# DESIGN STORM STUDY OVER THE DHAULIGANGA CATCHMENT UPTO TAPOVAN VISHNUGAD, UTTARANCHAL, INDIA

A Report Submitted to :

**National Thermal Power Corporation (NTPC) Ltd.
Corporate Centre, Noida**

By

B.N. Mandal, N.R. Deshpande, B.D. Kulkarni,
S.S. Nandargi, R.B. Sangam, S.S. Mulye and J.S. Pethkar



**Indian Institute of Tropical Meteorology**
**Dr.Homi Bhabha Road, Pashan Pune - 411 008**

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Dhauliganga - side view from 5050m

| ***Content*** | | ***Page*** |
|---|---|---|

# DESIGN STORM STUDY OVER THE DHAULIGANGA CATCHMENT UPTO TAPOVAN VISHNUGAD, UTTARANCHAL, INDIA

## 1. Introduction :

For all round developments of any region, knowledge of rainfall climatology is most essential. It is more so in the case of mountainous region like the Uttaranchal Himalayan region where such knowledge can be made use of for the planning and design of dams, drinking water tanks for villages in the interior of hilly terrain, barrages for generation of hydropower by storing surface runoff generated from rainfall. Besides, a knowledge about space time distribution of rainfall is useful for agricultural operations and hydro-electric power projects over hilly terrain where irrigation through a network of canals is not feasible as in plains. Moreover, knowledge of maximum rainfall is also required for the design of dams and drinking water tanks for villages in the interior of hilly terrain.

In view of the above, a number of water resources projects in this region have already been completed, like a) the Ichari dam on the Tons river, b) the Maneri Bhali and the Tehri dams on the Bhagirathi river, c) the Lakhwar dam on the Yamuna river, d) the Chuka dam on the Sharda river and e) the Kalagarh dam on the Ramganga river (Dhar et. al 1984).

At the request of the National Thermal Power Corporation (NTPC) Ltd., Noida, design storm study has been carried out over the Dhauliganga catchment upto Tapovan Vishnugad Hydro Electric Project having a catchment area of 3100 $km^2$. The Standard Project Storms (SPS) and Probable Maximum rainfall (PMP) and their time distribution have been worked out by hydrometeorological method.

## 2. Tapovan Vishnugad Hydro Electric Project :

Tapovan Vishnugad Hydro Electric Project is a run of the river scheme across the river Dhauliganga in the Alaknanda Valley in the Chamoli district. The project envisages to utilize a 518m drop available in the river Dhauliganga. The scheme involves construction of barrage with 4.80 m diameter on the river Dhauliganga near village Tapovan. 11.65 km long HRT and underground power house. The installed capacity of the project is 360 MW (3 x 120 MW) with a designed discharge of 90 cusecs which is available from middle of June to 10 September during 90 % dependable year (NTPC, 2003).

The geo-coordinates of proposed location of Tapovan Vishugad barrage site is at about Lat. 30° 29' 30"N and Long. 79° 37' 30"E in Joshimath Tehsil. Source of water supply is the Dhauliganga river which is an important tributary of the Alaknanda. Gross area of the catchment upto Tapovan is 3100 $km^2$ and snow bound area is 1900 $km^2$ (NTPC, 2003).

## 3. Physiographic features in and around the study region :

As stated above, the catchment under study falls in the Chamoli district of Uttaranchal state. The catchment is surrounded by Uttarkashi in the north-west, Tehri Garhwal in west, Pithoragarh, Nainital and Rudraprayag in south-west and Almora in southeast. To the northeastern side of the catchment, there are Nepal Himalayan ranges. This region contains within its limits lofty snowbound peaks of the outer Himalayas where, in the glaciers, the Alaknanda and its tributaries take their origin. The terrain is marked with deep and narrow valleys and steep and high ridges, whose general slope is towards the south or southwest. The land slopes down towards the south, where, in the valleys elevation at places comes down to about 1200m. Fig.1 shows the Dhauliganga catchment and topographical features along with some important stations in and around the catchment. It is seen from this figure that elevation over the catchment varies from about 2500m to 6500m a.s.l.

## 4. The Dhauliganga River Profile :

The Dhauliganga river rises from the Nitti Pass in outer Himalayan ranges at a height of about 5070 m. Its valley lies between the Kamet groups of peaks in the west and the Nandadevi group in the east. The Dhauliganga takes a northern course at Malari. Between Malari and Tapovan, it is almost a narrow gorge with perpendicular cliffs on either side, several thousand meters high. The Dhauliganga in its turn is fed by the Girthi Ganga at Kurkuti and the Rishiganga 500 m below Reni. The Dhauliganga is an important tributary of the Alaknanda.

## 5. Climatological features :

Depending upon the climatic conditions prevailing in and over the study region, the Dhauliganga catchment experiences the following four seasons :-

| | | |
|---|---|---|
| (i) | The Winter Season | - December to March, |
| (ii) | The Summer or Pre-monsoon | - April to May, |
| (iii) | The Southwest monsoon | - June to September and |
| (iv) | The Post monsoon | - October to November |

As the region under study is in a highly mountainous, the climate, therefore, depends very largely on topographic features. As most of the region is situated on the southern slopes of the outer Himalayas, monsoon current can penetrate through the trenched valleys and rainfall is found to be maximum in the monsoon months from June to September.

Analysis of long period rainfall data has shown that southwest monsoon is the principal rainy season. Normally, the Bay of Bengal branch of the monsoon current strikes the Uttaranchal Himalayas towards the end of June (see Fig. 2a). The monsoon normally starts withdrawing from the region towards the end of last week of September (see Fig. 2b). As the onset of monsoon over this region can be early or delayed by a week or ten days from normal date, similarly the withdrawal of monsoon can also be early or delayed.

Severe winter is the chief climatic feature of the Dhauliganga catchment. It lasts from December to March. The temperature begins to fall from October. January is the coldest month during which the mean minimum temperature is of the order of 2°C at 2 kms, -12°C at 6 kms in the northern altitudes. The occurrence of cold waves in the rear of western disturbances may cause temperature to fall appreciably during the winter season. After this the temperature begin to rise till June or July. The mean maximum temperature during warmest month is of the order of 27°C at stations 2 kms high, 15° to 18°C at 3 kms and lower temperature at higher stations. As for example, the temperature at Lokpal, a station located at about 6 kms a.s.l. is of the order of 9°C (IMD, 1989).

The relative humidity is high during the monsoon season generally exceeding 70% of the average. The driest part of the year is the pre-monsoon period, when humidity may become as low as 35% during the afternoons. During winter months humidity increases towards the afternoon at some high stations.

Owing to the nature of the terrain, local effects are pronounced and when the general prevailing winds are not too strong to mask these effects, there is a tendency for diurnal reversal of winds, blowing up the slopes during the day (anabatic flow) and down the slopes at night (katabatic flow). Katabatic wind can blow with considerable force.

