresponding to 29,30 and 31 dates would be blank while only 30 and 31 would be blank in case of a leap year.

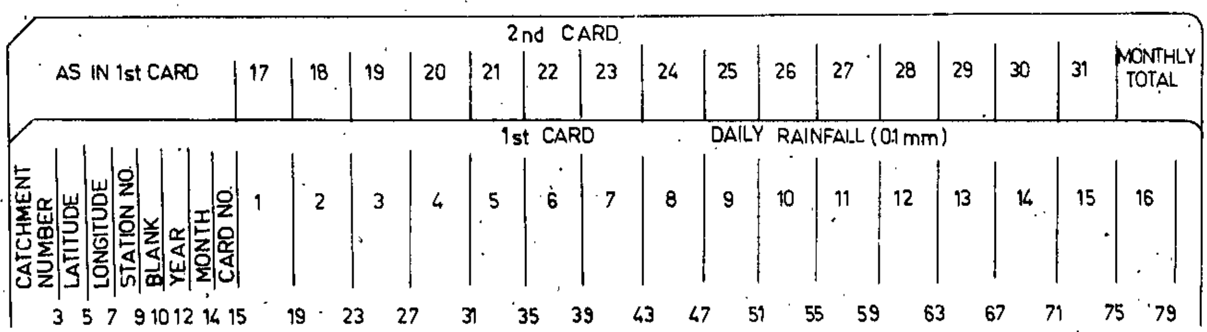


FIGURE 9 - DAILY RAINFALL - 24 CARD FORMAT

In the 24 card format, each month's rainfall data are punched on 2 cards, 16 days data on the first card and 15 days' data and monthly total on the second card. Thus, there would be 24 cards for the twelve months in a calender year. The card number and month are punched along with year in the 24 card format.

Thus, while retrieving the data for quality control and further processing, suitable provision needs to be made in the computer program for identifying the type of format and reading the data in the corresponding format.

3.3.2 Hourly rainfall data format

In the case of hourly rainfall data recorded at the self recording rainguages maintained by either India Meteorological Department or other Central and State organisations, the data were not published in printed form. India Meteorological Department, however, punches on to cards/magnetic tapes data of those self recording raingauge stations maintained by I.M.D. The relevant data format is shown in figure 10. The data are punched on two cards for each day. The first card contains besides station code, year, month, date and card number, data of hourly rainfall corresponding to 1st to 16th hour. The second card contains besides station code and other details, data of hourly rainfall, time of maximum rainfall occurrence and total rainy duration in the day given in hours and minutes.

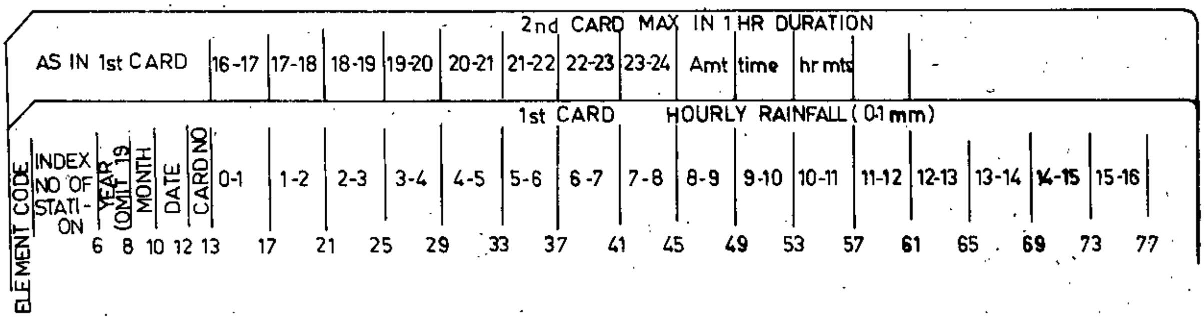


FIGURE 10- HOURLY RAINFALL FORMAT

3.4 Quality Control

Quality control of the precipitation data is an essential and principal step in the processing scheme and is sought to be carried out at every level from the observing point through the dissemination of data to the data processor.

Quality control programme is a prerequisite before the precipitation data are used either in an operational system for flood forecasting or archived for climatological purposes.

The basic objective of the quality control procedures is to detect and if possible correct errors in observational data at the earliest stage possible in the flow of data from the local data sources to the centralised data base. The quality control process is continuous and is performed by a series of computer programs, with some limited human interaction, at each level of data merging and processing.

The quality control procedure ,therefore, should be such that those developed for use in an operational system should be comprehensive enough so that no further quality control processing need to be carried out while archiving the data.

Computerised quality control procedures were developed by Meteorological office, United Kingdom (Bryant,1979 and Shearman,1975) where a separate section in Met 08 (Division of Agricultural Meteorology and Hydrometeorology) carries out the precipitation data processing in an operational way.

Ramasastri (1984) described a quality control procedure for precipitation data in an operational system for use by the

National Weather Service, U.S.A.

Dewan (1984) of India Meteorological Department described methods for computerised quality control and processing of climatological data. This, however, does not specify whether such machine processing or other methods are being used by India Meteorological Department.

3.5 Estimation of Missing Data

Precipitation for the missing data period is estimated from the data available at the stations surrounding the station under question. If the average annual precipitation at each of these stations is within 10% of that for the station with missing record, a simple arithmetic average of the precipitation at the neighbouring stations provides the estimated precipitation for the missing period(s).

In case, however, the normal annual precipitation at any of the neighbouring stations differs from that at the station in question by more than 10%, the weighted interpolation methods are used. The simple well known and widely used methods are the normal ratio and distance power method which were found to yield satisfactory results in a case study for Lower Mahanadi basin (Ramasastri and Seth, 1984). The two methods are described below:

3.5.1 Normal ratio method

In the normal ratio method, the precipitation P_A at station A is estimated as a function of the normal monthly or annual rainfall of the station under question and those of the neighbouring stations using concerned data of rainfall

$$P_A = \sum_{i=1}^{n} \frac{R_A}{R_i} \times P_i \qquad \ldots(1)$$

where,

P_A is the estimated rainfall at station A

R_A is the normal monthly or annual rainfall at station A

P_i is the rainfall at station i

R_i is the normal monthly or annual rainfall at station i, and

n is the number of surrounding estimator stations

3.5.2 Distance power method

In this method, the rainfall at a station is estimated as a weighted average of observed rainfall at the neighbouring stations. The weights are taken as equal to the reciprocal of the distance or some power of distance of the estimator stations from the estimated station:

$$P_A = \frac{\sum_{i=1}^{n} \frac{P_i}{D_i^x}}{\sum_{i=1}^{n} \frac{1}{D_i^x}} \qquad \ldots(2)$$

where,

P_A and P_i has the same notation as in equation 1.

D_i is the distance of the estimator station from the estimated station and

x is the power

In the United Kingodom, a value of 2.0 for x was found to yield good results (Bryant,1979). A value of 2.0 for x is also recommended for use in the estimation of missing precipitation data by the National Weather Service River Forecasting system (NWSRFS User Manual,1979). In the case study for Mahanadi by Ramasastri and Seth (1984), however, a value of 0.5 for x has been found to provide satisfactory values. Suitable regional values, therefore, need to be adopted after carrying out necessary studies for the respective region on the lines of the Mahanadi Study.

Other weighting procedures are also used which are reported by Dewan (1984). Cressman (1959) used :

$$W_i = \frac{(R_i^2 - D_i^2)}{(R^2 + D_i^2)} \qquad \ldots(3)$$

where,

R is scan radius and

D_i is the distance as in equation 2 and

W_i is the weight of station i

North-South and East-West lines are drawn through the point of station location under question. Using the station Coordinates (latitude and longitude), the station closest to the station under question is selected from each quadrant.

If one or more quadrants contain no precipitation gauging station, the averaging computation would involve only the remaining quadrants. If the estimator stations are found in only two quadrants and those two happen to be adjacent, then the estimate is given by $\Sigma P_i w_i$ and not $\Sigma P_i w_i / w_i$. A station which is located on a quadrant line will be placed in the nearest quadrant in a clockwise direction.

