*CHAPTER- III*

# HYDROLOGICAL NATURE AND THEIR RELATION WITH DRAINAGE VARIABLES

## INTRODUCTION

The purpose of studying the hydrological characteristics of the drainge basin in this study is to focus mainly the basic mechanism of surface run off in the channels as related to the catchment and climatic especially precipetation characteristic of the basins and to estabilish the emperical relations between the hydrological and morphological variables. The hydrological characteristics in a basin though primarily controlled by the hydrological cycle, the actual hydrological behaviour of the surface and sub-surface run off influence the dynamic activities of running water, erosion, deposition and transportation of load etc. Hence, the fluvial geomorphic forms and the channel morphology are closely inter related with the behaviour of the run off.

Without any detailed discussion of the hydraulic laws and mathematical derivations, the present subject matter of hydrological characteristics of the drainge basins provide and introduction to the hydrological and surface runoff cycles characteristics of a basin, the hydrographs, rainfall characteristics, stream flow conditions, linear properties i.e., its frequncy and density and also to the attributes of relief and slopes of morphological features and techniques and measurment of discharges of drainge basins.

## 3.1 CONCEPT OF HYDROLOGIC CYCLE

The endless circulation of water between atmosphere, hydrosphere and lithosphere is called the hydrologic cycle. The evaporated moisture is lifted in the atmosphere until it precipetates to earth, either on land or in the oceans. The precipetated water may be intercepted or transpired by plants may run over the ground surface and into the streams to oceans, or may infiltrate into ground. Much of water return to the air through evaporation and transpiration from surface run off. The infiltrated water percolate downwards to be temporarily stored as groundwater which later flows out of rocks as springs or steps into streams or runoff to ocean or evaporates into the atmosphere to complete the cycle. Thus, the hydrologic cycle undergoes various complicated process of evaporation, precipetation, interception, transpiration, infiltration, storage and runoff. The activities of water extends through their three parts of the earth system from an everage depth of about 1 km in the lithosphere to a height of about 16 km in the atmosphere. They creat a gigantic system of great complexity and intricacy.

In the global hydrological cycle, the oceans provide the bulk of the water supply of atmospheric moisture of which about 90% is derived from the evaporation of water bodies whereas the remaining amount through the processes of evaporation and transpiration from the land surface. But the total precipetation of land, 61% goes back to the atmosphere by the combined processes of evaporation and transpiration, 1% flows as groundwater and the remaining 38% flows as surface runoff. It is quite interesting to note that of the total quantity of moisture supply in the atmosphere on the land surface, 39% comes from the oceanic surface experiences a huge movement of water to the atmosphere, the huge bulk of it return back to the ocean in the form of precipetation.( Sen, 1993)

A watershed must be a combination of both the surface drainge area and the parcel of sub-surface soil and geologic formation that underlies it, the sub-surface hydrologic processes are just as important as the surface processes. In fact it can be argued that they are more important, for it is the nature of the sub-surface materials that controls infiltration rates, and infiltration rates influence the timing and partial distribution of surface runoff. The process of hydrologic cycle is also characterised by short-circuits such as, a part of water may evaporate directly from the vegetation, or percolation of water is the sub-surface and its evaporation through capillary action and evaporation. Simultaneously with the hydrologic cycle, a number of dissolved minerals like carbon also takes part in the geochemical cycles where water flow is the main process.

The importance of groundwater is relative to other components of hydrologic cycle. In recent years, much interest has been paid to the concept of the World Water Balance ( Nace, 1971) and most recent estimate of these data emphasize the ubiquitous nature of groundwater in the hydrosphere. With reference to Table 3.1 if it is removed from consideration the 94% of the earth's water which rests in the oceans and seas at high level of salinity, then groundwater acounts for about two thirds of the fresh water resources of the world. If the limit of consideration to the utilisable fresh water resources, groundwater accounts for almost the total volume. If it is considered that the only the most 'active' groundwater regime, which estimates $4x10^6$ $km^3$ (rather than $60x10^6$ $km^3$ of Table 3.1), the fresh water breakdown comes to be; groundwater 95%, lakes, swamps, reservoirs and river channels 3.5% and soil moisture 1.5%

**Table**–3.1 : Estimated World Water Balance.

| Sl. No. | Parameter | Surface area ($km^2$) x $10^6$ | Volume ($km^3$) x $10^6$ | Volume in % | Equivalent depth (m) | Residual time |
|---|---|---|---|---|---|---|
| 1. | Oceans and seas | 361 | 1,370 | 94 | 2;000 | 4,000 years |
| 2. | Lakes and Reservoirs | 1.55 | 0.13 | 0.01 | 0.25 | 10 years |
| 3 | Swamps | 0.1 | 0.01 | 0.01 | 0.007 | 1-10 years |
| 4. | River channels | 0.1 | 0.01 | 0.01 | 0.003 | 2 weeks |
| 5. | Soil moisture | 130 | 0.07 | 0.01 | 0.13 | 2 weeks - 1 year |
| 6. | Groundwater | 130 | 60 | 4 | 120 | 2 weeks- 10000 years |
| 7. | Icecaps and glaciers | 17.8 | 30 | 2 | 60 | 10-1000 years |
| 8. | Atmospheric | 504 | 0.01 | 0.01 | 0.025 | 10days |
| 9. | Biospheric water | 0.1 | 0.01 | 0.01 | 0.001 | 1week |

**Source:** *Nace, R.L., 1971*

## 3.2 PRECIPITATION

In order to study the groundwater resources of the Terai area of Darjiling district, it is necessary to analyse the climatic factors, namely – precipitation, relative humidity and temperature among which precipitation has been universally accepted that it is the main and ultimate source of all the surface and and the groundwater recharge of a region. The recharge of groundwater due to inflow of groundwater is compensated by the discharge of groundwater by groundwater outflow. Other factors–relative humidity and temperature are also significant for the estimation of the loss of groundwater by evapo-transpiration. In the study area all the precipitation occurs as rainfall. Therefore for studying groundwater resources of a region, the study of the quantity, intensity, areal distribution and the variations in different months, seasons and years of rainfall will be of utmost importance. Before discussing the present analysis, it is worthwhile to describe in brief the different reasons in a year of the area of Darjiling district which, as that of Indian Subcontinent, is termed as 'land of monsoon' as monsoons constitute the most important rain yielding winds. In relation to the monsoons which indicate the reasonal rhythm of weather, the year is popularly divided into three seasons : (a) the hot or pre monsoon season (March to Mid June), (b) The rainy or monsoon season (Mid June to September) and (c) The cold or post monsoon season (October to February).

## 3.3 PRECIPITATION ANALYSING PROCEDURES

On the basis of the seasonal variations, groundwater resources as well as the surface water resources of the study area, the study of the quantity, intensity, areal distribution and the variations in different months, seasons and years of rainfall will be of utmost importance and are described systematically:

**Rainfall measurements :**

There are a good number of rain gauges installed in the Terai region of the Darjiling district because the area is covered by a large number of tea gardens, but most of them are controlled by tea garden authority individually and only two or three are under controlled of Meteorological Department, Govt. of India. Out of these large number of rain gauges, regular records of rainfall for a large number of years are only available in the private tea garden records and three principal tea garden of the terai area have been selected- Lohagarh, Mohurgong and Simulbari tea estates and only one rain gauge station controlled by the India Metreorological Department, situated in the Gangaram tea estate have been considered for meteorological data analysis. For a detailed study rational delineation of rainfall, these four rain gauges records have been incorporated due to their greater reliability and availability of continuity for a long term. Approximately there is a well marked uniformity in the mode of rainfall distribution throughout the whole region. These four rain gauges are situated at different police stations of the district, so that they cover the whole study area and hence it is believed that, the analysis of only these four rain gauges records for detailed studies will not affect the accuracy of inferences and conclusions derived therefrom.

**Period of Records :**

For the present study rainfall data for twenty two years i.e. 1977-1998 have been selected and analysed. But the record of rainfall data collected from the Lohagarh, Mohurgong and Simulbari Tea Estates are of 76 years, 43years and 49years respectively and the only India meteorological Department's controlled rain gauge station records is only 22years. For the betterment of the comparison and the accuracy of the analysis of the data, all the four rain gauges rainfall records of years have been equalized. Here it should be mentioned that the accuracy of the analysis increases with the number of data available. Hence, it is to be considered that the analysis of rainfall for 22years period of record will be able to draw fairly accurate conclusions.

**a) Variation of Rainfall with Time :**

The long- term normal annual rainfall for the Terai area of the District as a whole amounts to 4350mm. The variation in rainfall with respect to time is low. The variability is obviously low, the annual rainfall deviating but little from the corresponding long term means. The departures from the annual means rarely exceed 50 percent. Thus, during the 22years period of rainfall record (1977-1998), station Terai Meteorological Substation recorded an annual rainfall excess

Table -3.2: Deviation values of annual rainfall in percentage (1977-1998).

| Stations → Year ↓ | Gangaram tea estate | Lohargarh tea estate | Mohurgong tea estate | Simulbari tea estate |
|---|---|---|---|---|
| (1) | (2) | (3) | (4) | (5) |
| 1977 | -8 | -9 | +5 | +2 |
| 1978 | -36 | -12 | -25 | -16 |
| 1979 | -12 | +2 | +4 | +9 |
| 1980 | -16 | -12 | -1 | +9 |
| 1981 | -0.08 | +6 | -6 | +4 |
| 1982 | +83 | -37 | -31 | -25 |
| 1983 | +3 | +9 | +18 | +16 |
| 1984 | +5 | -10 | -0.1 | +4 |
| 1985 | +18 | +7 | +2 | -9 |
| 1986 | -19 | +4 | -28 | -10 |
| 1987 | -2 | +8 | +14 | +10 |
| 1988 | +8 | +8 | +6 | +10 |
| 1989 | +20 | +9 | +28 | +9 |
| 1990 | +1 | +3 | +10 | -5 |
| 1991 | +23 | +15 | +19 | -3 |
| 1992 | -36 | -16 | -21 | -30 |
| 1993 | -12 | -4 | -3 | -24 |
| 1994 | -32 | -40 | -29 | -11 |
| 1995 | +17 | +20 | +25 | +34 |
| 1996 | -16 | -2 | -0.3 | +2 |
| 1997 | -23 | +4 | -15 | -8 |
| 1998 | +35 | +46 | +20 | +38 |
| Average R.F in mm | 3339.34 | 5508.21 | 3553.90 | 4997.35 |

of above 50% of mean on only one occasion and annual deficit of 50% of mean not on any occasion. During the same period, other three stations – Lohagarh, Mohurgong and Simulbari recorded no annual excess or deficit of 50 percent of mean on any occasion. But departures of 25-30percent of the mean have generally been quite frequent over the study area of four rain gauge stations. It will also be seen that in the Terai area of Darjiling district during 22 years period of records, heavy or low rainfall years do not occur in groups or in a definite cycle.