According to Mani (1979) the climate of Indian Himalayas is governed by the extra tropical weather systems of Asia, which during winter moves from west to east bringing rains in western Himalayas and during summer from east to west causing monsoon rains in eastern and central Himalayas including Uttaranchal Himalayas. During summer months the sub-tropical high pressure of central Asia weakens, causing a rise in temperature and consequently the southern slopes of mountains ranges receive greater solar radiation. On the other hand the northern slopes of Himalayan ranges get more snow accumulation and glacier action. According to Purohit (1977) the distribution of rainfall in the Garhwal Himalayas is mainly governed by altitude. Similarly, in the Himalayas, rainfall varies considerably with altitude, height and windward or leeward sides of high ridge from place to place.

## 5.1 Meteorological situations responsible for causing heavy rainfall :

During the monsoon season heavy rainfall in and around the study region were found to occur in association with the following weather situations :

a) Passage of low pressure / depressions and or cyclonic storms from the head Bay of Bengal over and near this region. These disturbances, after originating from the head Bay of Bengal, move in a northwesterly direction. As the monsoon advances, some of these disturbances after reaching west Madhya Pradesh, south Rajasthan and neighbourhood, recurve and move in a northerly to northeasterly direction and strike the Garhwal Himalayas causing exceptionally heavy falls of rain. In some years depressions from the Arabian sea after crossing the south Gujarat, north Maharashtra coasts strike the Garhwal region after their passage through Rajasthan and other neighbouring states.

b) When the axis of the monsoon trough shifts from its normal position to the foothills of the Himalayas it is called "break" monsoon situations. Due to this shift of the monsoon trough axis to the foot-hills of the Himalayas, rainfall activity decreases considerably over most parts of India but it increases over the Himalayan region causing floods in the Himalayan rivers. Break situations mostly occur during the monsoon months of July and August and occasionally in September.

c) Over northwest India, particularly in the months of August and September, heavy to very heavy rain falls occur in association with low level easterly systems and upper level westerly systems. This is more so when the low level easterly systems are in phase and are overlain by upper level westerly systems. When a westerly trough aloft moves slowly across northwest India or remain stationary for 2 to 3 days and if there is a low level easterly system, then because of interaction of these two systems heavy to very heavy falls occur over northwest India which cause floods (Desai et al, 1996).

d) Winter precipitation occurs in association with the extra tropical disturbances known as "Western Disturbances". On an average, 3 to 5 disturbances move during the winter season.

e) Rainfall occurs during the pre-monsoon season in association with thunderstorms which are caused either due to local convective activity or due to the passage of Western Disturbances.

f) The phenomenon of cloud burst is common in the mountainous regions. The term 'cloud burst' is used for very intense rainfall generated from cumulonimbus or thunder clouds (Upadhyay, 1995) usually occurring in mountainous regions.

In the past, the flood due to cloud burst of 1894 was the most severe in the Alaknanda valley in the Uttaranchal Himalayas that wiped out several localities along the river channel (Country Study Report, 2002). The then largest town Srinangar in the valley was completely wiped out, as it was situated just on the riverbank. The flood of 1970 in the Alaknanda valley is considered second major disaster. Two steel girder bridges, a number of suspension bridges were washed away, nearly 15 km of the Rishikesh-Joshimath-Malari road had been breached and Chamoli town disconnected from Joshimath. In general, the water level in Alaknanda rose by 10 m to 40 m between Joshimath and Srinagar depending upon the width of the stream (Country Study Report, 2002).

g) The post monsoon season by and large is comparatively a period of dry weather both in the hilly and plain areas.

## 6. Rainfall data used :

For planning and design of water and hydropower projects, a good network of rainfall stations having long period records in and near the problem catchment forms a basic tool. As per information given by the Govt. of Uttar Pradesh, Irrigation Department in their Report on Tapovan Vishugad Hydel Scheme, Vol.-II, prepared by Multipurpose and Hydro-Electric Project Organization Investigation and Planning Wing, Dehradun, (1992), there are 7 raingauge stations in the Dhauliganga catchment up to Tapovan barrage site and they are : Gamsali, Malari, Jelem, Markura, Lata, Reni and Tapovan from 1977. However, except Tapovan station's daily rainfall data for a period of 8 years (1951-1958), no other stations' daily rainfall records are available with the National Data Centre (NDC), IMD, Pune.

Attempts were therefore made to procure the daily rainfall data for the above stations from the concerned state rainfall authorities through the project authorities. Project authorities have supplied rainfall data of the above stations for few selected years. After critically examining the rainfall data at these stations it was found that the quality of rainfall data is not good as there are many missing records and lot of inconsistency in the data sets. As such the data supplied by the project authorities have not been used in the present report. In the Chapter on "Hydrology-Estimation of Design Flood " prepared by the Irrigation Design Organization, Roorkee, June,1992, it is stated that though there are seven raingauge stations in the Dhauliganga catchment upto Tapovan, but no reliable data are available for these stations.

In the absence of reliable rainfall data for stations within the catchment, daily rainfall data of about 73 stations from the surrounding region of the catchment under study have been obtained from the NDC, IMD, Pune for available period starting from 1901 for the analysis. Catalogue of rainfall stations whose daily data have been used in this report is given in Tables-1 & 2. It is, however, seen that out of 73 stations, 59 stations (see Fig. 3) are having relatively long period data and rest are having short period data with many missing records. Hourly rainfall data for 5 SRRG stations from the nearby region for the period as given against each of the SRRG stations (Table 3) have also been obtained for time distribution analysis.

However, it is to be mentioned here that the Dhauliganga catchment receives considerable amounts of snowfall, especially during the winter months. The hydrologic implications for flood due to snow are very complex and in the absence of proper snow recording stations data it is rather difficult to evaluate the snowmelt contribution to runoff. As such rainfall data has been used in this report to work out Standard Project Storms (SPS) and Probable Maximum rainfall (PMP).

## 7. Objectives :

In the present report, the design storm study have been carried out over the Dhauliganga catchment upto Tapovan Vishnugad site with the following objectives:-

(i) To analyse all severe rainstorms which affected the catchment on the basis of all the available long period rainfall stations around the catchment,

(ii) To estimate 1-day and 2-day Standard Project Storms (SPS) and Probable Maximum rainfall (PMP) raindepths and

(iii) To obtain the time distribution of design storm raindepths for 24-hour and 48-hour durations.