3.6 Adjustment of Data

To obtain homogenity among and within measurements of precipitation,adjustment of data becomes necessary. Adjustment of data has two principal objectives. First is to make the record homogeneous with a given environment and the second is to eliminate or reduce extraneous influences by correcting for change in gauge location or exposure.

While using the archived data for climatological analysis such as ten daily rainfall totals, rainfall series for water availability studies etc. these types of historical inconsistencies are noticed.

When data are arranged in long arrays,examination of usual expected trends can enable a trained eye to detect(i) displacement of record against a wrong date or station and (ii) wrong entries of amounts due to inadvertance or misprint. Incorrect and unreliable data can be detected by reference to normals or the trends of neighbouring stations. In case of small gauged catchment, the ten daily or monthly rainfall totals could also be compared with the corresponding stream flows. Adjustments for such errors are made by 'Double Mass Curve' analysis explained in 5.4

3.7 Editing

The precipitation data does not need editing in case of manually recorded and pre-processed data. Even if the data are punched on cards, they may be appropriately sorted using a sorting machine for a given precipitation code and fed to the computer. However, in case of data recorded on magnetic tapes or data logged in by microprocessors from automatic weather stations and satellite transmitted data from data collection platforms, necessary editing needs to be carried out and temporary disc files created for precipitation data for further processing.

3.8 Data Conversion

For hydrological analysis, often precipitation of shorter duration is required. The network of recording rain-gauges being small in comparison to that of the daily (non-recording) raingauges, it becomes necessary for conversion of the rainfall recorded at totalling gauges into shorter period (usually hourly) intervals either manually or by using appropriate computer subroutines. The converted data is stored on computer disc files, magnetic files or other such devices.

3.9 Areal Estimates

For a number of hydrological analysis and use in hydrological models, mean areal precipitation over the catchment or area of interest is used as input. It is,therefore, necessary that areal estimates of precipitation be available in a processed form for use directly as input in the hydrological models. Mean areal precipitation is estimated from the data (observed or converted) of precipitation at a number of locations by means of suitable methods. A number of well known methods are available which are described in 5.5 .

3.10 Storage of Processed Data

The processed data is stored generally on magnetic tapes as data archives for climatological studies and other uses. Areal estimates of precipitation,however, are written as scratch files on disc for temporary storage for use in Hydrologic models during flood forecasting and/or other uses.

4.0 DATA COLLECTION AND INVESTIGATION

The methods of data collection have been described earlier under section 3.1. Data collection problems at the time of archiving the precipitation data for climatological purpose are less as compared to those in case of real time analysis. In case of data used at the time of archiving most of the data from all stations and for all durations, days and months would have arrived to facilitate application of systematic quality control procedures for identifying missing and erroneous data by comparing the values with data of other durations at the station and from data at other neighbouring stations. However, when the precipitation data are used in real time analysis, data collection is fraught with many problems owing to a variety of reasons including instrument errors,recording errors, failure in communication link etc.

During the recording process, stations reporting the data are identified, the report decoded for type of data, time and date. This, of course, is necessary only in case of data received through telegram,telemetering,wireless and satellite. For data received by post, relevant details would be available in the report.

Investigations which do not form part of the data processing but all the same are required for data processing are the condition of the gauge i.e. whether the gauge is leaking etc, exposure of the gauge i.e. whether there was building activity and/or growth of tall trees and shifting of the gauge.

The India Meteorological Department undertakes inspection of raingauges maintained by I.M.D. and State Organisations for checking their condition,exposure and other aspects.

5.0 PROCEDURES

Some of the methods for carrying out the different constituent components of the processing system have been reviewed in the section 3.0. However, in view of the limitations of data and non-availability of high speed computers at a number of places in India, it may not be possible to adopt some of the methods. In this section, therefore, those methods which could be readily applied are described with the help of examples and computer programmes wherever possible.

5.1 Preliminary Scrutiny

In India, while no information is available on the nature of scrutiny carried out by the state organisations before the data is printed or communicated to India Meteorological Department, it is known that manual scrutiny of rainfall data was being carried out the hydrometeorology division in the office of the Additional Director General of Meteorology (Research) before the data is transferred on to cards/magnetic tapes. Sarkar (1980) mentioned about some of the steps being taken by India Meteorological Department to carry out complex quality control through computer.

5.2 Quality Control Procedure (QCP)

The Quality Control Procedure (QCP) is a continuous process and is performed by a series of computer programmes with limited human interaction. After the preliminary scrutiny of data, the manual errors would be referred to the observer for confirmation or correction as the case may be. However, in case of observations made by automated instruments like automatic weather stations an algorithm has to be developed and executed by a microprocessor to check the errors from these stations.

The flow chart of the QCP is given in Appendix I. As may be seen from the flow chart, the QCP consists essentially of the following three components:-

i) Climatological and meteorological check,

ii) Internal consistency or self consistency check, and

iii) Horizontal or spatial consistency checks

Some of the hydrometeorological parameters and climatological parameters could be used for checking the precipitation amounts. In case of snow fall reports, the maximum and minimum temperatures could be used as checks.

The climatological parameters which could be used as check are regional values of normal rainfall, highest observed rainfall and/or rainfall value corresponding to 25,50 or 100 years return period.

An example of checking the reasonableness of a report using methods described above is given in Appendix II.

5.2.1 Internal or self consistency checks

The self consistency checks are usually applicable in case of shorter duration rainfall where the reports corresponding to a particular duration are compared with sum or reports for the corresponding shorter durations. Thus, the 3 hour amounts are compared against the total of three corresponding 1 hour duration values, the six hour against the total of two corresponding 3 hour duration values and so on. These are explained in the example given at Appendix III.

5.2.2 Spatial consistency checks

The spatial checks in the case of precipitation data are limited to relating them to observations from neighbouring stations for the same duration, of interpolating the precipitation amount at the desired station location whose value is under check. The two methods of estimation for missing precipitation data exaplained in 3.5 are also used for estimating the precipitation at the station location whose value is under check.

The procedure of spatial consistency check is explained with example in Appendix IV. The procedure, however, needs to be applied with caution as the estimated precipitation need not represent the conditions at the station under question especially in case of precipitation associated with local thunderstorms.

5.3 Data Retrieval

A computer programme for retrieval of the daily rainfall data using either of the two formats (31 card or 24 card format) has been prepared. The flow chart of the programme is given in figure 11.

The data as is to be expected would contain gaps because of non-recording and non-availability of data due to instrument/observer failure, due to transmission failure, loss of records etc. The blanks would be read as zero by all computer systems. The missing values are estimated using estimation techniques described in 3.5

The Guide to Hydrological Practices (World Meteorological Organisation,1974) suggested that estimation of more than 5 to 10 percent of the period of record is not justified. However, individual judgement plays an important part in deciding how far to go in estimating missing data. If too many gaps are estimated, the aggregate becomes too fictitious to be of any practical use. In the computerised data processing system, before the values are estimated, it becomes necessary to identify the missing periods. A computer program developed for this purpose is given in Appendix V. The essential features of the programme are briefly described below:

5.3.1 Programme MISS

The programme MISS reads the daily rainfall data of different stations from the input disk file of rainfall data transferred from magnetic tapes supplied by IMD. As mentioned earlier, the data would be in two formats if climatological data for periods prior to and after 1970 are processed. Left to themselves, the blank spaces representing missing data would be read as zero by the computer. To overcome this difficulty, the blank spaces are identified by reading the data and replaced by-999 while rewriting the whole data onto another disk file.

5.3.2 Estimation of missing data

The precipitation for the missing period identified in 5.3.1. is estimated using either the normal ratio or distance power method described in 3.5. Examples of estimating the precipitation using the equations 1 and 2 for the normal ratio and distance power method respectively are given in Appendices VI and VII.