**Table-3.3:**Monthly and cumulative amounts of rainfall in mm. and their percentage to total (1977-1998).

| STATION | Cumulative | MONTHS | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| Gangaram tea estate | A | 13.10 | 13.49 | 32.73 | 59.74 | 227.30 | 585.33 | 974.36 | 768.85 | 510.17 | 123.93 | 15.10 | 15.31 |
| | ΣA | 13.10 | 26.59 | 59.32 | 119.06 | 346.29 | 931.62 | 1905.98 | 2674.83 | 3185.00 | 3308.93 | 3324.03 | 3339.34 |
| | %ΣA | 0.40 | 1.00 | 2.00 | 4.00 | 10.00 | 28.00 | 57.00 | 80.00 | 95.00 | 99.00 | 99.50 | 100.00 |
| Lohagarh tea estate | A | 24.30 | 46.59 | 53.65 | 148.73 | 422.93 | 1067.31 | 1546.77 | 948.14 | 923.45 | 263.68 | 48.79 | 13.87 |
| | ΣA | 24.30 | 70.89 | 124.54 | 273.27 | 696.20 | 1763.51 | 3310.28 | 4258.42 | 5181.87 | 5445.55 | 5494.34 | 5508.21 |
| | %ΣA | 0.40 | 1.00 | 2.00 | 5.00 | 13.00 | 32.00 | 60.00 | 77.00 | 94.00 | 99.00 | 99.50 | 100.00 |
| Mohurgong tea estate | A | 15.30 | 24.31 | 40.05 | 98.72 | 274.73 | 645.28 | 945.91 | 658.62 | 624.66 | 188.02 | 24.56 | 13.74 |
| | ΣA | 15.30 | 39.61 | 79.66 | 178.38 | 453.11 | 1098.39 | 2044.30 | 2702.92 | 3327.58 | 3515.60 | 3540.16 | 3553.90 |
| | %ΣA | 0.40 | 1.00 | 2.00 | 5.00 | 12.00 | 31.00 | 58.00 | 76.00 | 93.00 | 99.00 | 99.50 | 100.00 |
| Simulbari tea estate | A | 23.21 | 37.80 | 58.15 | 140.31 | 376.44 | 971.14 | 1324.50 | 884.21 | 903.00 | 224.08 | 41.97 | 12.54 |
| | ΣA | 23.21 | 61.01 | 119.16 | 259.47 | 635.91 | 1607.05 | 2931.55 | 3815.76 | 4718.76 | 4942.84 | 4984.81 | 4997.35 |
| | %ΣA | 0.50 | 1.00 | 2.00 | 5.00 | 13.00 | 32.00 | 59.00 | 76.00 | 94.00 | 99.00 | 99.50 | 100.00 |

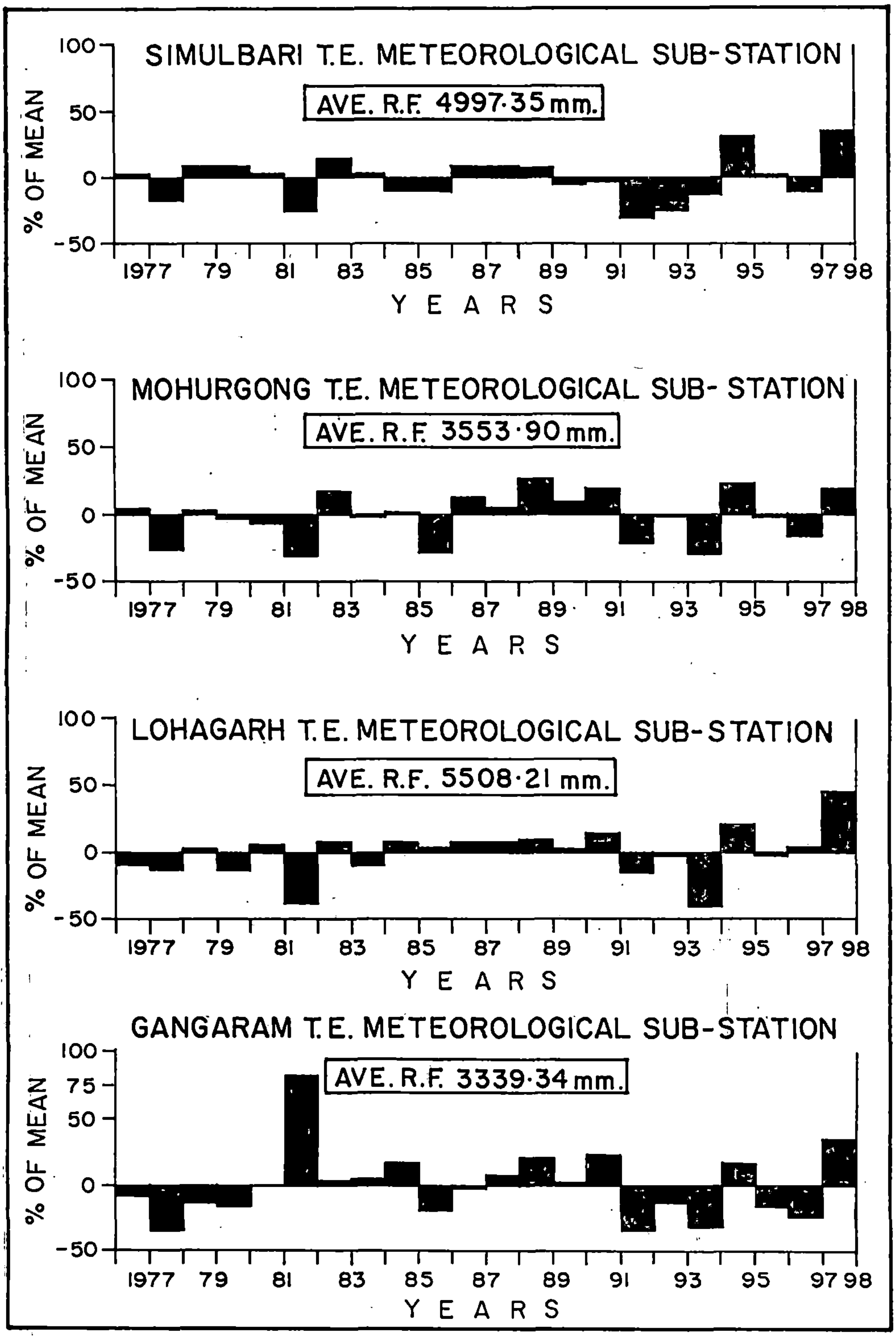



Fig. 3·1: DEVIATIONS OF ANNUAL RAINFALL FROM MEAN (1977–98)

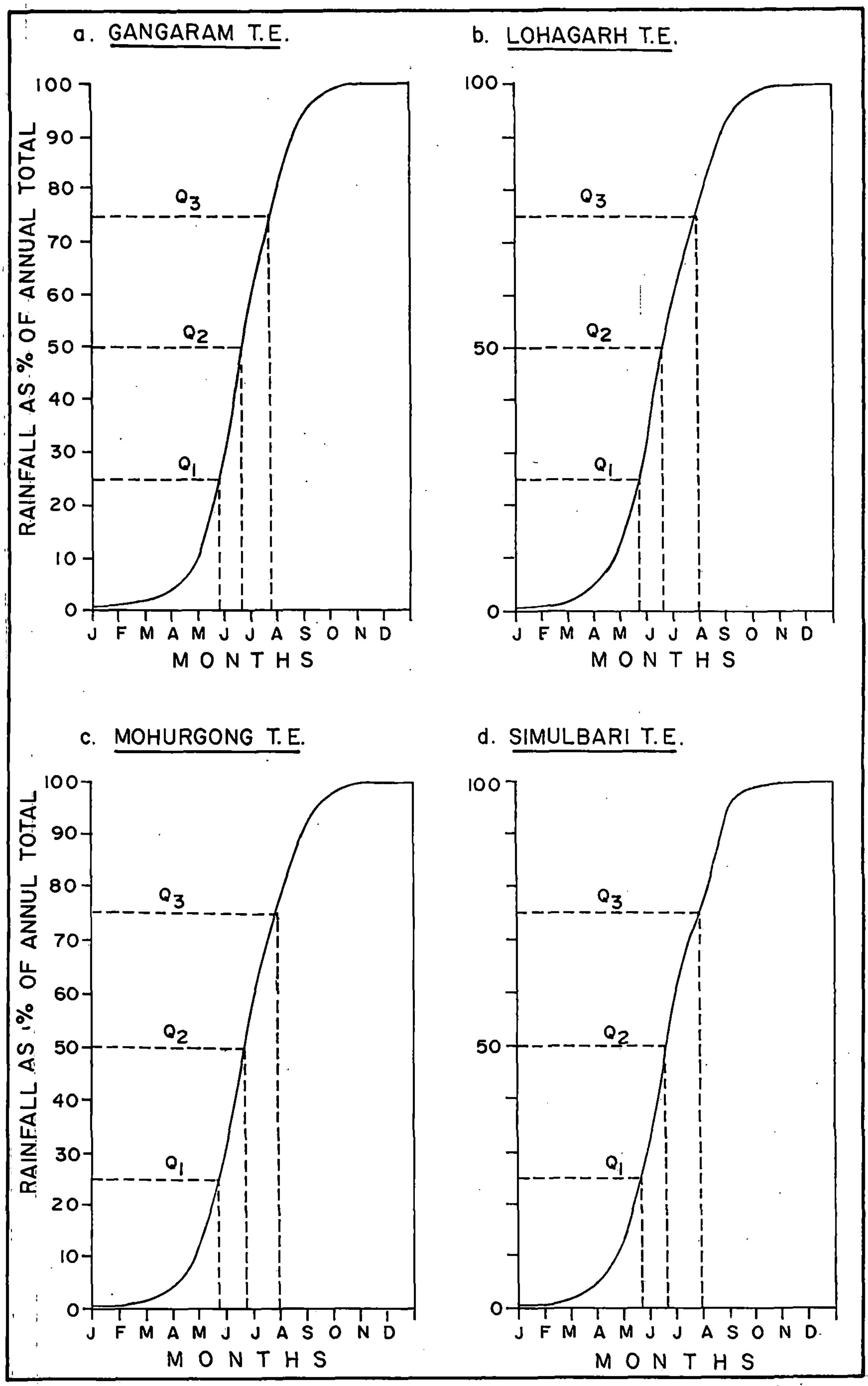



Fig.3·2: CUMULATIVE MONTHLY RAINFALL CURVE

There has, however, been no marked tendency towards a long term rise or fall in accumulated percentage deviation (Table–3.2). In fact an annual rise or fall occurs in quick succession. For instance, in the period 1977-1998, Station Terai recorded an annual rainfall deficit of 25 percent or more on three occasions (1978,1992and 1994) and during the same period, an annual excess of 25 percent or more on three occasions (1982,1990and 1998). Similarly during 22year period of record (1977-1998) Stations Lohagarh, Mohurgong and Simulbari recorded an annual rainfall deficit of same magnitude on two (1988 & 1994), four (1978,1982,1986 and 1994) and two (1982 &1992) occasions respectively and the annual rainfall excess of 25 percent or more on one (1998), two (1988&1994) and two (1994&1998) occasions respectively, (Fig.-3.1). Fig.-3.1 shows that only a small number of heavy or low rainfall periods occur during 22 years period of record (1977-98) and they do not show any periodicity. The well marked heavy rainfall periods in Terai meteorological sub-station at Gangaram tea estate are 1982, 1984,1987-88,1990,1994and 1998 and well marked low rainfall periods are 1978-1980, 1986, 1991-93, and 1996-97. These clearly exhibit that there is no definite periodicity of heavy or low rainfall periods and the same will be occur for other three rain gauge stations of the Terai region of the Darjiling district.