## 8. Rainfall distribution over and around the catchment :

Knowledge of rainfall distribution during individual months, seasons and the year as a whole is of vital importance for planning water resources projects and agricultural operations etc. over any region. Mean rainfall over a catchment during individual months, seasons and the year as a whole is of vital importance to determine the net availability of water that runs off into river. The raingauge network in the Himalayan region is very sparse due to difficult terrain and inaccessible areas. It, therefore, becomes an impossible task to make a correct estimation of rainfall distribution in any hilly catchment. In the absence of reliable rainfall data for stations inside the catchment, rainfall data for 73 stations for available period (see Tables 1 &2) from the surrounding region have, therefore, been used to estimate the mean rainfall characteristics over the catchment. In addition, available information from the published papers on rainfall distribution in the Himalayan region in general and with particular reference to the Garhwal Himalayan region; Hill (1881), Dhar (1962), Dhar and Bhattacharya (1976), Dhar et. al, (1981,1984, 1986,1987, 1994,2000) have been critically examined and information collected from such publications were also considered during the analysis. Though the rainfall data supplied by the project authorities have not been used in this report, broad mean annual and seasonal features of those stations have been taken into account while drawing isohyetal patterns of annual and seasonal rainfall maps.

With the help of available observed daily rainfall data, information from published papers as mentioned above, mean annual and seasonal rainfall maps over the Dhauliganga catchment upto Tapovan have been prepared. Figs. 4 and 5 show isohyetal patterns of the mean annual and the southwest monsoon (June to September) rainfall over the catchment. It may, however be mentioned that as stated earlier, there are no reliable stations inside the catchment, hence these patterns may need to be revised when long period rainfall data for stations inside the catchment becomes available. From Fig. 4 it is seen that the mean annual rainfall over the catchment broadly ranges from about 150 to to less than 50 cm.

Near the catchment, only Joshimath station has the longest rainfall records for about 86 years (see Table 1) and its long term mean annual rainfall is of the order of 92 cm while at Tapovan based on 8 years data mean annual rainfall is found to be of the order of about 76cm. Okhimath station located south of the great Himalayas marks maximum mean annual rainfall of the order of 186cm while at further higher elevation Lokpal recorded mean annual rainfall of 179 cm (based on 19 years data).

From Fig. 5 it is seen that mean monsoon rainfall over the catchment varies from about 100 to less than 45 cm. Joshimath and Tapovan have mean monsoon rainfall of 53 cm and 46 cm respectively. Mean monsoon rainfall at Okhimath and Lokpal were found to be 147 cm and 105 cm. Badrinath station's data has not been used in this report as the data were available only for few months period with lot of inconsistency in the data.

Mean monsoon,winter and annual rainfall at selected stations are given in Table 4 in order to know the rainfall characteristics features around the catchment. It is seen from this table that mean monsoon rainfall at these stations were 51 to 79 % of their respective mean annual rainfall. Mean annual and seasonal rainfall over the catchment as a whole have also been estimated by Depth-Duration (DD) method and the same are given in Table 4.

It is seen from Table 4 that the Dhauliganga catchment receives mean annual rainfall of the order of 94 cm while during monsoon and winter seasons the catchment receives about 63 cm and 20 cm of rainfall which are about 67% and 22% of the annual total respectively.

## 9. Highest observed point rainfall for 1 and 2-day durations :

Information on the magnitudes of maximum observed point rainfall of different durations is necessary for the adequate design of flood plain structures and for making management decisions about flood-plain land use etc. The highest ever recorded rainfall values for 1 and 2-day durations were picked up from the rainfall data for stations used in this report. Based on the highest rainfall, the isohyetal patterns of highest 1 and 2-day rainfall in around the catchment were prepared and the same are shown in Figs. 6 & 7. It is seen from Fig.6 that the highest 1-day point rainfall over the catchment varies from about 20 cm to 5 cm and from 30 to 10 cm for 2-day duration (Fig.7) respectively.

Highest ever recorded 1-day and 2-day rainfall at a few selected stations around the catchment along with their estimates of 1-day and 2-day PMP by statistical method are given in Table-5. From this table it is seen that the highest ever recorded rainfall at these stations varies from about 10 cm to 35 cm in 1-day while for 2-day it ranges from about 16 cm to 50 cm.

It may however be mentioned here that prior to 1901 there were few stations over the foothills of the study region which have recorded very heavy rainfall. Table-6 gives the catalogue of those rainfall amounts. It is seen that few stations in the Bijnor district recorded very heavy rainfall during 17-18 September, 1880 rainstorm caused due to the passage of a Bay depression (IITM, 1994). The centre of the storm was at Nagina station which recorded 82 cm of rainfall on 18 September.

## 10. Design Storm Analysis :

A design storm over a catchment is an estimate of maximum average depth of rainfall which is used for working out the spillway design flood. Design storms in common use are the Standard Project Storms (SPS) and Probable Maximum Precipitation (PMP). SPS is the most severe rainstorm which has actually occurred over a meteorologically homogeneous region over and near the catchment during the period of available records. The PMP is defined as, theoretically the greatest depth of rainfall for a given duration that is physically possible over a given size of area at a particular geographical location and at a certain time of the year (WMO 332-1986). The PMP is used where the failure of structure will lead to significant economic loss or loss of life. There are different methods for the estimation of design storms over a catchment which include Depth-Area-Duration (DAD) and Depth-Duration (DD) methods of rainstorm analysis. These methods are described in detail in WMO (1969), standard text books on Hydrometeorology like Wiesner (1970), etc. However a brief mention of these methods is made in the following section :-

### (a) Rainstorm analysis by Depth-Area-Duration (DAD) method :

In this method considering the rainstorm as a unit of study, all the selected severe rainstorms that have occurred in and around the catchment are analysed for different durations. As the name implies, the maximum raindepths of all rainstorms are then picked up from the DAD curves for standard areas and durations. DAD analysis is, however, not applicable for estimation of design rainfall over catchments in highly mountainous regions like the present one and as such this method has not been used in this report.

**(b) Rainstorm analysis by Depth-Duration (DD) method :**

In this method the catchment is considered as a unit of study. All the severe rainstorms that have occurred over and near the catchment are analysed for different durations. Maximum rain depths thus obtained for different durations are plotted as DD curves and highest rain depths are determined from the envelope curves. This method is the most suitable one for estimation of design rain depths over catchments in mountainous regions.

As the Dhauliganga catchment is located in highly hilly terrain, DD method of rainstorm analysis has been used for the design storm estimation.

## 10.1 Estimation of SPS by DD method :

The critical examination of all the available daily rainfall data of stations near the Dhauliganga catchment shown that there were 6 heavy rain spells affected the catchment (see Table 7). It was seen that due to hilly region, rainspells were mostly of 2-day duration.

Heavy rainfall recorded during each storm at each of the stations nearby the catchment were plotted on base maps of 1" = 16 miles and isohyetal maps were prepared for 1 and 2-day durations. From these isohyetal maps, raindepths over the catchment for each of the selected heavy rainspells were worked out by DD method. These raindepths were then plotted against durations as DD curves (Fig.8) and envelope raindepths over the catchment were then picked up from the DD curves and the same are given in Table 8.