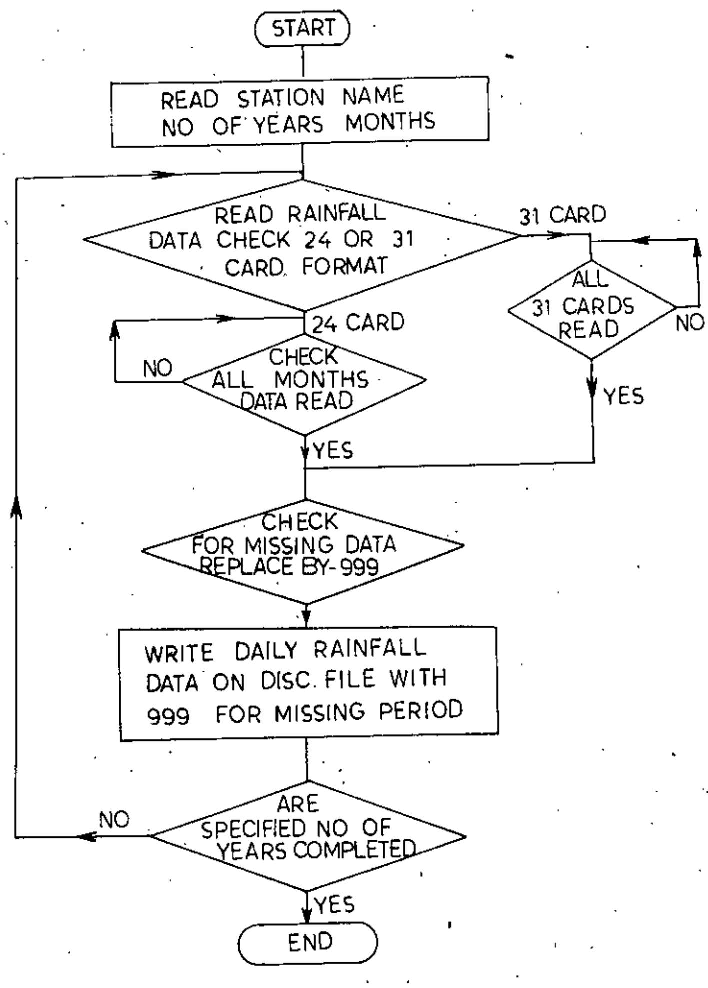


FIGURE 11 - FLOW CHART OF DAILY RAINFALL DATA RETRIEVING PROGRAMME

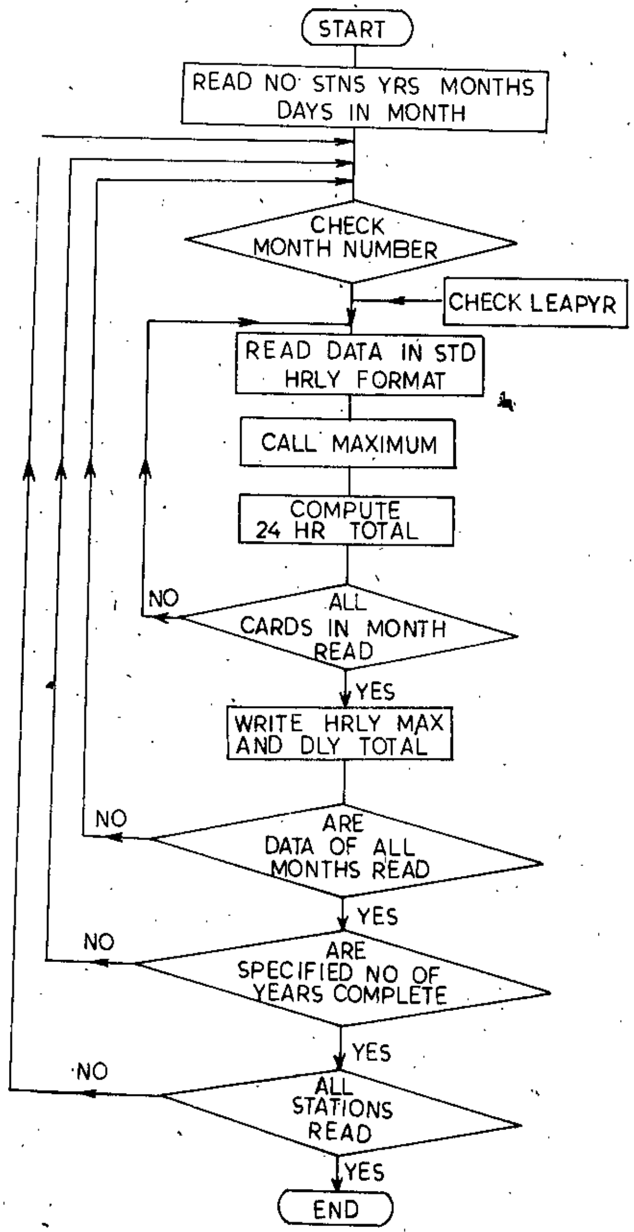


FIGURE 12 - FLOW CHART OF HOURLY RAINFALL DATA RETRIEVING PROGRAMME

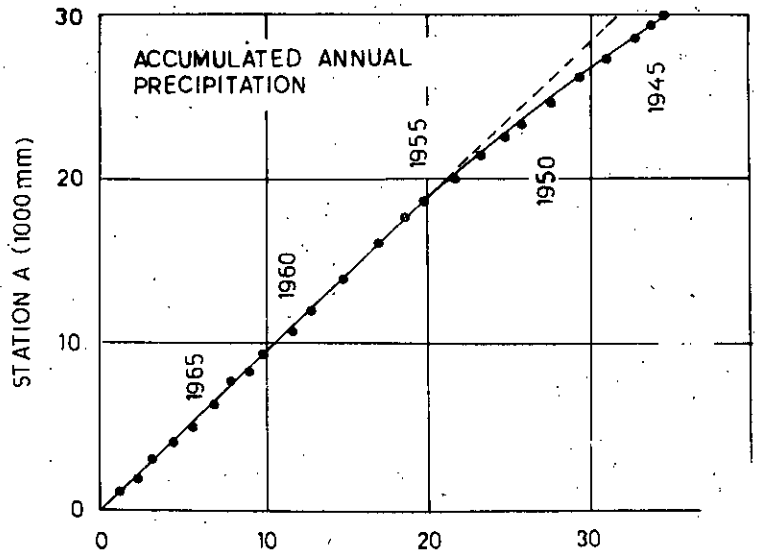
5.3.3 Hourly rainfall

For retrieving the hourly rainfall data also, a computer programme has been prepared. Sometimes, the 24 hours total given in the second card has been found to be not matching with the actual 24 hrs total. Similarly, the maximum hourly rainfall was found to be not punched in a number of cases. The routine used for this purpose is shown in the flow chart at figure 12.

5.4 Double Mass Curve Analysis

Double mass analysis is a graphical method for identifying and adjusting inconsistencies in a stations data by comparing with the trend of reference stations data. As the name itself implies a double mass curve's both axis are accumulated rainfall values. Usually the accumulated seasonal or annual rainfall values of reference station or stations is taken as abscissa and those of the station under test as ordinate.

A change in the regime of the raingauge such as change in exposure, change in location is revealed by a change in the slope of the straight line fit as shown in figure 13. It could be seen from the figure that the slope of the line changes sharply at 1945 with the slope changing from 0.95 after 1945 to 0.75 prior to 1945. The older records are, therefore, adjusted by multiplying the rainfall values by the ratio of 0.95 to 0.75 to compensate for the change in the



12 Station Mean (1000 mm)

Figure 13 - DOUBLE - MASS ANALYSIS EXAMPLE

regime of the station's data. Such changes could also be corroborated by referring to the records of the maintenance of the rain gauge.

5.5 Hydrometeorological Analysis

Generally, precipitation data are used in the hydrological analysis in a processed form. These derived data include:

i) Weekly and/or ten daily rainfall totals for determining water availability,

ii) maximum rainfall series for use as annual or partial duration series and

iii) mean areal precipitation for use in unit hydrograph analysis and other model studies.

5.5.1 Ten daily rainfall

Using the precipitation data which has been rewritten with gaps identified, the missing data periods are filled up using appropriate estimation procedures. The daily rainfall data is then used for computing 10 daily totals for the three ten day periods in each month periods namely 1-10,11-20 and remaining days.