It is also clear that during a heavy rainfall period, all the four rain gauge stations show more or less similar tendencies and in the case of low rainfall period, all the stations record low rainfall amounts. These similar tendencies of all the rain gauge stations confirm the uniformity in mode of rainfall distribution throughout the whole Terai region of Darjiling district.

**b) Cumulative Monthly Rainfall Amounts :**

This method is perhaps too rarely used. In Table–3.3, the monthly individuals and cumulated amounts of rainfall are given in mm. and in percentage of annual total. It is seen that the cumulated percentages are more or less same for each stations, the characteristics of annual variation has been represented in Fig.-3.2 for all the four stations. In this context, the actual monthly amounts are not suitable for this method because of the differing annual totals of rainfall at four

Table-3.4 : The annual rainfall in descending order (1977-1998)

| Gangaram T.E. | | | Lohagarh T.E. | | | Mohurgong T.E. | | | Simulbari T.E. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | R.F. (mm) | Cumu % of R.F. | Year | R.F. (mm) | Cumu % of R.F. | Year | R.F. (mm) | Cumu % of R.F. | Year | R.F. (mm) | Cumu % of R.F. |
| 1982 | 6096 | 0.00 | 1998 | 8048 | 0.00 | 1989 | 4556 | 0.00 | 1998 | 6911 | 0.00 |
| 1998 | 4520 | | 1995 | 6587 | | 1995 | 4459 | | 1995 | 6688 | |
| **1991** | **4118** | **13.64** | **1991** | **6330** | **13.64** | **1998** | **4269** | **13.64** | **1983** | **5779** | **13.64** |
| 1989 | 4007 | | 1983 | 6011 | | 1991 | 4239 | | 1988 | 5494 | |
| 1985 | 3926 | | 1989 | 6008 | | 1983 | 4176 | | 1979 | 5460 | |
| **1995** | **3908** | **27.27** | **1987** | **5961** | **27.27** | **1987** | **4037** | **27.27** | **1980** | **5454** | **27.27** |
| 1988 | 3621 | | 1988 | 5948 | | 1990 | 3897 | | 1989 | 5424 | |
| 1984 | 3489 | | 1985 | 5912 | | 1988 | 3781 | | 1987 | 5347 | |
| **1983** | **3430** | **40.91** | **1981** | **5809** | **40.91** | **1977** | **3745** | **40.91** | **1984** | **5178** | **40.91** |
| 1990 | 3358 | | 1986 | 5750 | | 1979 | 3679 | | 1981 | 5172 | |
| 1981 | 3337 | | 1997 | 5750 | | 1985 | 3626 | | 1977 | 5073 | |
| **1987** | **3258** | **54.55** | **1990** | **5685** | **54.55** | **1984** | **3557** | **54.55** | **1996** | **5068** | **54.55** |
| 1977 | 3061 | | 1979 | 5590 | | 1996 | 3542 | | 1991 | 4843 | |
| 1993 | 2936 | | 1996 | 5377 | | 1980 | 3513 | | 1990 | 4746 | |
| **1979** | **2926** | **68.18** | **1993** | **5283** | **68.18** | **1993** | **3435** | **68.18** | **1997** | **4615** | **68.18** |
| 1996 | 2817 | | 1977 | 5022 | | 1981 | 3342 | | 1985 | 4527 | |
| 1980 | 2815 | | 1984 | 4960 | | 1997 | 3017 | | 1986 | 4489 | |
| **1986** | **2702** | **81.82** | **1978** | **4872** | **81.82** | **1992** | **2819** | **81.82** | **1994** | **4430** | **81.82** |
| 1997 | 2586 | | 1980 | 4825 | | 1978 | 2675 | | 1978 | 4176 | |
| 1994 | 2267 | | 1992 | 4633 | | 1986 | 2563 | | 1993 | 3822 | |
| **1992** | **2148** | **95.45** | **1982** | **3490** | **95.45** | **1994** | **2518** | **95.45** | **1982** | **3738** | **95.45** |
| 1978 | 2143 | 100.00 | 1994 | 3332 | 100.00 | 1982 | 2450 | 100.00 | 1992 | 3506 | 100.00 |
| **Ave R.F.** | **3339** | **100.00** | **Ave R.F.** | **5508** | **100.00** | **Ave R.F.** | **3554** | **100.00** | **Ave R.F.** | **4997** | **100.00** |

stations of the study area hence, the values are only comparable when the mean monthly amounts are converted into percentage of the mean annual totals.

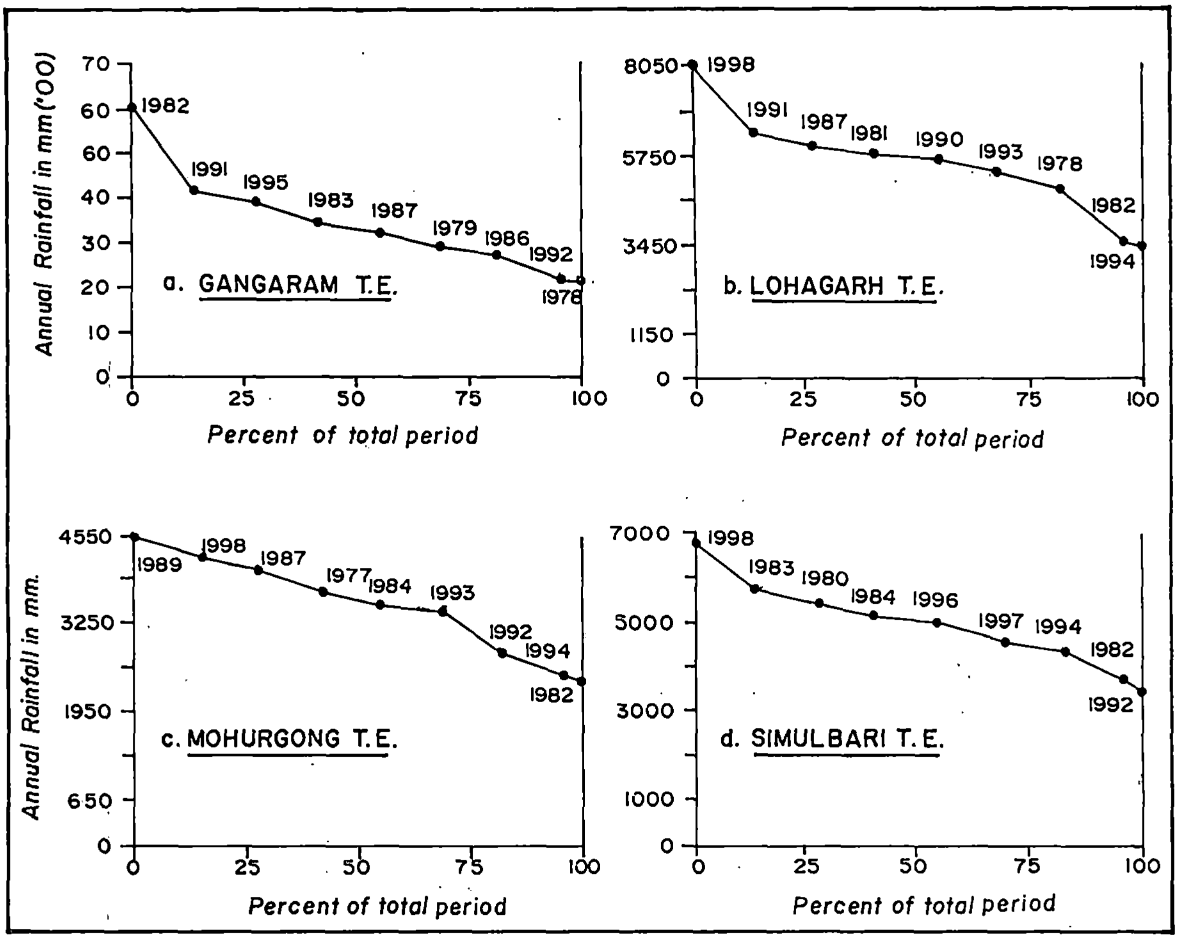



Fig.3.3: TIME-RAINFALL DEPENDENT CURVE (1977-1998)

This gives more than a uniform representation and also offers the advantage of showing directly some numerical characteristics if horizontal parallels are drawn at 0,25,50,75,and 100 percents. It is seen that at Terai, one-fourth of the annual amounts falls between January 1st and June 24th; one-half of the annual amounts falls between January 1st and July 24 and three-fourth of the annual amounts falls between January 1st and August 24th, and in the beginning of the month September, 95 percent of the annual amount is surpassed. The same picture is true for each of the four rain gauge stations. So, major portion of the annual amount of rainfall falls in four months (June to September) during south–west monsoon season. Similarly cumulated amounts at four stations of the Terai region (Table-3.3), once again confirm the uniform mode of rainfall distribution throughout the study area of the district.

**c) Frequency of Occurrence of Annual Rainfall :**

The study of the frequency of occurrence of annual rainfall amounts of different magnitudes at the different stations shows that with an increase in magnitude there is a decrease in its frequency of occurrence and vice versa. Hence, there is an increase proportionality between frequency of occurrences and amounts of annual rainfall. Thus, the frequency curve in the present study is an undulatory line except for an abrupt change near the two ends where the rainfall amounts approach the maximum or minimum figures which, in fact, are the maximum departures or the abnormal occurrences recorded during the period under consideration of all the four rain gauge stations of the Terai region. By arranging the annual rainfall of all the rain gauge stations of the 22years records in a descending order and by taking the cumulative percentage of every three years gap of the total period of records (1977-1998) in Table-3.4 and the Fig.-3.3 shows that with the change of cumulative percentage of rainfall interval, the frequency curves do not show any appreciable change in shape and thus it can be concluded that the frequency curves for the four stations which have been represented in the figure are much more accurate and only the frequency curves show an abrupt change when annual amount reaches its maximum or minimum value. The abrupt change is less prominent for minimum rainfall than that for maximum rainfall.