It is seen from Table-8 that the envelope raindepths of 11.3 cm and 19.8 cm in 1 and 2-day respectively were contributed by the 27-28 September, 1924 rainstorm over the catchment. These raindepths are, therefore, called as the Standard Project Storms (SPS) raindepths over the catchment. These SPS raindepths are then maximized to obtain PMP raindepths. Figs 9 and 10 show the isohyetal patterns of September, 1924 for maximum 1-day (28 Sept.) and 2-day (27-28 Sept.) over the catchment. Figs.11 and 12 show the isohyetal patterns of 28 Sept. and 27-28 Sept.,1924 rainstorm over and near the catchment.

As the Sept.,1924 rainstorm contributed SPS raindepths, meteorological causes and flood damage due to this rainstorm has also been examined and a brief account of the same is given below :-

### *10.1.1 Synoptic situations which caused heavy rainfall during the Rainstorm of 27 -28 Sept. 1924 :*

Heavy rainfall over the Ganga and the Yamuna basins and surrounding region occurred in association with passage of a Bay depression which formed near Lat. 8°30'N, Long. 88°30'E in the Andaman sea on the morning of 23rd September and passed through Maharashtra on 27th. Thereafter, the track of the depression became northnorthwesterly and then northwards. It subsequently curved to northeast and disappeared over the Simla-Kumaon hills on 30th Sept. after causing exceptionally heavy and continuous rain there as well as over the adjacent plains from 27-29 September. Track of the Sept., 1924 depression is shown in Fig.13. According to the Annual Summary for 1924 published by the India Meteorological Department (IMD), exceptionally heavy and continuous rain occurred in the Simla-Kumaon hills because the line of advance of the depression was practically perpendicular to the line of the Himalayas and the humid southerly current in the eastern semi-circle of the depression fed both from the Bay of Bengal and the Arabian Sea, was being continuously forced up against the same part of the Himalayas namely the Simla- Kumaon hills (Ramaswamy, 1987).

### *10.1.2 Flood damage associated with the above rainstorm :*

The abnormally heavy and continuous rain in association with the Sept., 1924 depression caused catastrophic floods in the Upper Ganga and the Yamuna in October,1924, which resulted in very widespread and serious damage in Uttar Pradesh and Punjab (undivided). According to the official reports, areas covering roughly about 14,245 sq.kms were badly affected. About 242,400 houses were washed away and 1100 persons, 1 lakh cattle head, were drowned (Ramaswamy, 1987). Besides, considerable damage was done to canals and bridges in Saharanpur and Dehradun districts, to channels and tributaries in Garhwal and to railways and other communications in several divisions. The damage to communications in the Kumaon division was estimated to be more than 15 lakhs of rupees. At Nainital, the landslide of the Charta Hill caused a damage of about 1 lakh of rupees to the Govt. buildings.

## 11. PMP by storm maximization of envelope DD raindepths :

In evaluating PMP by the above method, the envelope raindepths obtained from DD analysis of severe rainspells over the catchment are maximized with appropriate moisture maximization factor (MMF). The MMF is a ratio of the highest amount of moisture observed over the catchment during the month (based on long period data) when the rainstorm occurred to that observed during the rainstorm period. The moisture in a vertical column of air from which heavy rainfall occurs is considered to be a function of the surface dew points decreasing with height at the saturated pseudo-adiabatic lapse rate. Storm dew points data for selected stations have been collected from the Archives of IMD, Pune while the highest ever-recorded dew points were taken from the IMD publication by Lal et al, 2000. The moisture maximization factor (MMF) for the Sept.1924 severe rainstorm has been worked and the same is given in Table 8. It was found that MMF for the most severe rainstorm of Sept., 1924 is 1.40.

Using this MMF factor, estimates of PMP raindepths have been obtained over the catchment for maximum 1 and 2-day by adjusting the envelope raindepths (SPS) and the same are given Table 8. It is seen from this table that the estimates of PMP by physical method over the catchment were 15.8 cm and 27.7 cm in 1 and 2-day durations respectively.

## 12. Estimation of PMP by statistical method :

In this method design storm estimates are derived by the analysis of annual maximum rainfall series of the catchment under study. World Meteorological Organization (WMO 1969, 1986) has recommended Hershfield (1961) statistical technique for the estimation of PMP/ extreme point rainfall. The detailed description of the method is available in WMO manual for estimation of PMP (WMO, 1986). According to Wiesner (1970) this method takes into account the actual data, expressing it in terms of statistical parameters and easy to use.

The Hershfield statistical technique for estimating point PMP for a station is as follows:

$$X_{PMP} = \overline{X}_n + S_n \cdot K_m \qquad \text{--- (1)}$$

where,
- $X_{PMP}$ = the extreme rainfall for a station,
- $\overline{X}_n$ = mean of the annual maximum series,
- $S_n$ = standard deviation of the annual maximum series, and
- $K_m$ = frequency factor which depends upon the number of years of data and the return period.

According to Hershfield (1961), the values of the frequency factor '$K_m$' is obtained by using the following equation :

$$K_m = (X_1 - \overline{X}_{n-1}) / S_{n-1} \qquad \text{--- (2)}$$

where, $X_1$ = largest value of the annual maximum series,

$\overline{X}_{n-1}$ = mean of the annual maximum series omitting the largest value from the series, and

$S_{n-1}$ = standard deviation of the annual maximum series omitting the largest value from the series.

From this, an envelope value of the frequency factor ($K_m$) was determined. Using this factor, PMP estimates of individual stations are computed by using Eqn. (1). The PMP estimates thus obtained for different durations are then plotted on a large scale base map of the catchment and generalized PMP charts were prepared for 1 and 2-day durations.

Fig.14 shows the spatial patterns of the generalized PMP for 1-day duration over and near the catchment. It is seen that 1-day PMP over and near the region can range from greater than 30 cm to about 10 cm while in 2-day duration (Fig. 15) it may be of the order of 60 cm to 20 cm. In Table-5 statistical PMP for 1 and 2-day durations at some selected stations near the catchment are given.

In order to estimate areal PMP raindepths over the catchment as a whole, isohyetal maps of 1 and 2-day were subjected to DD analysis and PMP raindepths were worked out and the same are given in Table 8. It is seen from this table that PMP by statistical method over the catchment were 19.0 cm and 29.5 cm in 1 and 2-day durations respectively.

It is also seen from Table 8 that estimates of PMP by physical method and statistical methods are in close agreement to each other. It, may however, be mentioned here that many stations which have been used in the preparation of generalized PMP maps have short data period (i.e. < 30 years), the above PMP estimates may be considered as the tentative. These estimates are subjective to revise as and when more rainfall data becomes available in the study region.