5.5.2 Maximum rainfall

Identification of maximum rainfall is necessary for two purposes.

i) computing maximum 1 day,2 days,3 days, 4 days and 5 days during each month or overlapping two months and

ii) computing annual maximum and other maxima in each year for preparing annual and partial duration maximum rainfall series.

The subroutine used for identifying the maximum and computing the 1,2,3,4 and 5 days rainfall totals is given in Appendix VIII.

5.5.3 Estimation of mean areal precipitation

Several methods of estimating mean areal precipitation are available which are described in text books of Hydrology, manual of Hydrometeorology of IMD and others. The most commonly used methods are :

i) Arithmetic average

ii) Thiessen polygon method

iii) Isohyetal method

The choice of the method should be based on a judicious consideration of the quality and nature of data, the importance and required precision of the result.

In manual analysis isohyetal method is considered to be superior to the first two methods in view of its ability to take the orographic effects and analysts experience into consideration. However, from the computerised analysis point of view, thiessen polygon method is more adaptable.

The three methods of mean areal precipitation referred above are described in brief:

5/5.3.1 arithmetic average

The arithmetic mean of the precipitation values observed at stations in a drainage basin is the simplest objective estimate of the average precipitation over the basin. This method is suitable for basins with a large number of precipitation stations which are spaced fairly uniformly or in some other way adequately sample the precipitation distribution over the basin.

5.5.3.2 thiessen polygon method

The Thiessen polygon method is used with non-uniform stations spacing and gives weights to stations data according to the area which is closer to that station than to any other station. This area is found by drawing the perpendicular bisector of the lines joining the nearby stations so that polygons are formed around stations. A computer programme which computes the average catchment precipitation using user supplied Thiessen weights after distributing the daily precipitation into hourly amounts is given in Appendix IX.

The determination of Thiessen weights by machine is done rather easily. The polygon for a station is thought of as the boundary of all points which are closer to the subject station than to any other station. The number of grid points close to a station when normalised are the Thiessen weights of the respective stations. For this purpose, the catchment map is input to the computer programme as a 80 x 80 element grid map (Ramasastri,1984).

The weighted rainfall is given by:

$$\bar{P} = \frac{\sum_{i=1}^{n} P_i \, W_i}{\sum_{i=1}^{n} W_i} \qquad \ldots(5)$$

where, $\bar{P}$ is the average catchment precipitation P_i is the precipitation at stations 1 to n and W_i the corresponding station weights.

A sample Thiessen network and computation of mean areal precipitation estimation using Thiessen weights is given in Appendix X.

If a few observations are missing it is better to estimate the missing data than to construct new set of polygons.

Stations outside the catchment can also be used in this method with appropriate weight using only that portion of the polygon inside the catchment. This method assumes that precipitation between two stations varies linearly and does not make any allowance for variation due to topography or meteorological factors.

5.5.3.3 isohyetal method

The isohyetal method employs the area encompassed between isohyetal lines. Rainfall values are plotted at their respective stations on a suitable base map and lines of equal rainfall, called isohyets are drawn. In regions of little or no physiographic influence, the drawing of isohyetal contours is a relatively simple matter of interpolation in which the degree of smoothness of contours and of profiles which may be drawn or inferred from their spacing, is consistent with the spacing of stations, and the quality and variability of the data.

In regions of pronounced orography, where the precipitation is influenced by topography, the analyst should take into consideration, the orographic effects, storm orientation etc. to adjust or interpolate between station values.

The modern computers equipped with plotters have the ability to draw isohyetal maps .Analysts, however, prefer to carry out the analysis manually after getting the values plotted on the maps.

The average depth of precipitation is computed by measuring the area between successive isohyets and determining the total volume and dividing by total area.

The average depth is given by the relation:

$$\bar{P} = \frac{\sum_{i=1}^{n} P_i A_i}{\sum_{i=1}^{n} A_i} \qquad \ldots (6)$$

where A_i is the area between successive isohyets

$\bar{P}$ and P_i have the same notation as in equation 5

A typical isohyetal map and example of the mean areal precipitation computation are given in Appendix XI.