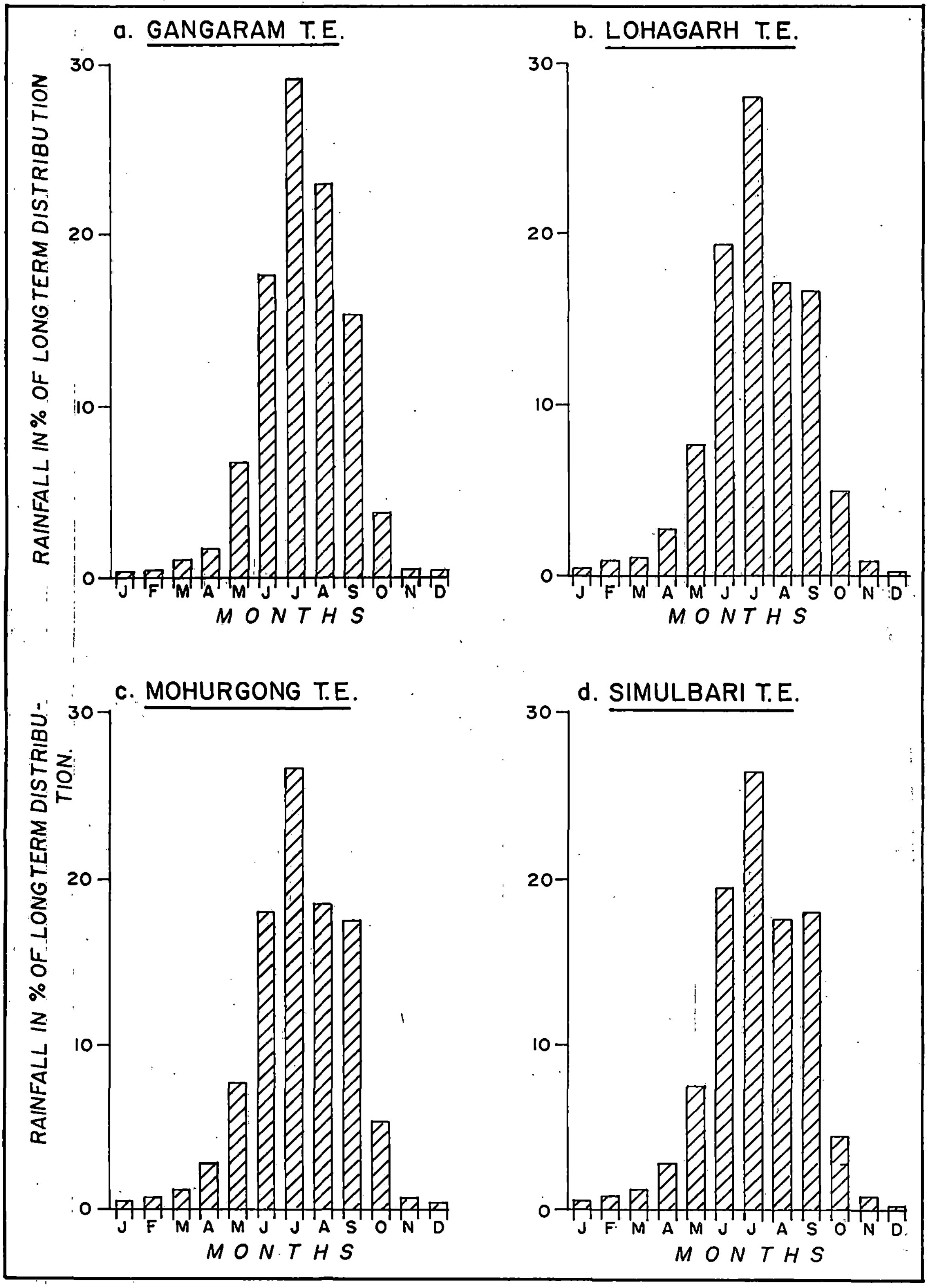



Fig. 3·4: NORMAL MONTHLY DISTRIBUTION OF RAINFALL (1977-98)
(EXPRESSED AS PERCENTAGE)

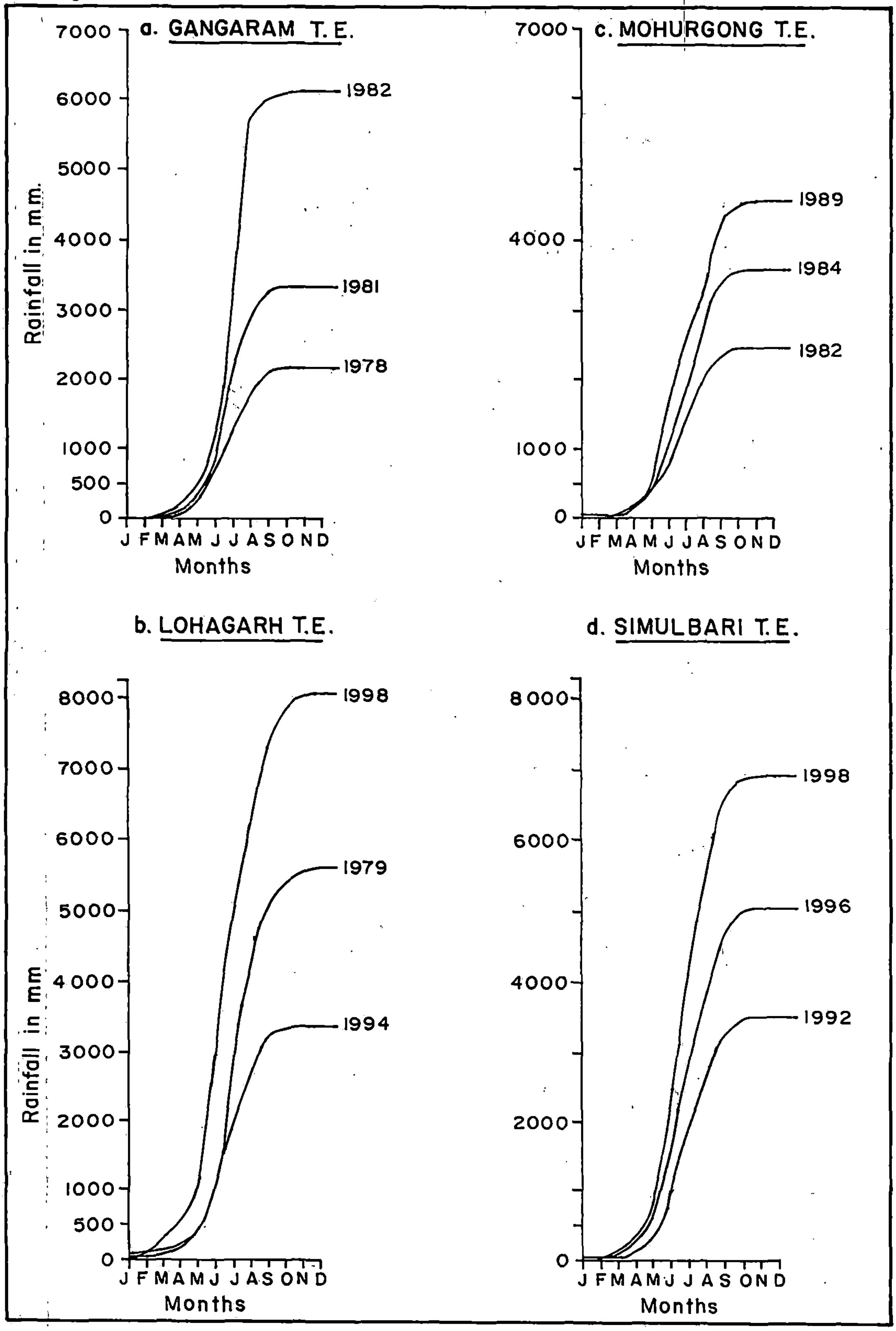
This is obviously due to the fact that these annual rainfall figures represent the maximum departure or the abnormal occurrences that have been recorded during the twenty two years period of record (1977-1998). Moreover, in Terai region of Darjiling district , the abnormality of minimum annual rainfall occurrence is less than that of maximum annual rainfall occurrence or in other words minimum annual rainfall amounts occur more frequently than maximum annual rainfall amounts.

From Fig. –3.3 it is further observed that the frequency of heavy rainfall is higher at stations where the average or long term mean annual rainfall is higher with respect to other stations in the study area. Table–3.4 shows the maximum, median and minimum rainfall in mm. at four stations for the period of 1977-1998. Considering the records of these four stations the corresponding ranges of variation in each of the maximum, median and minimum amounts are respectively 3491mm, 2253mm, and 1364mm. Thus the range of variation in either of three cases does not exceed 3500mm. Over terai region during the period of record (1977-1998) which once again indicates truthfulness of uniform mode of rainfall distribution over the study area. Besides this point of view, the similarity of frequency curves at four stations of Terai region of Darjiling district again supports the uniform mode of rainfall distribution throughout the study area of the district

**d) Monthly and Seasonal Distribution of Rainfall :**

It has been observed that about 80 percent of the annual rainfall of the study area occurs in the monsoon season i.e. from June to September (Table–3.5). For irrigation and drinking purposes of the area, monthly and seasonal distribution of rainfall are of main importance rather than the total amount of annual rainfall. Sometimes due to the late arrival of monsoon the monthly and seasonal distribution of rainfall varies giving rise to an adverse effect to the agricultural economy. Variability also increases in September-October when the monsoon is retreating. A premature cessation of rain may involve both failure of standing Kharif crops and very unfavourable showing conditions for Rabi crops. From Fig.

Fig.-3·5: MASS DIAGRAMS OF RAINFALL STATIONS



–3.4 it is clear that out of all, only the July receives more than onefourth of the normal annual amounts while in dry seasonal rainfall amounts, averaging fifteen to twenty percent of the normal annual rainfall and more than one-fifth of this percentage is recorded during January and February and these rainfall amounts are mainly associated with the western disturbances. The monthly and seasonal distribution of rainfall varies considerably in a heavy or low rainfall year from its general trend in an average rainfall year. In the terai region of the Darjiling district it is especially found that this variation of wet seasonal amounts (June to September) of rainfall clearly reflects the variation of annual amounts of rainfall. This is certainly due to the fact that the percentage distribution of wet monsoon seasonal amount of rainfall to the annual rainfall amounts is large. The important characteristic of monsoon rainfall is its variation in annual amount which is clearly exhibited by the variation of rainfall amount during the season of a heavy or low rainfall year.

**Table** – 3.5 : Percentage of rainfall distribution of selected Tea Estate Meteorological Stations (1977 –1998).

| Stations | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Gangaram | 0.39 | 0.40 | 0.98 | 1.79 | 6.80 | 17.53 | 29.18 | 23.02 | 15.28 | 3.71 | 0.45 | 0.46 |
| Lohagarh | 0.44 | 0.85 | 0.97 | 2.70 | 7.68 | 19.38 | 28.08 | 17.21 | 16.76 | 4.79 | 0.86 | 0.25 |
| Mohurgong | 0.43 | 0.68 | 1.13 | 2.78 | 7.73 | 18.16 | 26.62 | 18.53 | 17.58 | 5.29 | 0.69 | 0.39 |
| Simulbari | 0.46 | 0.76 | 1.16 | 2.81 | 7.53 | 19.43 | 26.50 | 17.69 | 18.07 | 4.48 | 0.84 | 0.25 |

Fig.-3.5 represents the mass diagrams of rainfall at four stations of the terai region of Darjiling district for the year of heavy rainfall year, mean rainfall year and low rainfall year of the respective stations (Table–3.4). From these mass diagrams seasonal character of rainfall can be very easily seen either in a heavy, low or an average rainfall year. The similarity of four mass diagrams, their similar pattern and trends once again establish the general character of rainfall to be uniform throughout the study area.