## 13. Time distribution analysis of design storm rainfall for design flood :

Design flood is that flood discharge the structure to be designed can safely pass. The criteria for design flood varies according to the importance of the structure. One of the most important factors affecting the peak discharge is the variability of rainfall in time. If it is spread uniformly over a period of say 24 hours, the peak rate will be much less than the same rain occurs during 2 to 3 hours of 24-hour period. It is, therefore, essential to know what proportion of 24-hour rain usually does occur in different hours. It is also essential to know whether this proportion varies with the magnitude of 24-hour rainfall. For knowing this 1-day, 2-day design storm rain depths are required to break up into depths of smaller intervals of say 1, 3, 6, 9,----- etc. hours, called unit intervals.

As stated earlier, there are no SRRG stations inside the Bhagirathi catchment whose hourly rainfall data are available. Time distribution analysis was, therefore,carried out on the basis of hourly rainfall data of nearest available stations, viz. Dehradun, Uttarkashi, Tehri, Mukhim and Mussoorie. Heavy rain spells were selected on the basis of heaviest rainfall received by each of these stations using a criteria that each rainspell has received ≥ 10% of its seasonal rainfall within a rainspell. For all selected rain spells, hourly rainfall distribution for maximum 1, 3, 6, 9, 12, ----, 24-hour and 48-hour have been estimated and based on that average time distribution during different hours for each of the stations have been worked out separately. These average time distribution for each of the stations were then plotted and envelope time distribution curves are then drawn for maximum 24-hour and 48-hour and the same are shown in Fig.15. Hourly break up for different short intervals are given in Table-9 and design storm rain depths of shorter durations can be obtained by using the average time distribution given in Table-9.

## Summary and conclusions :

The Dhauliganga catchment is situated on the southern slopes of the outer Himalayas at altitudes ranging from about 2500 m to 6500 m. The catchment region is highly mountainous and there are no reliable raingauge stations inside the catchment. As such daily rainfall data of stations from the surrounding region for their available records have been used for the estimation of SPS and PMP rain depths. The analysis of daily rainfall data revealed that the mean annual rainfall over the catchment varies from about 150cm to less than 50cm and the seasonal rainfall (June to September) varies from about 100 cm to less than 45cm. The highest 1-day rainfall recorded by some of the stations near the catchment were found to vary from about 10 cm to 35 cm.

By considering the orography of this region, Depth-Duration (DD) analysis using long period rainfall data over and around the catchment is the most suitable technique applicable to this region. SPS rain depths of 11.3 cm and 19.8 cm in 1 and 2-day thus obtained from the DD analysis have been used to estimate PMP raindepths. PMP raindepths obtained by physical method by adjusting the SPS values with the MMF of 1.4 are 15.8 cm and 27.7 cm in 1 and 2-day durations respectively. PMP raindepths were also estimated by statistical method and found to be 19.0 cm for 1-day and 29.5 cm for 2-day durations. Design storm rain depths for shorter intervals can be estimated by using the average time distribution given in this report.

It may, however, be mentioned here that the lack of authentic and adequate data with regard to daily rainfall and SRRG stations, renders the analysis rather difficult. Estimation of SPS and PMP and their time distribution have been carried out within the above constraints. Estimates of SPS and PMP given in this report need to be re-examined when long period rainfall data for stations becomes available over the study region.

## Acknowledgments :

The study carried out in this report was entrusted to this Institute by the National Thermal Power Corporation (NTPC) Ltd., Noida. Scientists associated with this project work are highly grateful to Dr. G. B. Pant, Director, IITM, Pune for granting permission to carry out this study. They are also grateful to Dr. K. Rupa Kumar, Scientist-F, Head, Climatology and Hydrometeorology Division, IITM, Pune for his encouragement.

Authors are also very much thankful to Dr. O. N. Dhar, Hon. Emeritus Scientist, IITM, Pune and IMS Fellow for his valuable suggestions.

During the above project work, interaction and useful discussions with Officers from the Project Authorities (NTPC) as well Officers from Central Water and Power Research Station (CWPRS), Pune were held and authors are thankful to them.

Rainfall data used in this report were obtained through the courtesy of the Additional Director General of Meteorology (ADGM) Research, IMD, Pune and from the Irrigation Department, Uttaranchal state through Project authorities for which the authors are highly thankful to them.

Last but not the least authors are highly thankful to LIP Division, IITM and especially to Sh. V.H. Sasane and Sh. C.T. Jadhav for their sincere efforts in bringing out this report in nice getup in record time.

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## LIST OF TABLES

Table 1 : List of stations whose data considered for analysis nearby the study region

| Station | Data years | Station | Data years | Station | Data years |
|---|---|---|---|---|---|
| 1. Saharanpur | 85 | 21. Pithoragarh | 80 | 41. Tehri Garhwal | 27 |
| 2. Roorkee (O) | 87 | 22. Chaukuari | 73 | 42. Narendranagar | 31 |
| 3. Muhammadpur | 18 | 23. Beringag | 71 | 43. Dhanolti | 31 |
| 4. Muzaffarnagar | 15 | 24. Almora | 86 | 44. Keertinagar | 29 |
| 5. Kairana | 19 | 25. Ranikhet | 86 | 45. Deoprayag | 30 |
| 6. Budhana | 18 | 26. Champawat | 15 | 46. Uttar Kashi | 24 |
| 7. Najibabad | 20 | 27. Lokpal | 19 | 47. Dehradun (O) | 100 |
| 8. Bijnor | 19 | 28. Tapovan | 8 | 48. Mussoorie (O) | 19 |
| 9. Dhampur | 20 | 29. Badrinath (O) | 7 | 49. Rajpur | 15 |
| 10. Mukteshwar (O) | 99 | 30. Joshimath (O) | 86 | 50. Chakrata | 20 |
| 11. Kaladhungi | 18 | 31. Ghangaria (O) | 13 | 51. Ambari | 66 |
| 12. Nainital | 86 | 32. Okhimath | 86 | 52. Rohru | 43 |
| 13. Bazpur | 21 | 33. Karnaprayag | 19 | 53. Jubbal | 48 |
| 14. Kashipur | 18 | 34. Chamoli | 8 | 54. Chopal | 48 |
| 15. Haldwani | 18 | 35. Pauri | 83 | 55. Rampur | 48 |
| 16. Ramnagar | 85 | 36. Srinagar | 69 | 56. Paonta | 32 |
| 17. Askote | 32 | 37. Landsdown | 85 | 57. Nahan | 47 |
| 18. Dharchula | 32 | 38. Bironkhol | 83 | 58. Kalpa | 48 |
| 19. Munsiyari(O) | 25 | 39. Mukhim (O) | 44 | 59. Sangla | 46 |
| 20. Tijjam (T) | 13 | 40. Tehri (O) | 26 | | |