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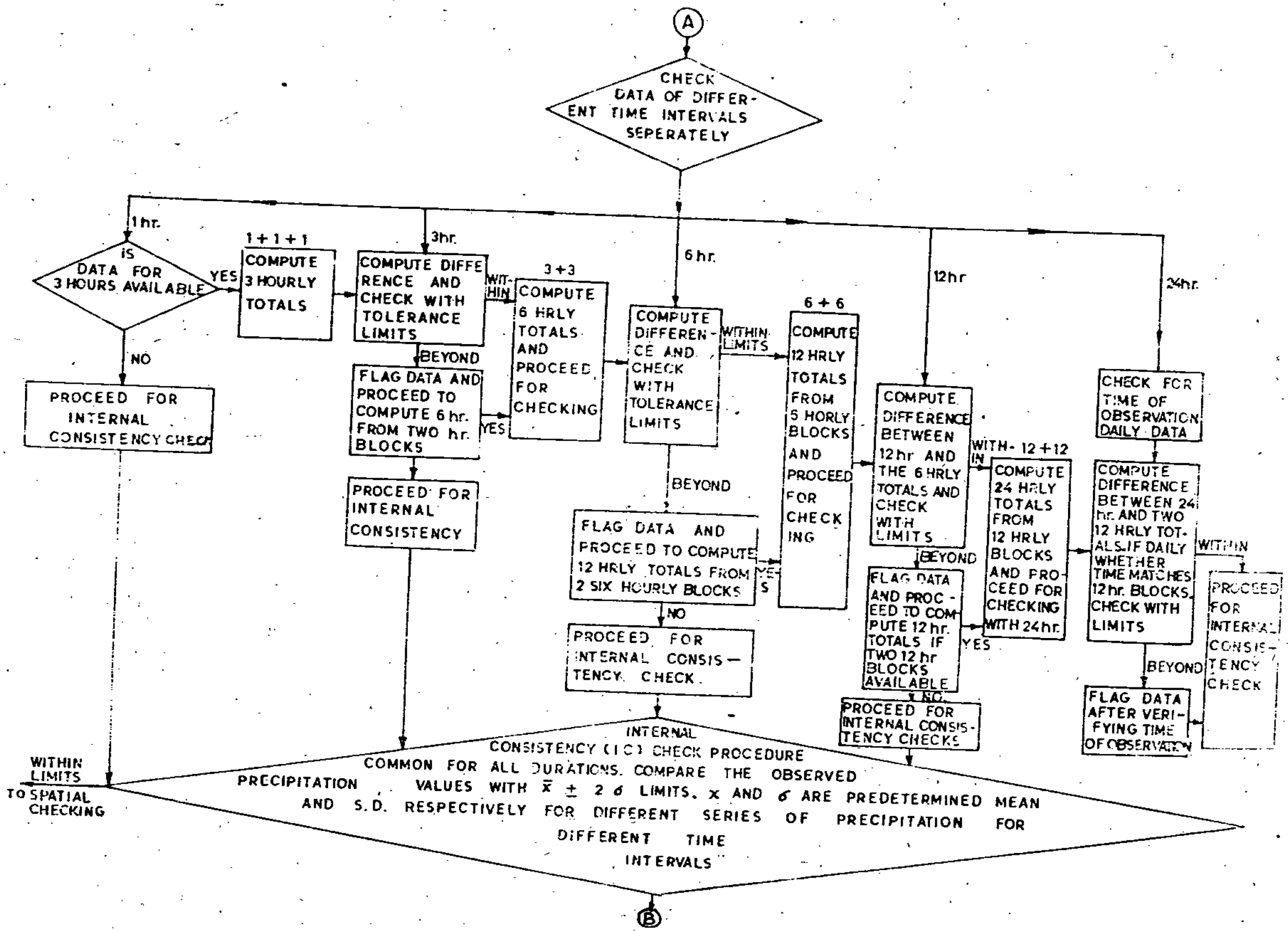
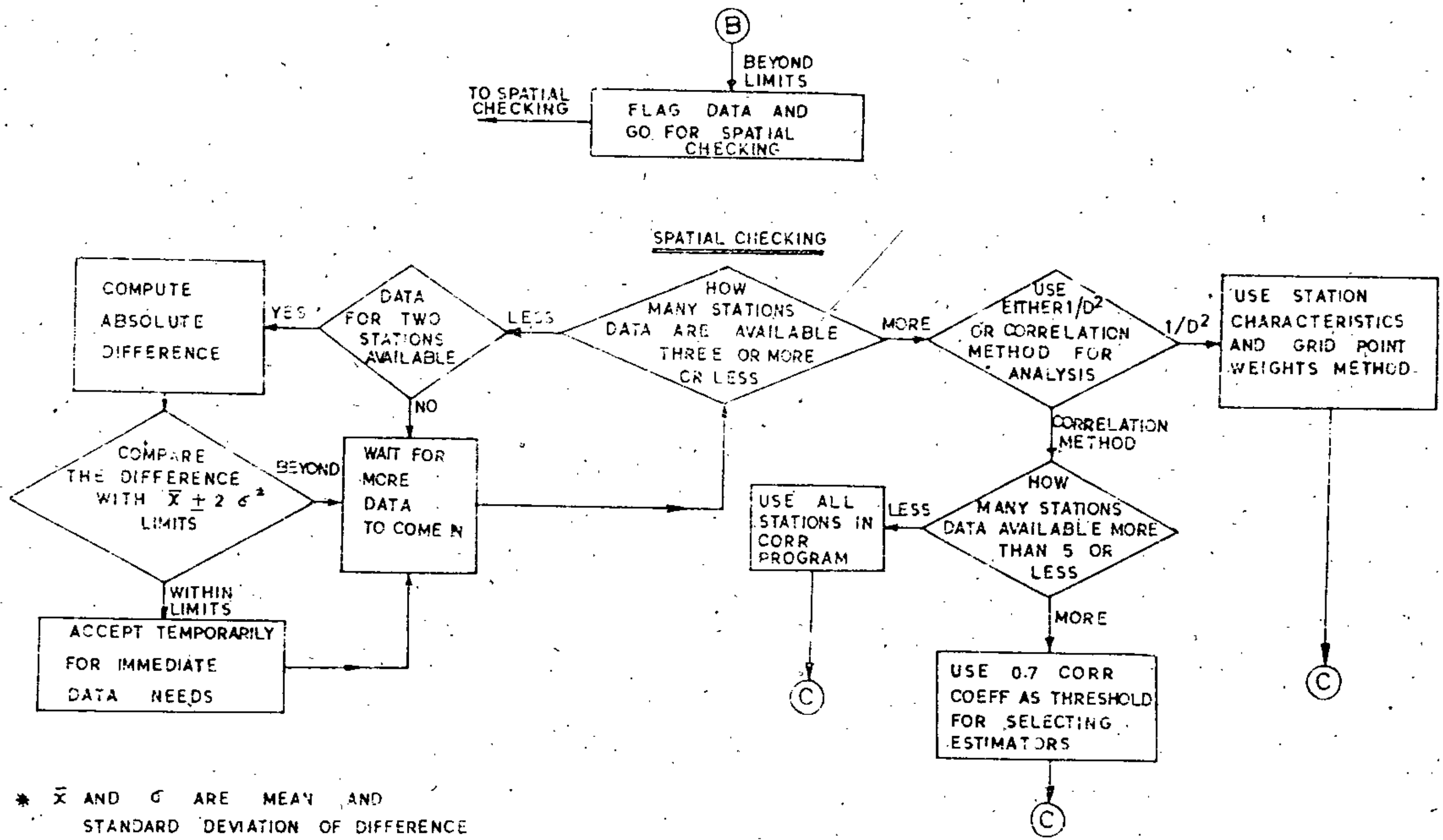
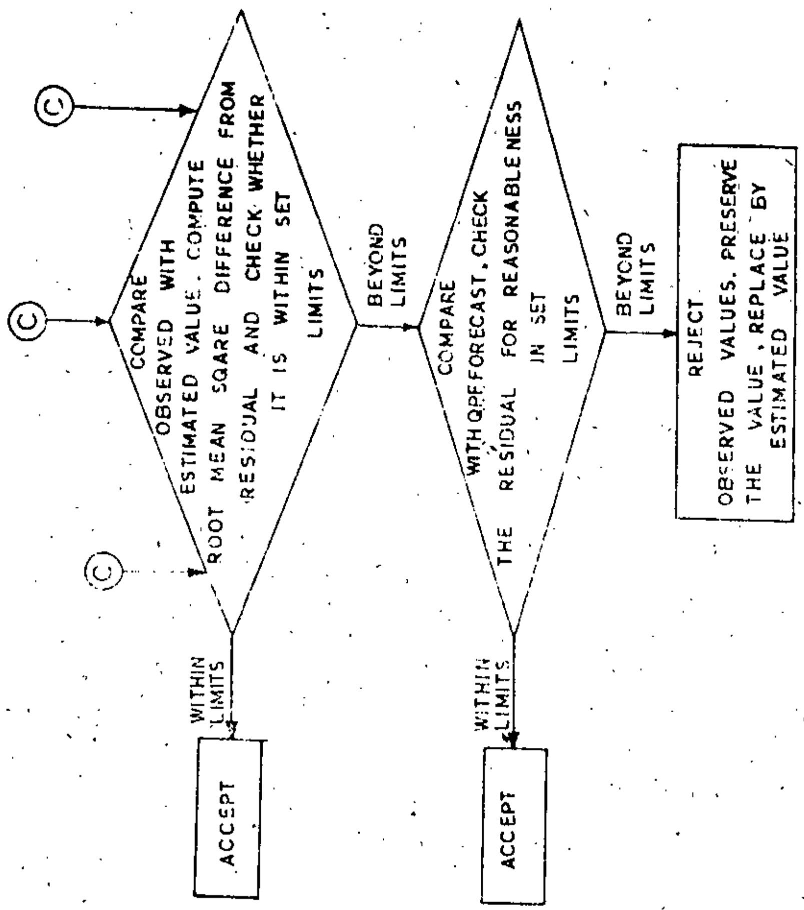


A
CHECK DATA OF DIFFERENT TIME INTERVALS SEPERATELY
1 hr.
3hr.
6 hr.
12hr
24hr.
IS DATA FOR 3 HOURS AVAILABLE
YES
NO
1+1+1
COMPUTE 3 HOURLY TOTALS
PROCEED FOR INTERNAL CONSISTENCY CHECK
COMPUTE DIFFERENCE AND CHECK WITH TOLERANCE LIMITS
WITHIN
BEYOND
3+3
COMPUTE 6 HRLY TOTALS AND PROCEED FOR CHECKING
FLAG DATA AND PROCEED TO COMPUTE 6 hr. FROM TWO hr. BLOCKS
YES
PROCEED FOR INTERNAL CONSISTENCY
COMPUTE DIFFERENCE AND CHECK WITH TOLERANCE LIMITS
WITHIN LIMITS
BEYOND
6 + 6
COMPUTE 12 HRLY TOTALS FROM 5 HORLY BLOCKS AND PROCEED FOR CHECKING
FLAG DATA AND PROCEED TO COMPUTE 12 HRLY TOTALS FROM 2 SIX HOURLY BLOCKS
YES
NO
PROCEED FOR INTERNAL CONSISTENCY CHECK.
COMPUTE DIFFERENCE BETWEEN 12hr AND THE 6 HRLY TOTALS AND CHECK WITH LIMITS
WITHIN
BEYOND
12 +12
COMPUTE 24 HRLY TOTALS FROM 12 HRLY BLOCKS AND PROCEED FOR CHECKING WITH 24hr.
FLAG DATA AND PROCEED TO COMPUTE 12 hr. TOTALS IF TWO 12 hr BLOCKS AVAILABLE
YES
NO
PROCEED FOR INTERNAL CONSISTENCY CHECKS
CHECK FOR TIME OF OBSERVATION DAILY DATA
COMPUTE DIFFERENCE BETWEEN 24 hr. AND TWO 12 HRLY TOTALS. IF DAILY WHETHER TIME MATCHES 12hr. BLOCKS. CHECK WITH LIMITS
WITHIN
BEYOND
PROCEED FOR INTERNAL CONSISTENCY CHECK
FLAG DATA AFTER VERIFYING TIME OF OBSERVATION
INTERNAL CONSISTENCY (I C) CHECK PROCEDURE COMMON FOR ALL DURATIONS. COMPARE THE OBSERVED PRECIPITATION VALUES WITH x̄ ± 2 σ LIMITS. x AND σ ARE PREDETERMINED MEAN AND S.D. RESPECTIVELY FOR DIFFERENT SERIES OF PRECIPITATION FOR DIFFERENT TIME INTERVALS
WITHIN LIMITS
TO SPATIAL CHECKING
B