Table:-3.6:Cumulative amounts of rainfall of maximum, median and minimum (mm) of selected meteorological stations (1977-98).

| STATION | Mass R.F. mm & Year | | MONTHS | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| Gangaram tea estate | Max R.F 1982 | A | - | - | 51.30 | 148.20 | 289.20 | 720.90 | 1568.80 | 2957.40 | 242.60 | 68.70 | 48.40 | - |
| | | ΣA | - | - | 51.30 | 199.50 | 488.70 | 1209.60 | 2778.40 | 5735.80 | 5978.40 | 6047.10 | 6095.50 | 6095.50 |
| | Median R.F. 1981 | A | 25.70 | 3.70 | 27.70 | 58.30 | 292.60 | 524.90 | 1226.70 | 699.60 | 470.30 | 6.30 | - | 1.00 |
| | | ΣA | 25.70 | 29.40 | 57.10 | 115.40 | 408.00 | 932.90 | 2159.60 | 2859.20 | 3329.50 | 3335.80 | 3335.80 | 3336.80 |
| | Min R.F 1978 | A | 2.80 | 4.90 | 10.50 | 19.20 | 317.50 | 343.50 | 518.30 | 574.50 | 327.70 | 21.30 | 2.40 | - |
| | | ΣA | 2.80 | 7.70 | 18.20 | 37.40 | 354.90 | 698.40 | 1216.70 | 1791.20 | 2118.90 | 2140.20 | 2142.60 | 2142.60 |
| Lohagarh tea estate | Max R.F 1998 | A | - | 132.50 | 126.50 | 353.90 | 330.00 | 1900.00 | 2100.00 | 1182.50 | 1202.50 | 537.50 | 182.50 | - |
| | | ΣA | - | 132.50 | 259.00 | 612.90 | 942.90 | 2842.90 | 4942.90 | 6125.40 | 7327.90 | 7865.40 | 8047.90 | 8047.90 |
| | Median R.F. 1979 | A | 1.00 | 63.30 | 3.80 | 93.10 | 251.70 | 720.20 | 2062.80 | 955.50 | 848.00 | 304.90 | 239.20 | 46.70 |
| | | ΣA | 1.00 | 64.30 | 68.10 | 161.20 | 412.90 | 1133.10 | 3195.90 | 4151.40 | 4999.40 | 5304.30 | 5543.50 | 5590.20 |
| | Min R.F 1994 | A | 114.80 | 29.90 | - | 81.50 | 168.40 | 814.50 | 712.20 | 807.70 | 553.70 | 46.40 | 2.70 | - |
| | | ΣA | 114.80 | 144.70 | 144.70 | 226.20 | 394.60 | 1209.10 | 1921.30 | 2729.00 | 3282.70 | 3329.10 | 3331.80 | 3331.80 |
| Mohurgong tea estate | Max R.F 1989 | A | 30.00 | 35.20 | 6.00 | 15.40 | 523.70 | 1094.90 | 921.00 | 620.80 | 967.20 | 243.50 | 84.80 | 13.40 |
| | | ΣA | 30.00 | 65.20 | 71.20 | 86.60 | 610.30 | 1705.20 | 2626.20 | 3247.00 | 4214.20 | 4457.70 | 4542.50 | 4555.90 |
| | Median R.F. 1984 | A | 47.40 | 13.80 | 14.20 | 79.60 | 284.50 | 792.80 | 1000.00 | 472.20 | 666.30 | 186.00 | - | - |
| | | ΣA | 47.40 | 61.20 | 75.40 | 155.00 | 439.50 | 1232.30 | 2232.30 | 2704.50 | 3370.80 | 3556.80 | 3556.80 | 3556.80 |
| | Min R.F 1982 | A | - | 6.40 | 43.60 | 138.00 | 167.60 | 359.80 | 759.10 | 236.40 | 650.00 | 58.90 | 22.20 | 8.20 |
| | | ΣA | - | 6.40 | 50.00 | 188.00 | 355.60 | 715.40 | 1474.50 | 1710.90 | 2360.90 | 2419.80 | 2442.00 | 2450.20 |
| Simulbari tea estate | Max R.F 1998 | A | - | 11.50 | 164.80 | 198.00 | 392.90 | 1512.30 | 1900.10 | 1257.50 | 1108.60 | 352.50 | 12.50 | - |
| | | ΣA | - | 11.50 | 176.30 | 374.30 | 767.20 | 2279.50 | 4179.50 | 5437.00 | 6545.60 | 6898.10 | 6910.60 | 6910.60 |
| | Median R.F. 1996 | A | 43.50 | 22.50 | 32.50 | 102.00 | 481.00 | 982.50 | 1102.90 | 1023.20 | 850.50 | 427.50 | - | - |
| | | ΣA | 43.50 | 66.00 | 98.50 | 200.50 | 681.50 | 1664.00 | 2766.90 | 3790.10 | 4640.60 | 5067.60 | 5067.60 | 5067.60 |
| | Min R.F 1992 | A | 45.70 | 8.70 | - | 64.20 | 205.20 | 386.00 | 1349.00 | 626.00 | 601.50 | 191.50 | 28.20 | - |
| | | ΣA | 45.70 | 54.40 | 54.40 | 118.60 | 323.80 | 709.80 | 2058.80 | 2684.80 | 3286.30 | 3477.80 | 3506.00 | 3506.00 |

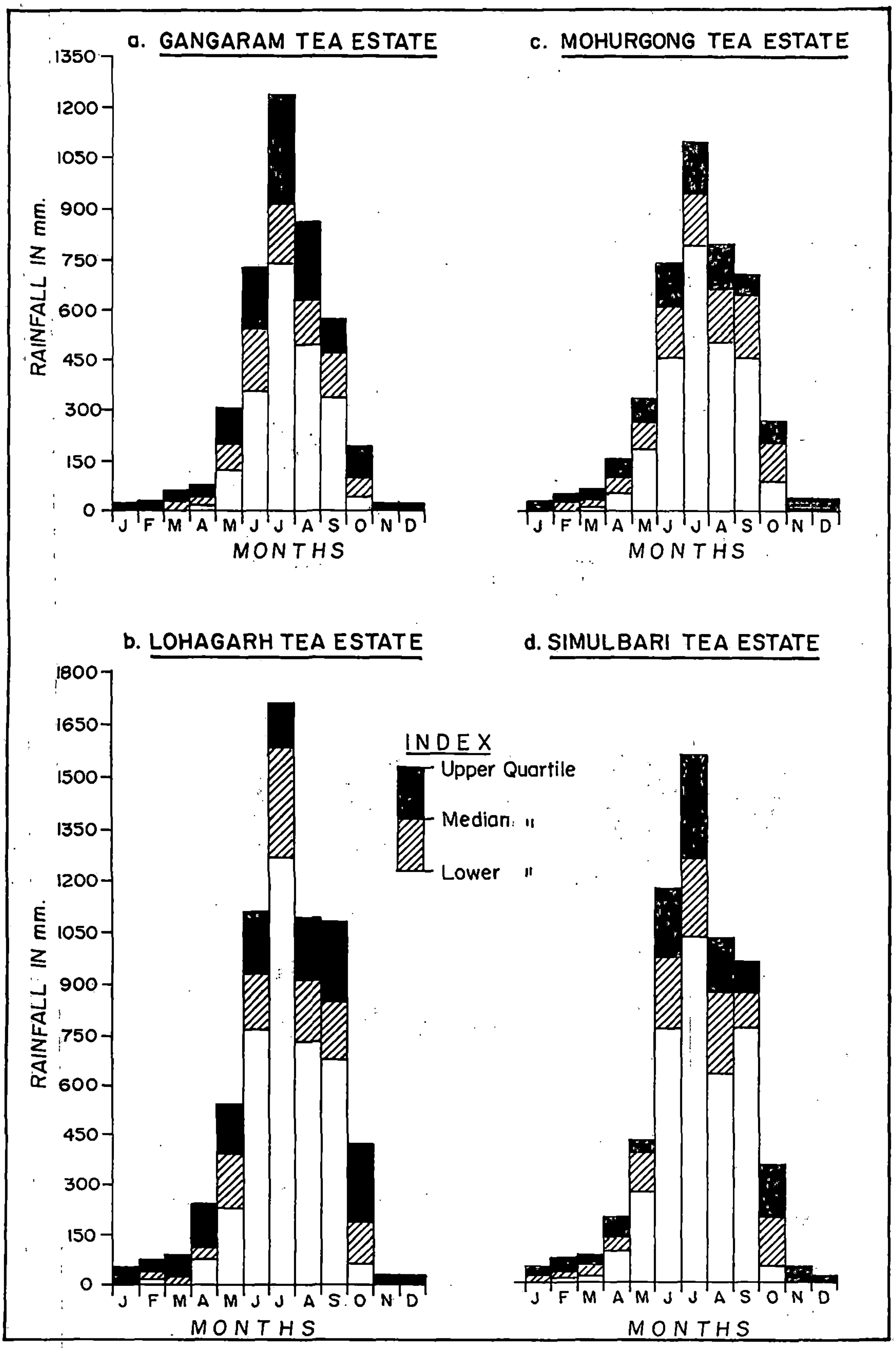



Fig. 3·6: MONTHLY DISPERSION DIAGRAMS OF RAINFALL

In these mass diagrams wet season at each station is marked by steep curves that completely flatten out over the dry season . This clearly indicates the greatest contribution of wet seasonal rainfall to the annual amounts either in a heavy, average or low rainfall year. The annual amounts in mm recorded at four stations and their corresponding wet seasonal amounts expressed as percentage and normally concluded that the wet seasonal amounts of rainfall contribute more than 80 percent of the annual amounts and dry seasonal amounts are too insignificant in either a heavy, low or average rainfall year (Table–3.5). In any year, the wet seasonal variability in rainfall clearly reflects the annual variability on account of the predominantly summer-rainfall maxima.

### e) Dispersion of Rainfall :

Most of dry seasonal rainfall is due to the western disturbance or in other words is associated with western depressions and wet seasonal rainfall is due to the south-west monsoon, in the Terai area of Darjiling district. Thus it goes without saying that meteorological conditions in these two seasons are completely different. The rainfall dispersion diagrams (Fig.–3.6) are useful in an analysis of the rainfall distribution (Table–3.6). The median and quartile values have been marked in these diagrams and of the upper and lower quartile ranges have been shaded.

A major discontinuity between any two months at a station exists if the lower quartile of one month lies above the upper quartile of the other. And a minor discontinuity is indicated when the median and the lower quartile of one month lie above the upper quartile and median respectively of the other. These discontinuities, from one month to the other are an indication of the existence of a difference in meteorological conditions causing the rainfall in these months and indicate sudden appearance or departure of some rain producing conditions.