Table 2 : List of stations whose data used from IMD 50-year normals for annual and seasonal rainfall distribution

| Stations | Stations | Stations | Stations |
|---|---|---|---|
| 1. Hardwar | 8. Kuankhera | 15. Nagina | 22. Tanakpur |
| 2. Salimpur | 9. Bhainswal | 16. Khatima | 23. Kausanie |
| 3. Nakur | 10. Khandhla | 17. Rudrapur | 24. Thakurdwara |
| 4. Deoband | 11. Jaoli Jansath | 18. Kilpuri | 25. Kotdwara |
| 5. Nayashahr | 12. Meerut (O) | 19. Gadarpur | 26. Bhogpur |
| 6. Jarauda | 13. Sardhana | 20. Kathgodam | 27. Raipur |
| 7. Kalsia | 14. Mawana | 21. Nagla | 28. Ambari |

Table 3 : List of SRRG stations used for time distribution analysis

| | SRRG Station | Data period | No. of years |
|---|---|---|---|
| 1 | Dehradun | 1969-79, 1981-87, 1992-93, 1995-2000 | 24 |
| 2 | Mussoorie | 1971-72, 1984 | 3 |
| 3 | Mukhim | 1970-71, 1995 | 3 |
| 4 | Uttarkashi | 1978-79, 1981 | 3 |
| 5 | Tehri | 1970-72, 1975 | 4 |

Table 4 : Average seasonal and annual rainfall distribution of some selected stations and the catchment as a whole for the Dhauliganga catchment

| Station | Altitude (m) | Seasonal rainfall (cm) | | | | | | | | Annual Rainfall (cm) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Winter | % of annual | Pre - Monsoon | % of annual | Monsoon | % of annual | Post - Monsoon | % of annual | |
| Lokpal | > 5000 | 51 | 28 | 11 | 6 | 105 | 59 | 12 | 7 | 179 |
| Tapovan | > 2500 | 14 | 19 | 7 | 10 | 41 | 58 | 9 | 13 | 72 |
| Joshimath (O) | 1875 | 25 | 27 | 10 | 10 | 53 | 58 | 4 | 5 | 93 |
| Ghangaria (O) | 3077 | 43 | 29 | 19 | 13 | 75 | 51 | 9 | 6 | 145 |
| Okhimath | 1861 | 22 | 12 | 13 | 7 | 149 | 79 | 5 | 3 | 188 |
| Chamoli | > 2500 | 20 | 16 | 14 | 11 | 86 | 69 | 5 | 4 | 124 |
| Bironkhol | 1707 | 18 | 17 | 8 | 7 | 78 | 72 | 5 | 4 | 109 |
| Munsiyari | 2202 | 18 | 10 | 12 | 6 | 142 | 79 | 8 | 4 | 180 |
| Tijjim | 1847 | 33 | 19 | 11 | 6 | 118 | 69 | 9 | 5 | 170 |
| **Catchment as a whole =** | | **20.3** | **22** | **7** | **7** | **62.6** | **67** | **4** | **4** | **93.9** |

Table 5 : Highest rainfall (cm) and PMP (cm) for some selected stations in neighbourhood of Dhauliganga catchment (≥ 10 cm) for 1 and 2-day durations (1901 onwards)

| Station | 1-day | | | 2-day | | |
|---|---|---|---|---|---|---|
| | Highest (cm) | Date of occurrence | PMP (cm) | Highest (cm) | Date of occurrence | PMP (cm) |
| 1 Joshimath (O) | 30.0 | 21/06/1973 | 39 | 50.0 | 21-22/06/1973 | 65 |
| 2 Lokpal | 10.0 | 17/12/1961 | 21 | 16.0 | 17-18/12/1061 | 33 |
| 3 Okhimath | 20.8 | 08/08/1925 | 40 | 30.8 | 10-11/08/1925 | 54 |
| 4 Karnaprayag | 19.1 | 26/07/1970 | 59 | 33.8 | 10-11/08/1970 | 106 |
| 5 Bironkhol | 25.5 | 29/09/1924 | 50 | 44.6 | 28-29/09/1924 | 77 |
| 6 Srinagar | 13.5 | 29/09/1924 | 25 | 25.4 | 28-29/09/1924 | 44 |
| 7 Keertinagar | 19.8 | 08/10/1956 | 37 | 24.9 | 08-09/10/1956 | 51 |
| 8 Pauri | 17.3 | 09/10/1956 | 30 | 21.6 | 08-09/10/1956 | 45 |
| 9 Munsiyari(O) | 23.3 | 17/06/1973 | 63 | 44.2 | 17-18/06/1973 | 108 |
| 10 Tijjam (T) | 11.0 | 05/03/1966 | 22 | 18.6 | 05-06/07/1971 | 42 |
| 11 Dharchula | 27.1 | 14/06/1971 | 61 | 30.9 | 11-12/06/1971 | 79 |
| 12 Askote | 25.0 | 10/09/1982 | 59 | 26.6 | 30/6-1/7/1979 | 71 |
| 13 Chaukuari | 27.4 | 22/06/1916 | 45 | 35.1 | 21-22/06/1916 | 61 |
| 14 Berinag | 22.6 | 09/08/1961 | 39 | 44.2 | 15-16/08/1961 | 63 |
| 15 Almora | 22.3 | 29/09/1924 | 38 | 35.2 | 28-29/09/1924 | 59 |
| 16 Ranikhet | 35.1 | 16/06/1970 | 50 | 41.6 | 24-25/07/1985 | 70 |

Table 6 : List of stations which recorded 1-day highest rainfall prior to 1901

| No. | Station | District | Highest 1-day (cm) | Date of occurrence |
|---|---|---|---|---|
| 1. | Bhogpur | Dehradun | 38 | 29/07/1890 |
| 2. | Mussoorie | - do - | 44 | 19/08/1890 |
| 3. | Chakrata | - do - | 25 | 29/07/1871 |
| 4. | Saharanpur | - do - | 27 | 02/07/1895 |
| 5. | Kathgodam | Nainital | 31 | 15/07/1897 |
| 6. | Champawat | Almora | 39 | 27/09/1897 |
| 7. | Kotdwara | Garhwal | 35 | 27/08/1892 |
| 8. | Pauri | - do - | 18 | 18/09/1880 |
| 9. | Srinagar | - do - | 19 | 18/09/1880 |
| 10. | Hardwar | Saharanpur | 49 | 18/09/1880 |
| 11. | Muhammadpur | - do - | 45 | 17/09/1880 |
| 12. | Jaolijansath | Muzaffarnagar | 41 | 17/09/1880 |
| 13. | Nagina | Bijnor | 82 | 18/09/1880 |
| 14. | Dhampur | - do - | 77 | 18/09/1880 |
| 15 | Najibabad | - do - | 72 | 18/09/1880 |