* $\bar{X}$ AND σ ARE MEAN AND STANDARD DEVIATION OF DIFFERENCE


C
C
C
COMPARE OBSERVED WITH ESTIMATED VALUE. COMPUTE ROOT MEAN SQARE DIFFERENCE FROM RESIDUAL AND CHECK WHETHER IT IS WITHIN SET LIMITS
WITHIN LIMITS
ACCEPT
BEYOND LIMITS
COMPARE WITH QPF FORECAST, CHECK THE RESIDUAL FOR REASONABLENESS IN SET LIMITS
WITHIN LIMITS
ACCEPT
BEYOND LIMITS
REJECT OBSERVED VALUES, PRESERVE THE VALUE, REPLACE BY ESTIMATED VALUE

APPENDIX II

Typical example of checking reasonableness of a report

1. Daily Rainfall reported : 360. 6 mm
2. Rainfall statistics of the reporting station

i)	Normal monthly rainfall of the corresponding month	... 350.5 mm
ii)	Mean ($\bar{x}$) maximum 1 day rainfall	... 210.6 mm
iii)	Standard Deviation(σ) of maximum 1 day rainfall	... 50.5 mm
iv)	Highest observed 1 day rainfall	... 285.3 mm
v)	100 year return period value of 1 day maximum rainfall	... 300.0 mm
vi)	Probable Maximum Precipitation value of 1 day rainfall	... 370.8 mm

Step 1 The reported daily rainfall value of 360.6 mm is more than the normal monthly rainfall of the corresponding month and is, therefore, doubtful but not unreasonable. The reasonableness is checked with other statistics.

Step-2 Compare with the highest observed value. The reported value is more than the highest ever observed value. It is also more than the 100 year return period value.

Step-3 Compute ($\bar{x}+\sigma$) and ($\bar{x}+2\sigma$). They are 261.1 mm and 311.6 mm respectively. The reported value is higher than both the values.

Step-4 Compare with the 1 day PMP value which is 370.8 mm. The value is less than the PMP and is, therefore, reasonable and is further checked by spatial consistency.

APPENDIX III

Typical example of Internal Consistency Check

Step 1 Hourly rainfall data reported is scrutinised

Hour	1	2	3	4	5	6
Rainfall mm	8.0	10.8	85.8	28.5	19.8	15.0

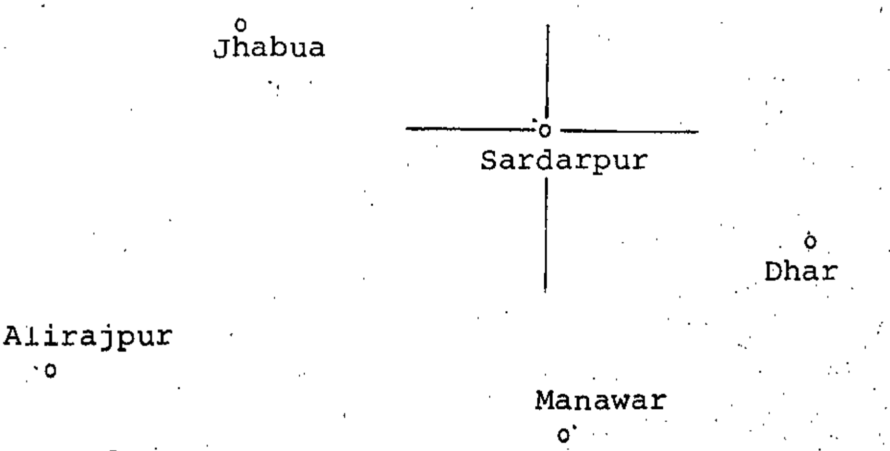
Step 2 The value of 85.8 mm in 3rd hour though could not be ruled out, is suspected because of the possibility of 35.3 being reported as 85.8.

Step 3 When the value of 3 hrs. total (54.1 mm) is reported, the arithmetic total of ist to 3rd hour is compared with the 3 hour reported total. If the value in the third hour is taken as 85.8 the total would be 104.6 mm which is 50.5 mm more than the 3 hour total reported. The 3rd hour value is, therefore, corrected as 35.3 and the 6 hour total is awaited for further confirmation.

Step 4 When the 6 hour total 117.4 mm is reported, the value of 35.3 mm is confirmed for 3rd hour. Further checking for erroneous values is carried out similarly.

APPENDIX IV

Typical example of spatial consistency check



Step 1 Data reported at a group of five stations is as follows

Station	Jhabua	Sardarpur	Dhar	Manawar	Alirajpur
Rain-fall mm	132.1	10.3	103.3	125.7	149.8

Step 2 During the quality control process the data at Sardarpur is identified as doubtful

Step 3 The data at Sardarpur is checked by spatial consitency check

Step 4 The rainfall data at Sardarpur is estimated using the distance power method and compared with the observed value

Step 5 From the four quadrants around Sardarpur one nearest from each quadrant is selected for the estimation of rainfall at Sardarpur.

Step 6 Using the reference coordinate system, the distance of each of the estimator stations from Sardarpur is determined.

Sl.No.	Station	Distance from Sardarpur (Km)	$\frac{1}{D_i^2}$	$\frac{P_i}{D_i^2}$
1	Jhabua	42	5.67×10^{-4}	.075
2	Dhar	39	6.57×10^{-4}	.068
3.	Alirajpur	75	1.78×10^{-4}	.027
		Total	14.02×10^{-4}	.170

Step 7 The rainfall at Sardarpur is estimated using the

equation

$$P_A = \frac{\sum_{i=1}^{3} P_i/D_i^2}{\sum_{i=1}^{3} 1/D_i^2}$$

The estimated rainfall at Sardarpur is 121.3 mm and is very much different from the observed value and is rejected and replaced by estimated value.

APPENDIX V.