From Fig.- 3.6 revealed that from January to April, there is not any marked discontinuity and the rainfall receiving amounts are gradually increase from January to April. But a well defined charge is observed in the month of May since its lower quartile lies above the upper quartile of April which indicate the

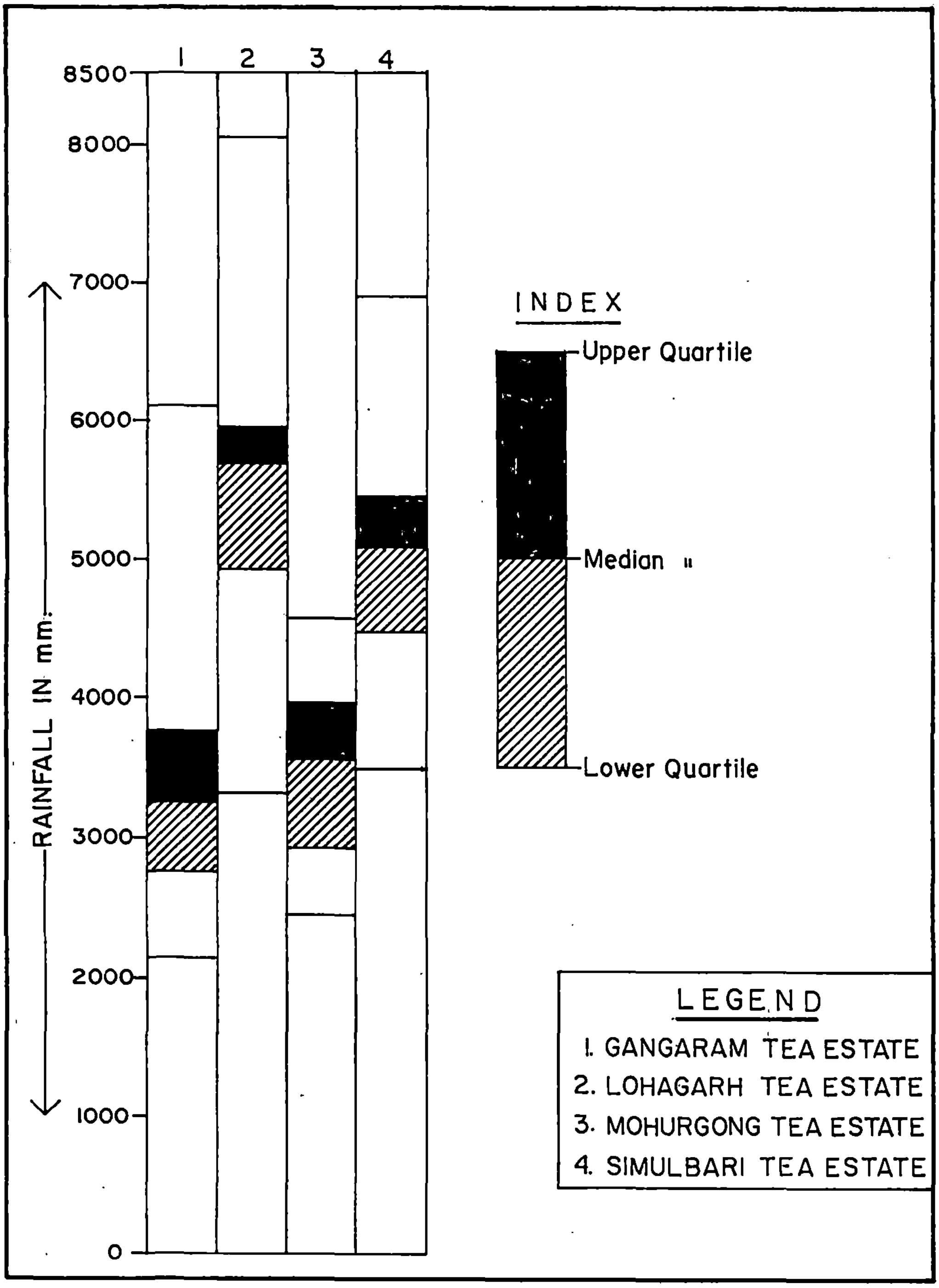



Fig. 3.7 : ANNUAL RAINFALL DISPERSION DIAGRAM
(PERIOD : 1977-98)

beginning of the change in meteorological conditions from April to May and also an indication of the start of the break of monsoon, which in fact commence in the mid June. These discontinuities may often represent differences between the two months in at least some of their meteorological conditions. For instance, a major discontinuity between May and June is indicative of the break of monsoon in the later month, whereas a similar break between June and July is indicative of the firm establishment of the monsoon in the latter month. The declining vigour of the monsoon in September is marked by another discontinuity between August and

**Table-3.7** : Elementary characteristics (annual) of rainfall of selected Meteorological stations (1977-1998).

| Meteorological stations | Absolute minimum (mm) | Lower quartile (mm) | Median (mm) | Upper quartile (mm) | Absolute maximum (mm) |
|---|---|---|---|---|---|
| Gangaram T. E. | 2142 | 2750 | 3250 | 3750 | 6096 |
| Lohagarh T. E. | 3332 | 4925 | 5675 | 5950 | 8048 |
| Mohurgong T.E | 2450 | 2925 | 3550 | 3950 | 4556 |
| Simulbari T. E. | 3506 | 4470 | 5075 | 5450 | 6911 |

September, and a major break between September and October in all the four stations indicates the final retreat of the monsoon in the later month.

The Fig.–3.7 is depicting that there is a great discontinuity of rainfall distribution (Table-3.7) as it goes from one rain gauge station to the other and thus the meteorological conditions over four stations are more or less unequal for the 22years period of record (1977-98)which again ordains the statement that the rainfall distribution over the Terai region of Darjiling district is not uniform because of its physiographic conditions.

## 3.4 SURFACE AND SUB-SURFACE RUNOFF CYCLE

Sub-surface runoff experiences some specific behaviour of flow either on the landsurface and in the sub-surface. When there is an input of precipitation on a catchment, a part of it returns back to the atmosphere in the process of evaporation and transpiration, whereas a part of the residual portion experiences a flow in the underground through infiltration depending upon the nature of the porosity and permeability of the ground surface which increases the groundwater table and maintains a sub-surface runoff. The amount of precipitation which can not escape the sub-surface partly returns back to the atmosphere or moves on the land surface as overland flow which may be collected in shallow depressions depending upon the slope and topographic forms, whereas a part of it ultimately flows into the channels from the lower order streams to the higher orders. The amounts of discharge, its flow pattern and fluctuations constitute the specific streamflow conditions of the channels at selected sites. The process of overland flow and the channel flow vary considerably from one catchment to the other and their hydrological behaviour constitutes an important aspect of the study area.

The surface and sub-surface runoff experience a cyclic phenomenon expressed as the respective runoff cycles, as like as the hydrological cycle. The nature of the runoff cycle can be assessed either for the whole catchment or sub-catchment or for any specific period or for the whole year which plays an important part of their system or sub-systems. During the dry season the cyclic trend of the water movement is characterised by no input of rainfall, though the sub-surface water table may maintain a very lean flow down the slope and is the only source of water supply to the drainage channels. Simultaneously with this flow there is a continuous evaporation from the ground surface through the capillary action and the reserve of the soil moisture coupled with transpiration from the vegetational surface. This process continues without any input and thus carpets the path of continuous depletion of sub-surface water reserves. Thus this cyclic process is rather an one way movement with no input till the occurrence of precipitation when at the initial stage much of the water may be evaporated, or percolate to the underground as infiltration. Overland flow may be smaller magnitude and the occurs in the channel runoff or sub-surface runoff. However the entire nature of hydrological behaviour and the surface and subsurface cycles will depend upon the quantity and duration of rainfall as influenced by nature of catchments. On the other hand, the wet monsoon period will be characterised with rapid inflow of water to the groundwater table and thus will cause recharging in the initial period followed by greater amount of overhead flow and channel flow. Simultaneously with the input, there will be evaporation and transpiration from the ground surface to the atmosphere. Thus a cycle of surface runoff will be set up. Similarly groundwater table will have sub-surface flow and will increases the channels. Therefore, the channel flow inspite of predominant influence of surface runoff will further experience augmentation due to sub-surface flow. Water table will rise up closer to the ground surface from its position during the dry season.

## 3.5 CATCHMENT AREA AND THEIR CHARACTERISTICS

The area from which a river collects surface runoff is known as catchment area. The hydrological behaviour of catchments which varies both under temporal and spatial conditions shows large amount of varieties, grouped under the climatic and catchment characteristics as follows :

**Climatic Characteristics** — (a) Precipitation, (b) Insolation, (c) Wind direction and velocity, (d) Evaporation, (e) Transpiration.

**Catchment characteristics** — (a) Size, (b) Shape, (c) Relief and slope, (d) Geographical structure, (e) Lithology and (f) Vegetation.

The basic input in the hydrologic cycle of the nature of precipitation, insolation, wind direction and velocity are received on the catchment surface and play important roles as the basic determinants of the hydrological behaviour of the catchment as influenced by the catchment characteristics.

The criterion of size obviously has varying cumulative effect in the surface runoff. The shape has a remarkably influences the relative time taken for the attainment of peak discharge and rate of travel of the floods. In comparison with funnel shaped and narrow funnel shaped to oval shaped or circular shaped basins, the later generally is characterised by a quicker flow and attainment of the peak discharge within a shorter time span and a gradual falling limb of the hydrograph. Relief with slope, geological structure, lithology and land use patterns are also the influential parameters for the nature of overland flow, rate of travel of the surface runoff and attainment of peak discharges.

In the hilly areas with conspicuous slope, the overland flow and channel flow are much quicker with greater amount of turbulent flow, whereas in gently sloping land it is more slower. The consideration of geological features, specially the lithology has the most dominant influence on the surface runoff, some being highly impervious which does not allow considerable amount of infiltration and thus facilitates a greater amount of overland flow and channel flow. The most important influences on the surface and sub-surface runoff cycles are the amount of infiltration and evaporation. While the rocky surfaces such as granite or gneiss will not allow adequate infiltration, the sandy and alluvium soils on the other hand will allow the process adequately.

The rate of infiltration of the study area vary with time for a few hours till the attainment of a steady rate on different types of ground surfaces. On barren land the infiltration rate will be very rapid within the first hour of the precipitation followed by little amount of it in the subsequent hours. On good grassland also, the infiltration of a substantial amount will take place rapidly within the first hour followed by little amount of it in the subsequent hours. In forest lands the rate will be slower and persists for a longer period.