Table 7 : Depth-Duration analysis over and near Dhauliganga catchment

| Rainstorms | DD raindepths (cm) of severe rainstorms for durations of | |
|---|---|---|
| | 1-day | 2-day |
| 1. 02-03 Oct., 1910 | 7.0 (03/10) | 13.0 |
| 2. 18-19 Sept., 1914 | 5.1 (19/09) | 8.3 |
| 3. 24-25 Jun., 1921 | 5.0 (25/06) | 7.8 |
| 4. 27-28 Sept., 1924 | 11.3 (28/09) | 19.8 |
| 5. 08-09 Oct., 1956 | 5.1 (09/10) | 9.4 |
| 6. 25-26 Jul., 1966 | 5.7 (25/07) | 8.8 |

Table 8 : SPS and PMP raindepths over Dhauliganga catchment

| | Rainstorm | Duration | |
|---|---|---|---|
| | | 1-day | 2-day |
| 1. Envelope DD raindepths (cm) (SPS) | 27-28 Sept., 1924 | 11.3 (28/9) | 19.8 |
| 2. PMP by Physical method | MMF = 1.40 | 15.8 | 27.7 |
| 3. PMP by Statistical method | | 19.0 | 29.5 |

Table 9 : Average Time Distribution for 24 hr and 48 hr extreme rainfall

| | % Contribution | |
|---|---|---|
| Duration (Hrs.) | 24 - hr | 48 - hr |
| 1 | 19 | 12 |
| 3 | 37 | 23 |
| 6 | 54 | 35 |
| 9 | 66 | 45 |
| 12 | 75 | 54 |
| 15 | 83 | 62 |
| 18 | 90 | 69 |
| 21 | 96 | 75 |
| 24 | 100 | 80 |
| 27 | | 84 |
| 30 | | 87 |
| 33 | | 90 |
| 36 | | 93 |
| 39 | | 96 |
| 42 | | 98 |
| 45 | | 99 |
| 48 | | 100 |