PROGRAMME MISS

```
      DIMENSION IR(12,31),NDAY(12),SUMMON(100,13)
      CHARACTER*10 AMSTAT
      CHARACTER*16 AMDIST,AMSTN
      DATA NDAY/31,28,31,30,31,30,31,31,30,31,30,31/
      OPEN(UNIT=1, FILE= 'TAPE31.DAT', STATUS ='OLD')
      OPEN(UNIT=2, FILE= 'TAPE311.DAT', STATUS ='NEW')
      GO TO 777
888   BACKSPACE(UNIT=1)
777   READ(1,109)NOSTAT,NODIST,AMSTAT,AMDIST,AMSTN
      WRITE(2,110)NOSTAT,NODIST,AMSTAT,AMDIST,AMSTN
109   FORMAT(2I2,A,2A/)
110   FORMAT(1X,2I2,A,2A/)
      NYR=1000
      DO 40 II=1,NYR
      DO 10 I=1,12
      READ(1,101,ERR=111,END=999)IDATNO,LAT,LONG,ISTANO,IYEAR,IMONTH,IORDNO,
     2(IR(I,J),J=1,15)
      IF(LAT.EQ.'  ')GO TO 111
C     IF((IR(I,2)-1900).GT.0)GO TO 111
      DO 600 J=1,15
      IF(IR(I,J).EQ.'    ') IR(I,J)='-999'
600   CONTINUE
      WRITE(2,201)IDATNO,LAT,LONG,ISTANO,IYEAR,IMONTH,IORDNO,
     2(IR(I,J),J=1,15)
      IYEAR=IYEAR+1900
      IF(I.EQ.2) CALL LEAPYR(IYEAR,NDAY)
      READ(1,101)IDATNO,LAT,LONG,ISTANO,IYEAR,IMONTH,IORDNO,(I
     1R(I,J),J=16,NDAY(I))
      DO 601 J=16,NDAY(I)
      IF(IR(I,J).EQ.'    ') IR(I,J)='-999'
601   CONTINUE
      WRITE(2,201)IDATNO,LAT,LONG,ISTANO,IYEAR,IMONTH,IORDNO,(IR(I,J), J=16,
     1NDAY(I))
10    CONTINUE
      GO TO 40
111   BACKSPACE (UNIT=1)
      DO 50 K=1,31
      READ(1,105,ERR=888,END=999)IDATNO,STN,LAT,LONG,ISTANO,IYEAR,IDATE,
     1(IR(J,K), J=1,12)
      DO 603 J=1,12
      IF(K.GT.NDAY(J)) GO TO 603
      IF(IR(J,K).EQ.'    ') IR(J,K)='-999'
603   CONTINUE
      WRITE(2,205)IDATNO,LAT,LONG,ISTANO,IYEAR,IDATE,(IR(J,
     1K), J=1,12)
50    CONTINUE
40    CONTINUE
101   FORMAT(I3,A2,2I2,2X,2I2,I1,15A4)
201   FORMAT(1X,I3,A2,2I2,2X,2I2,I1,16A4)
105   FORMAT(I3,A2,2I4,I2,4X,I4,I2,12A4)
205   FORMAT(1X,I3,2X,2I4,I2,4X,I4,I2,12A4)
999   STOP
      END

      SUBROUTINE LEAPYR (IYEAR,NDAY)
C     YEAR SHOULD BE DEFINED IN FULL DIGITS IN MAIN PROGRAMME
      DIMENSION NDAY(2)
      LPYR=MOD(IYEAR,4)
      IF(LPYR.EQ.0) NDAY(2)=29
      RETURN
      END
```

APPENDIX VI

Typical example of Estimation of Precipitation using Normal Ratio Method

Step 1 Write down the observed rainfall at the estimator stations B,C and D

Station	B	C	D
Rainfall(mm)	98.9	120.5	110.0

Step 2 Write down the normal monthly,seasonal or annual rainfall at the estimator and estimated stations

Station	A	B	C	D
Rainfall(mm)	331.3	290.8	325.9	360.5

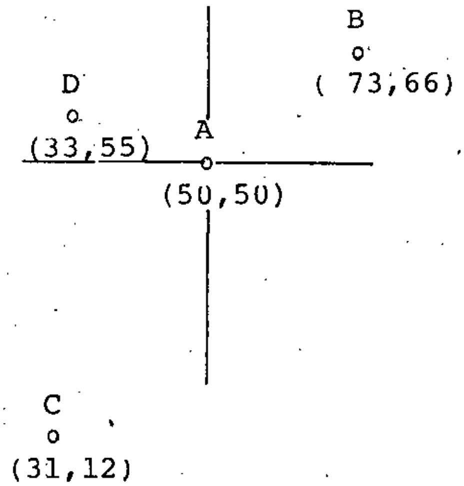
Step 3 Estimate the rainfall at station A as given below

$$P_A = \frac{\frac{290.8 \times 98.9}{331.3} + \frac{325.9 \times 120.5}{331.3} + \frac{360.5 \times 110.0}{331.3}}{3}$$

$$= \frac{1.14 \times 98.9 + 1.02 \times 120.5 + 0.92 \times 110.0}{3} = 112.3 \text{ mm}$$

APPENDIX VII

Typical example of Estimation of precipitation using distance power method



Step-1 Write the coordinates of the raingauge locations with respect to reference coordinate system

Step-2 Determine the distance of each estimator station (B,C and D) from the estimated station (A) using the formula

$$D_i = \sqrt{[(X - X_i)^2 + (Y - Y_i)^2]}$$

where X and Y are the coordinates of the estimated station and X_i and Y_i are the coordinates of the estimator stations.

Step-3 Compute $1/D_i^2$ for each estimator station and estimate the rainfall station A as given below

Station	Distance from station A (Km)	$\frac{1}{D_i^2}$	Rainfall mm	Weighted Rainfall mm
B	28	1.27×10^{-3}	98.9	125.6×10^{-3}
C	17.7	3.19×10^{-3}	120.5	384.6×10^{-3}
D	42.5	0.55×10^{-3}	110.0	60.5×10^{-3}
	Total	5.01×10^{-3}		570.7×10^{-3}

$$\text{Rainfall at Station A} = \frac{570.7\times10^{-3}}{5.01\times10^{-3}} = 113.9 \text{ mm}$$

APPENDIX VIII

```
      SUBROUTINE MAXMUM(MNTS,MNTE,IYEAR,NDAY,IR,MAX,IT)
      DIMENSION IR(12,31),NDAY(12),MAX(12),IT(12)
      DO 10 I = MNTS,MNTE
      IF (I.EQ.2) CALL LEAPYR (IYEAR,NDAY)
      NDAYS=NDAY (I)
      MAXM= IR (I,1)
      DO 20 J = 2,NDAYS
      IF (MAXM.GE.IR(I,J)) GO TO 20
      MAXM = IR (I,J)
      IPT=J
20    CONTINUE
      MAX(I)= MAXM
      IT(I) = IPT
10    CONTINUE
      RETURN
      END

      SUBROUTINE LEAPYR(IYEAR,NDAY)
C     YEAR SHOULD BE DEFINED IN FULL DIGITS IN MAIN
C     PROGRAMME
      DIMENSION NDAY (2)
      LPYR=MOD(IYEAR,4)
      IF(LPYR.EQ.0)NDAY(2)=29
      RETURN
      END
```