## 3.6 HYDROLOGIC ATTRIBUTES OF RELIEF AND SLOPE

### a) Relief :

The relief is the study of the vertical elevation of the landscape of an area. Some of the concepts relating to relief pertain to the range in altitude (Smith, 1935), depth of dissection (Dury, 1966), difference in altitude between a 'Stream Surface' and 'Summit Surface' (Evans, 1972) and some such measures. The most important source of the relief assessment is the contour map, the closer the contour interval the greater the micro-details of relief. The contour form is the most significant clue to understanding of the relief. The measures of the relief properties in quantitative terms require some sophisticated methods of grid mesh analysis so that some of the areal attributes of relief in special dimensions are revealed which can also be subsequently studied for their distribution pattern,

## SLOPE ZONE
(Wentworths Method )

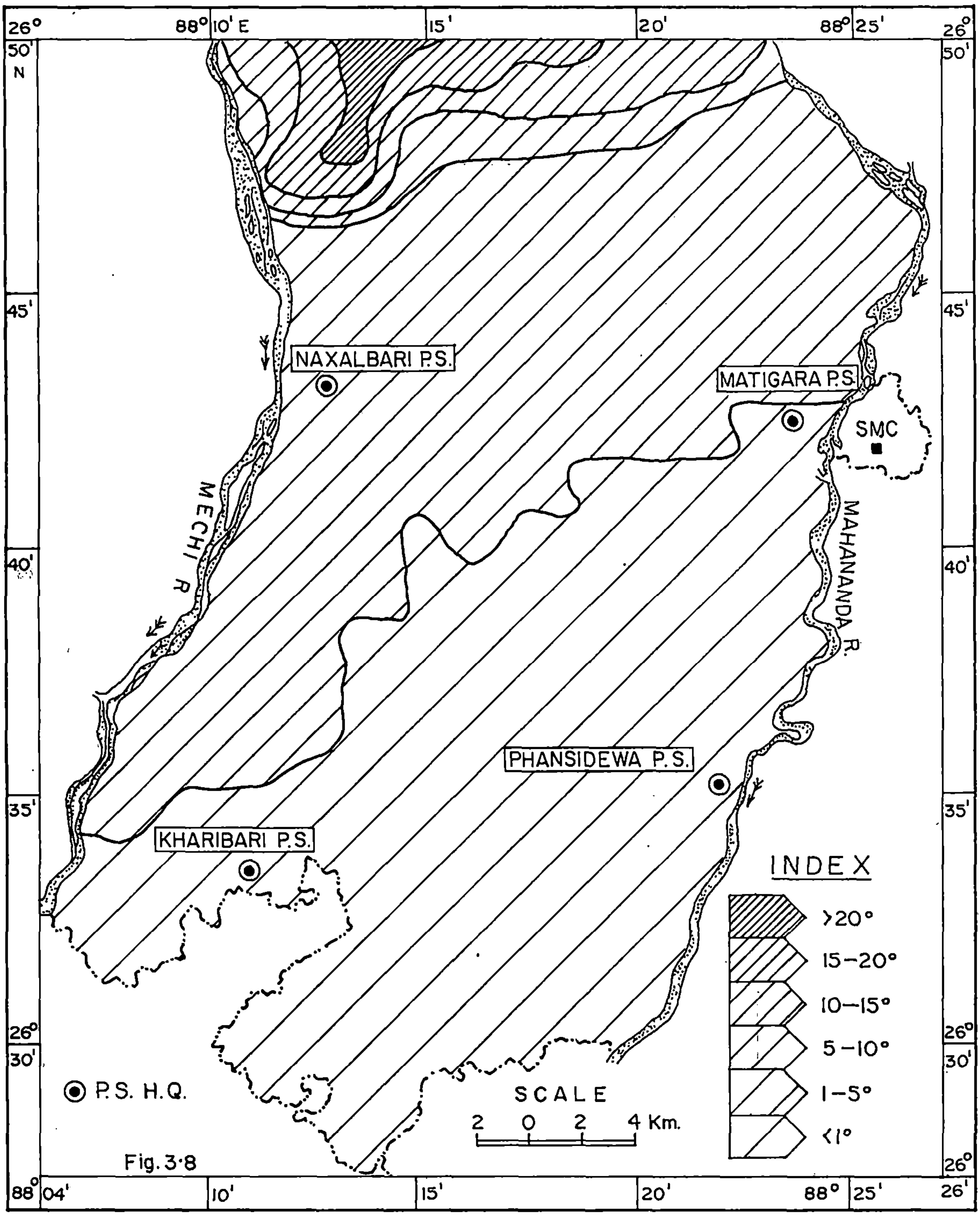



Fig. 3·8

detection of erosional surfaces and interrelationships of the different parameters and finally divisions into morphometric regions. In reality some of the attributes of relief are closely correlated with the slope and a gainful exercise of the slope of the study area is explained here.

**b) Slope :**

In modern geological sciences, slope is considered not only as an important object of landform but at the same time the basic features of landform analysis, an ecological site where the operation of the geomorphic, climatic and other physical forces maintain the slope in a stage of equilibrium. The entire processes operative through time, either unicyclic or polycyclic development, simultaneously with the structural features have in fact a very significant imprint on the forms of the slope. The study includes many aspects such as gradient, alignment, aspects and composite features. The techniques of slope measurements constitute rather the most cardinal aspect of the analysis. A slope is not only measured by the gradient over distance but also in areal studies, on its profile characteristics, composite characters and aspects.

In an areal study of slope analysis, the slope aspect is of crucial importance as some of the interesting phenomena of slope evolution are controlled by it, such as the insolation, rainfall, wind and other climatic elements, ecological conditions and alignment of drainage network. The slope profile shows the nature of gradient of ground surface along a particular line depicting the nature of slope of the surface. In the study of the drainage basins, there are two cardinal directions of slope, one along the river valley from source to mouth, conventionally known as the longitudinal profile of the river and the other along the lateral expanse of the valley generally at the right angles to the main direction of flow of the stream.

To determinate the average slope, the area can be divided into a network of grids. The smaller is the grid the greater is the precision confirming the actual distribution of the slope pattern (Wentworth, 1930). On the basis of the above mentioned method, a slope zone map of the Terai area of Mechi–Mahananda interfluve (Fig.-3.8) shows that the area can be broadly sub-divided into 6 zones having 5° intervals of which the minimum slope is 0° and maximum slope is recorded 23° at Panighata .

**Slope-zone I** : Very steep slope (above 20°) found in north-western corner of the Mechi-Mahananda and are at Belgachi, Udiarip, Kadma, Panighata and M.M.Terai tea garden.

**Slope-zone II** : Steep slope (15° - 20°) found in the northern and north-eastern part of the study area and at Bara Chenga, Nipania, Mir Jangla, Bir Sing and Dhemal of Naxalbari P.S. and Sukna Forest and Mohurgong Tea Garden of Matigara P.S.

**Slope-zone III** : Moderate slope (10° - 15°) have been identified along the northern part of the Mahananda river at Omi and Bara Bhita of Naxalbari P.S. and Patan, Chamta and Panchanai of Matigara P.S

**Slope-zone IV** : Low steep slope (5° - 10°) have been observed along the northern part of the study area and at Maha sing, Atal, Deomani of Naxalbari P.S. and Kalabari, Dhakuria and Nimai of Matigara P.S.

**Slope-zone V** : Very low steep slope (1° - 5°) have been identified in the middle part of the study area and at Bhim Ram, Mudir Jangal, Sat Bhaia and Dhakna of Naxalbari P.S., Matigara Hat, Dhakni Kata, Ujanu of Matigara P.S., Jiban Sing, Shyam Dhan and Bhulka of Kharibari P.S. and Ambari, Molani and Liusi Pukuri of Phansidewa P.S.

**Slope-zone VI** : Flat to gentle slopes (less than 1°) most extensive slope zone have been identified along the middle part and most of the southern part of the study area.

Thus it has been found that most of the northern part of the study area is characterised by steep to moderately steep slopes which is the indicator of the youthful stage and the middle and the southern part of the investigated area are characterised by low to flat slopes, which is the indicator of the mature stage.

## 3.7 DRAINAGE FEATURE AND THEIR VARIABLES

In the morphometric analysis of drainage basins, besides the areal and relief properties, the spacing, branching and lineaments of drainage network are of fundamental importance and no morphometric analysis can be complete without the morphometric analysis of the interrelated growth pattern of the drainage network. The pattern of the drainage network may be of infinite varieties representing the nature of structural and lithological adjustments of the running water and other geomorphological processes. The measure of spacing of drainage network is of fundamental importance for the assessment of closeness of the drainage network as it gives the measure of overland flow besides fluvial processes and forms developing of the catchment. Besides the immense academic interest of such studies, it is rather an initial step for the evaluation of the drainage basin.

The value of the drainage density, drainage texture and drainage frequency are the most common measures, each of them being distinctive and interrelated. Furthermore, some correlative idea can be gathered by finding out the mean spacing of the channels of different orders.

**a) Drainage Density** :

Drainage density is a function of the geologic structure and climatic characteristics (Ward, 1978) of the basin area. Therefore, in areas of identical relief, structure and climatic condition the variations of density is primarily influenced by the lithological variations. In the hard and resistant rocks, the density will be low where as in soft and easily erodible type of rocks, it will be high. The drainage density could be assessed for the entire basin or can also be assessed for a specified stream order where it will represent length of all channels above the specified stream order, per unit of drainage area (Langbein, 1947). High drainage density affects runoff pattern i.e., a high drainage density moves surface water rapidly decreasing the lag time and increasing the peak of hydrograph. The drainage density exhibits a wide range of volumes in nature and varies from 3 to 4 to as high as 1300 (Chorley, 1971). In areas having comparable rainfall pattern it is a function of permeability of the soil mantle. The sandy soils show the least volumes and the impermeable clays the highest.

## DRAINAGE DENSITY ZONE

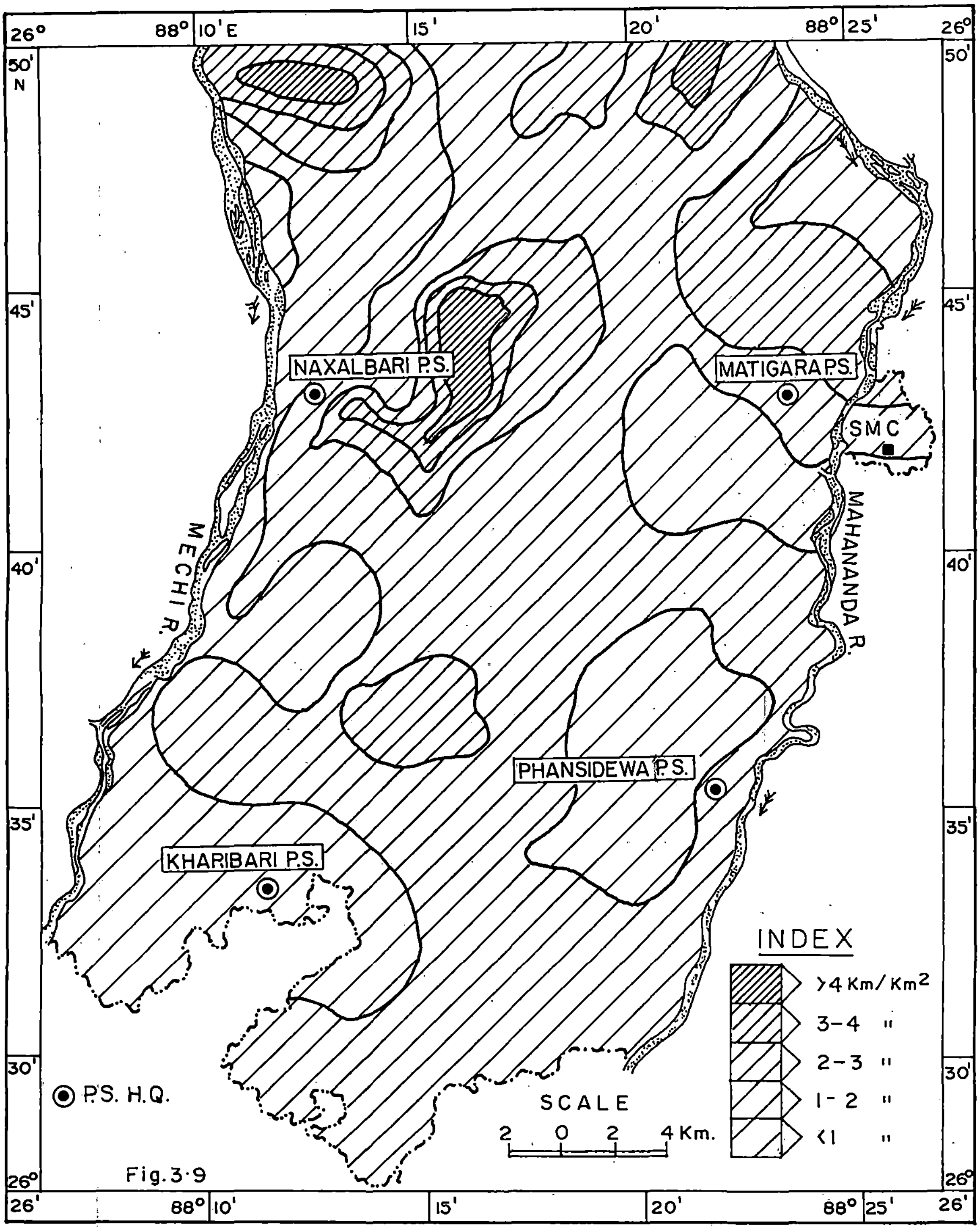



Fig. 3·9

It is apparent from the Fig.–3.9 that drainage density of the region varies from 0 km to >4 km/ $km^2$ and for a better understanding of the geographical distribution it has been classified into 5 (five) categories having 1 km/ $km^2$ interval of each type and have been put forward.