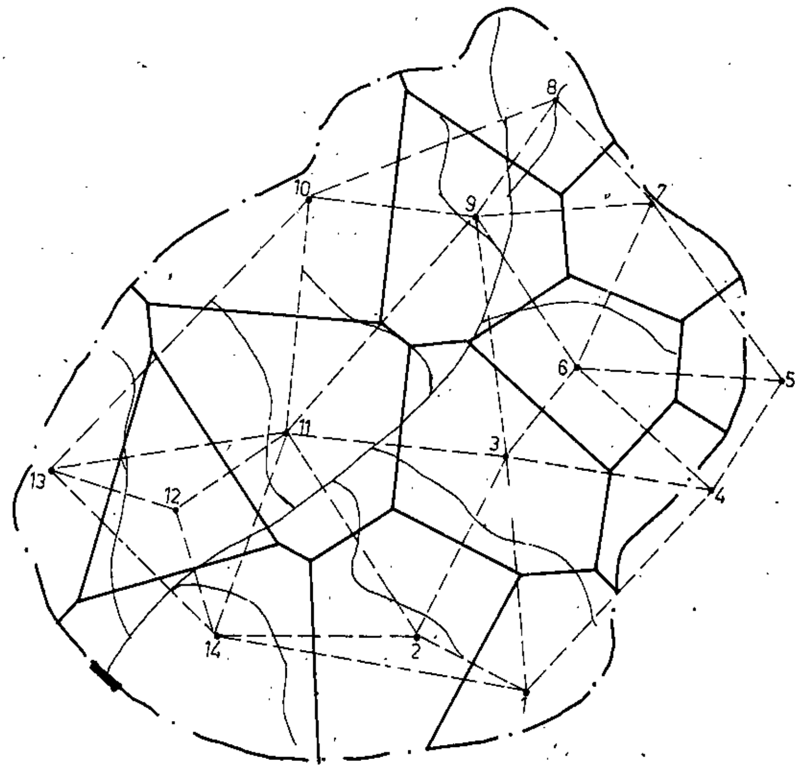
APPENDIX IX

```
C       PROGRAMME RAIN - FOR COMPUTING HOURLY AVERAGE RAINFALL
        CHARACTER*25 T1,ST1(20),ST2(20),ST3(20)
        DIMENSION TR(20),WTN(20),HR(10,24),WTR(10),RTH(24)
        DIMENSION WTH(20,24),AWTH(24),RAIN(30,20),PRCP(24)
        OPEN (UNIT = 1, FILE = 'RAIN.DAT',STATUS = 'OLD')
        OPEN (UNIT = 2, FILE = 'RAIN.OUT',STATUS = 'NEW')
C       READ CATCHMENT NAME AND NUMBER OF DAYS
        READ(1,10) T1, ND
  10    FORMAT( A25,I2 )
        WRITE(2,15) T1
  15    FORMAT(//10X,'AVERAGE RAINFALL FOR'A25'CATCHMENT')
        ND1 = 0
C       READ NUMBER OF ORG , SRRG AND THEIR WEIGHTS
 555    READ (1,20) M, N
  20    FORMAT (2I2)
        ND1 = ND1 + 1
        WRITE (2,25) ND1, M, N
  25    FORMAT(//10X,I2' DAY NO OF ORG ='I3,' NO OF SRRG ='I3)

        READ(1,30)(WTN (I), I = 1,M)
        READ(1,30)(WTR (I), I = 1,N)
  30    FORMAT(10F5.1)
C       READ ORDINARY RAINGAUGE NAMES AND DATA
        DO 90 I = 1,M
  90    READ (1,40) ST1(I),ST2(I),TR(I)
  40    FORMAT( 2A7, F6.1)
C       READ HOURLY RAINFALL DATA
        DO 100 I = 1,N
        SUMHR=0.0
        READ (1,50) ST3(I)
  50    FORMAT (A15)
        READ (1,60) (HR (I,J), J = 1,24)
  60    FORMAT(16F5.1)
        DO 110 J=1,24
 110    SUMHR=SUMHR+HR(I,J)
        WRITE(2,35)ST3(I),SUMHR,WTR(I)
  35    FORMAT(/10X,'HOURLY RAIN FALL AT',A15,4X,'24 HOUR TOTAL ='
        1F6.1,4X,'WEIGHT=',F5.1/)
        WRITE(2,45)(HR(I,J),J=1,24)
  45    FORMAT (10X,24F5.1)
 100    CONTINUE
C       COMPUTE AVERAGE HOURLY DISTRIBUTION
        SUMPH = 0.0
        DO 120 J = 1,24
        PRCP (J) = 0.0
        DO 130 I = 1,N
 130    PRCP(J) = PRCP(J) + (HR(I,J) * WTR(I)) / 100.0
 120    SUMPH = SUMPH + PRCP(J)
C       DISTRIBUTE TOTAL(DAILY) RAINFALL INTO HOURLY RAINFALL
        DO 150 I = 1,M
        DO 140 J = 1,24
 140    WTH(I,J) = TR(I) * PRCP(J) / SUMPH
        WRITE (2,55) ST1(I),ST2(I),TR(I),WTN(I)
        WRITE (2,45) (WTH(I,J), J = 1,24)
 150    CONTINUE
  55    FORMAT (/10X,'STATION =',2A7,4X,'DAILY RAINFALL =  ,
        1F6.1,4X,'WEIGHT = ',F5.1)
C       COMPUTE WEIGHTED AVERAGE HOURLY RAINFALL
        SUM3 = 0.0
        DO 160 J = 1,24
        AWTH(J) = 0.0
        DO 170 I = 1,M
 170    AWTH(J) = AWTH(J) + (WTH(I,J)*WTN(I)) / 100.0
 160    SUM3 = SUM3 + AWTH(J)
        WRITE (2,65)
        WRITE (2,45) (AWTH(J), J = 1,24)
        WRITE (2,75) SUM3
  75    FORMAT(/10X,'AVERAGE DAILY RAINFALL FOR THE CATCHMENT'F6.1)
  65    FORMAT (/10X,'AVERAGE WEIGHTED CATCHMENT RAINFALL')
        IF ( ND . GT . ND1) GO TO 555
        STOP
        END
```

APPENDIX X

Typical example of Computation of catchment average rainfall by Thiessen Polygon method



Step 1 Join the raingauge station locations to form triangles

Step 2 Draw perpendicular bisectors for each of the sides of the triangles to form polygons.

Step 3 Measure the area of each polygon and determine its weight with respect to the total catchment area.

Step 4 Compute the catchment average rainfall as given below:

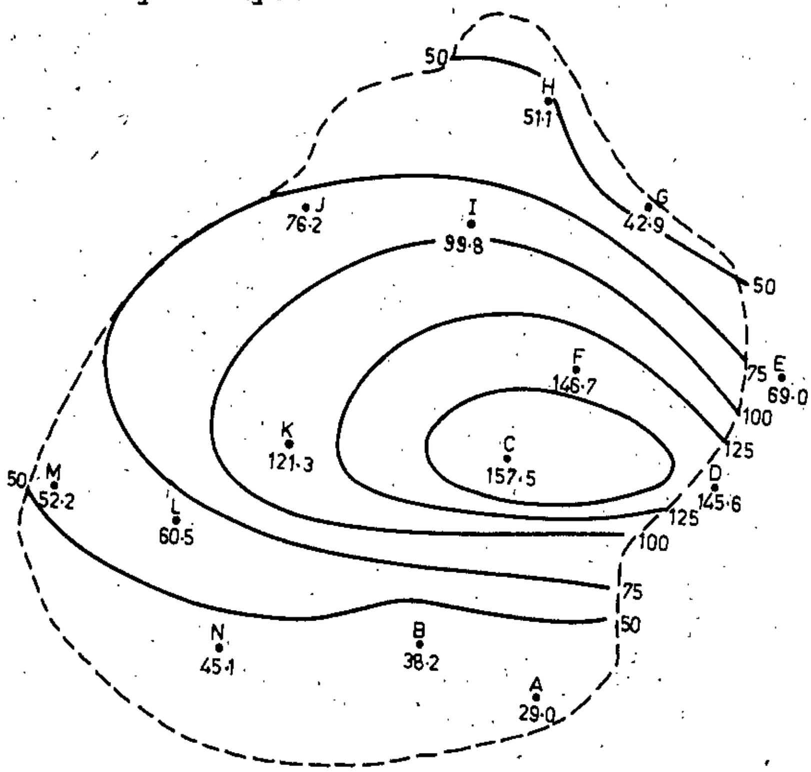
Station	Thiessen Weight	Rainfall mm	Weighted Rainfall mm
1	.056	29.0	1.6
2	.099	38.2	3.8
3	.096	157.5	15.1
4	.029	145.6	4.2
5	.020	69.0	1.4
6	.066	146.7	9.7
7	.044	42.9	1.9
8	.070	51.1	3.6
9	.085	99.8	8.5
10	.093	76.2	7.1
11	.116	121.3	14.1

Station	Thiessen Weight	Rainfall mm	Weighted Rainfall mm
12	.063	60.5	3.8
13	.059	52.2	3.1
14	.103	45.1	4.6
Total	1.000		82.5

Catchment average rainfall 82.5 mm

APPENDIX XI

Typical example of Computation of Catchment average rainfall by Isohyetal Method



Step 1 Plot the rainfall data at respective raingauge locations

Step 2 Draw Isohyetal map interpolating between rainfall values

Step 3 Planimeter the area between Isohyets and convert to geographical area using map scale

Step 4 Compute the rainfall volume and catchment average rainfall as given below:

Isohyetal Range	Average Value mm	Area between Isohyets (Km^2)	Volume $10^3 m^3$
157.5 - 150	153.75	430	66112.5
150 - 125	137.5	670	92125.0
125 - 100	112.5	1230	138375.0
100 - 75	87.5	1300	113750.0
75 - 50	62.5	1470	91875.0
50 - 42.9	46.45	1400	65030.0
50 - 29.0	39.5	180	7110.0
		6680	574377.5

Catchment average rainfall = 574377.5/6680 = 86.0 mm