**Zone I** : Very high drainage density (more than 4 km/ $km^2$) are found in the N-E, N-W corner, middle of the eastern portion of the study area and at Lohagar Forest, Panighata and M.M. Terai Tea Garden of Naxalbari P.S., Mahananda Forest, Sukna Forest and Paharu of Matigara P.S., Budh sing, Rangali and Dhulia of Kharibari P.S. and Mahideb, Chaupukuria and Krishnapur Tea Garden of Phansidewa P.S.

**Zone II** : High drainage density (3 to 4 km/ $km^2$) are covered the northern part both on the east and west side, middle part of the study area and at Nipania, Belgachi and Kadma of Naxalbari P.S.; Khoklong, Chamta and Panchanai of Matigara P.S.; Katia, Bagha and Dohaguri of Kharibari P.S. and Jabarali, Singi Jhor and Halal of Phansidewa P.S.

**Zone III** : Moderate drainage density (2 to 3 km/ $km^2$) are observed on the extreme N-W and N-E corner as well as middle portion of the study area and at Kila Ram, Fakna and Naksal Bari of Naxalbari P.S; Dhakuria, Gouri and Ujanu of Matigara P.S.; Bhanjapur, Jagir and Munjaya of Kharibari P.S.

**Zone IV** : Low drainage density (1 to 2 km/ $km^2$) are found intensively on the middle part of the study area and at Chhota Ganja, Siubar and Suraj Bar of Naxalbari P.S.; Bairatisal, Gaurcharan of Matigara P.S.; Bhog Bhita , Sing Bhita and Badal Bhita of Kharibari P.S. and Barai Gachh, Antu Gachh and Rupan Dighi of Phansidewa P.S.

**Zone V** : Very low drainage density (less than 1 km/ $km^2$) are found most of the gentle slope area and are extensively observed all over the study area of the Terai region.

Finally the drainage density of the study area exposed a higher degree of consistency with the spread of other morphometric attributes and reflects the nature of variation in relief, soil, rock, vegetation etc. along with the changes of infiltration rate of different segments. It concerns mainly with the general extent, alignment and the frequency of streams.

# DRAINAGE FREQUENCY ZONE

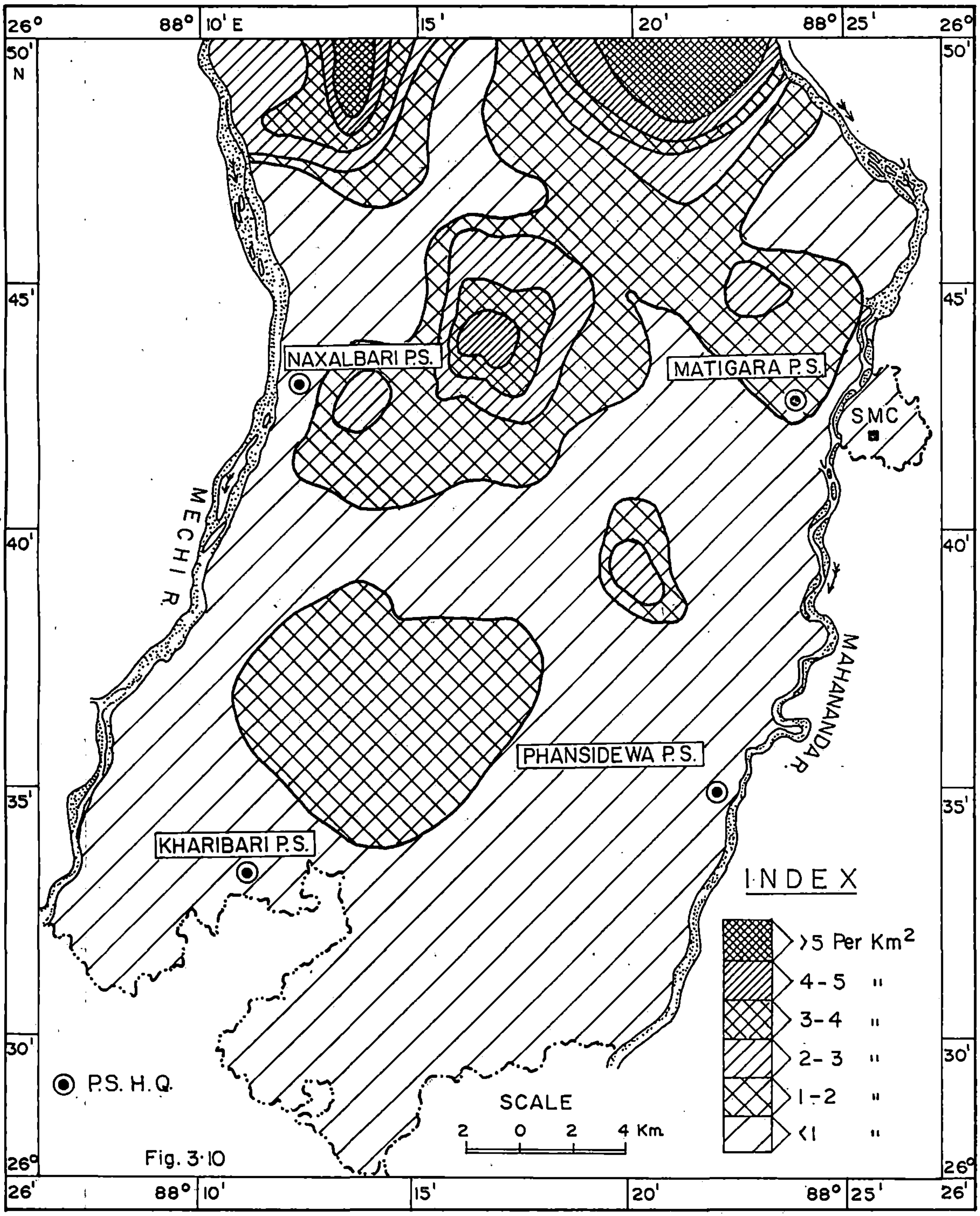



Fig. 3·10

**b) Drainage Texture :**

Drainage texture is a measure of the spacing of the drainage net work which is devised after Smith (1950). The drainage texture of the study area can be classified into four grades according to Smith, 1950.

| | Grades | Texture Ratio / Unit area |
|---|---|---|
| 1. | Super fine | > 25 |
| 2. | Fine | 10 – 25 |
| 3. | Medium | 4 – 10 |
| 4. | Coarse | < 4 |

Drainage density and drainage texture are obviously positively closely correlated with each other, the higher the density, the higher is the texture.

**c) Drainage Frequency :**

Drainage frequency is also another simple but useful measure of the drainage network. Equal drainage of two basins do not imply equal stream frequency and also vice-versa. Both of them are highly correlated with each other with high values of coefficient of correlation. A drainage frequency map has been drawn. (Fig.–3.10). The drainage frequency of the region varies from 0 to 8 per $km^2$ and for a better understanding of geographical distribution, it has been classified into 6 zones having 1 per $km^2$ interval of each type have been put forward.

**Zone I** : Very high drainage frequency (more than 5/ $km^2$) are found in the north-west and north-east corner of the study area and at Bara Chenga, Mara Pur and Panighata of Naxalbari P.S. and Champasari Forest, Maha Nadi Forest and Mohurgong Tea Garden of Matigara P.S.

**Zone II** : High drainage frequency (4 –5 / $km^2$) are also observed in N-W and N-E corner of the investigated area and at Manjha Tea Garden, Chhota Chenga and Kadma of Naxalbari P.S. and Paharu, Raj Pairi and Sisa bari of Matigara P.S.

**Zone III** : Moderately high drainage frequency (3–4 / $km^2$) are found in N-W and N-E corner as well as middle portion of the study area and at Mechi forest, Nipania, Bhelu, Min Ghara, Damdama, Atal and Lakshman of Naxalbari P.S. and Fulbari, Khopalashi, and Dhukuria of Matigara P.S.

**Zone IV** : Moderately low drainage frequency (2–3 / $km^2$) are found in N-W and N-E corner, middle part especially in east and west portion of the study area and at Amar Sing, Nimu, Sebdela, Jamindarguri and Panta Pari forest of Naxalbari P.S.; Sivok hill forest, Sivok forest, Sitong forest and Malahar of Matigara P.S. and Tar Bandha, Radha and Nirmmal of Phansidewa P.S

**Zone V** : Low drainage frequency (1–2 / $km^2$) are observed extensively all over the study area, especially at N-E, N-W, eastern, western, and south-western portion of the interfluvial region.

**Zone VI** : Very low drainage frequency (less than 1 / $km^2$) are observed in western, south-eastern and north-eastern corner of the investigated area and at Naxalbari, Bhim Ram and Sat Bhaia of Naxalbari P.S.; Tomba, Matigara Hat and Dakni Kata of Matigara P.S.; Tari, Gadhira and Jagir of Kharibari P.S. and Rupan Dighi, Bansgaon Paschim and Paschim Madati of Phansidewa P.S.

## CONCLUSION

The foregoing analysis in this chapter reveals that the groundwater hydrology in the terai region is principally governed by the precipitation and its characteristic features, magnitude of relief and slope of the morphological parameters and drainage features and their variables. The statistical analysis of 22 years of rainfall data has shown that the rainfall is of monsoon type and is concentrated within the four month period of June to September in the year, which accounts for about 80% of the total annual rainfall. The long term average annual rainfall is recorded about 3968 mm which is adequate and the second highest rainfall in India.

The recharge to groundwater body is chiefly through rainwater by the return seepage of irrigation water and downward percolation of stream runoff are also the sources of groundwater supply, tapped through a number of different types of wells. This percolation system of water mainly depends upon a number of hydrogeologic properties of rock formations which have been discussed in the following Chapter.