## LIST OF FIGURES

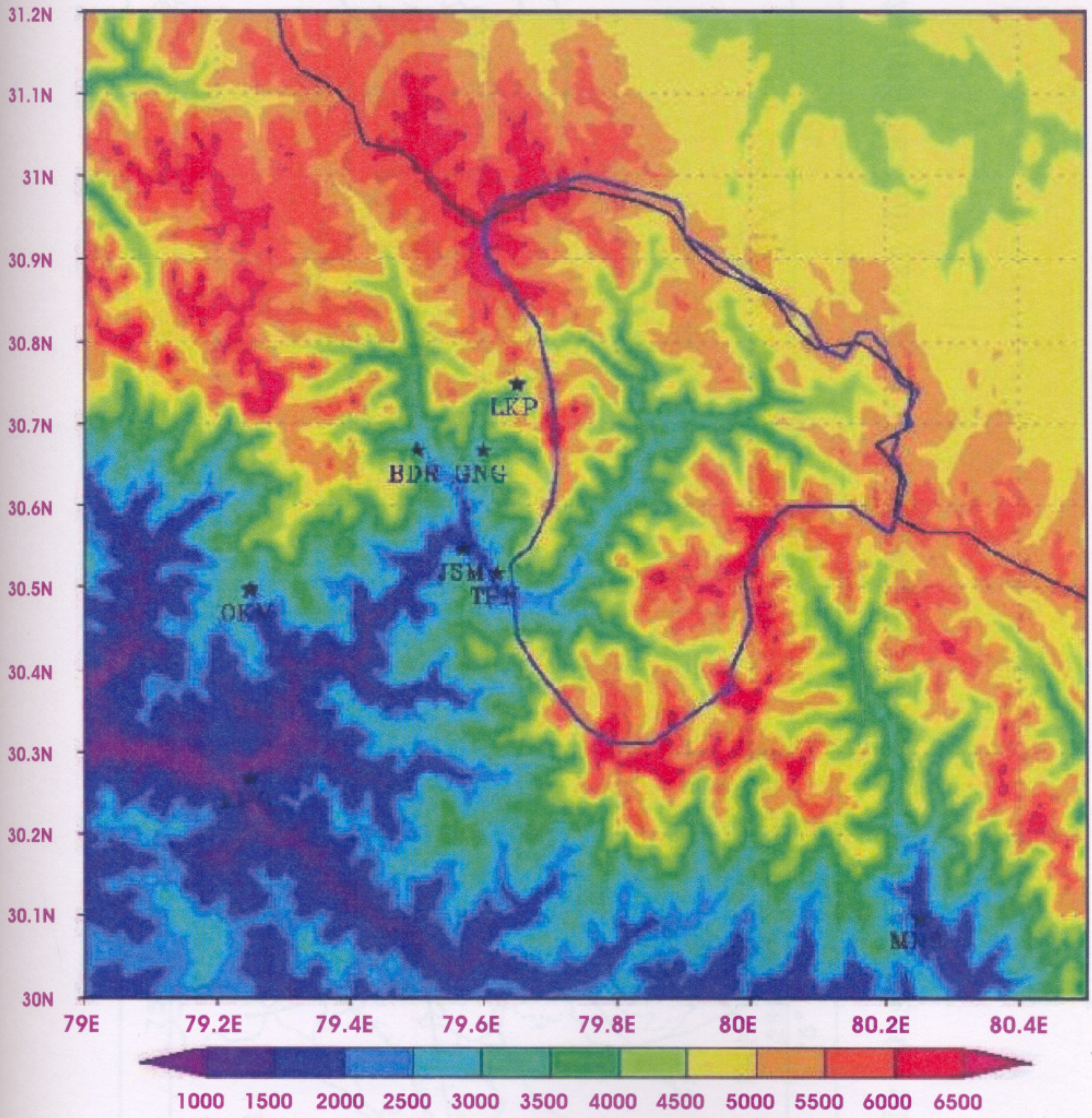


Fig. 1 : Topographical features over and near the catchment

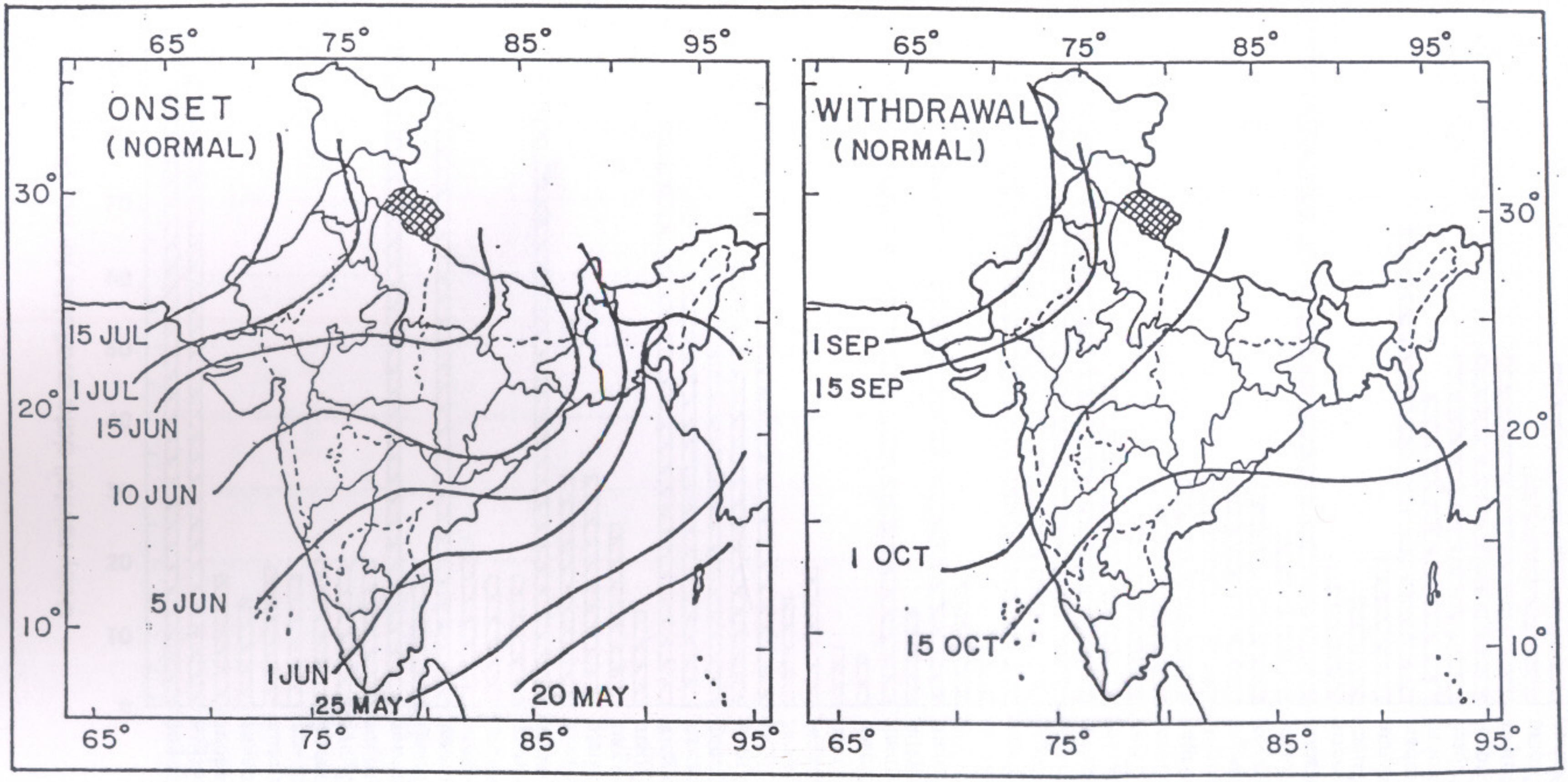


**Fig2 : Onset and withdrawal of monsoon over and near the catchment**

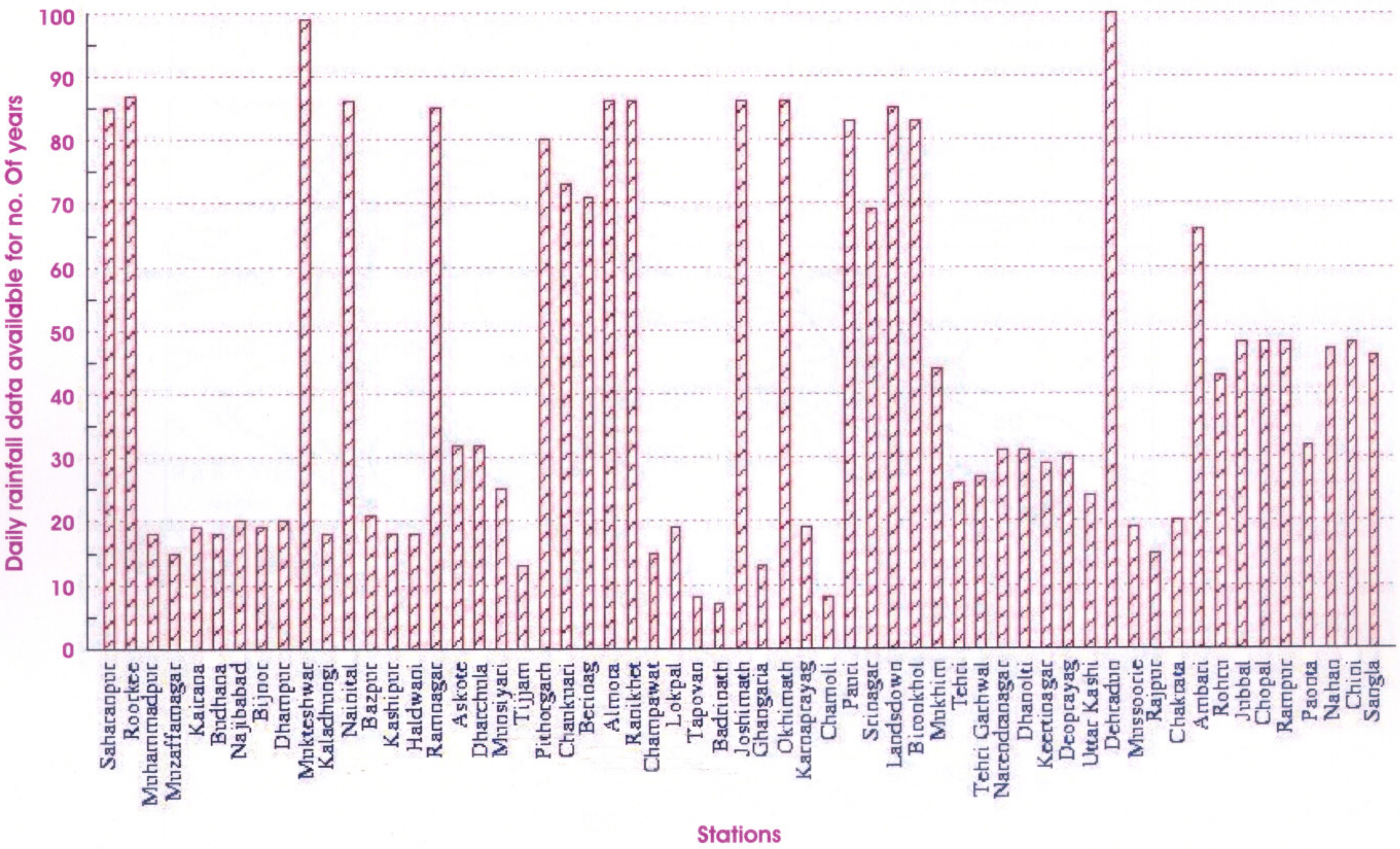


Fig. 3 : Daily rainfall data availability for stations near study region

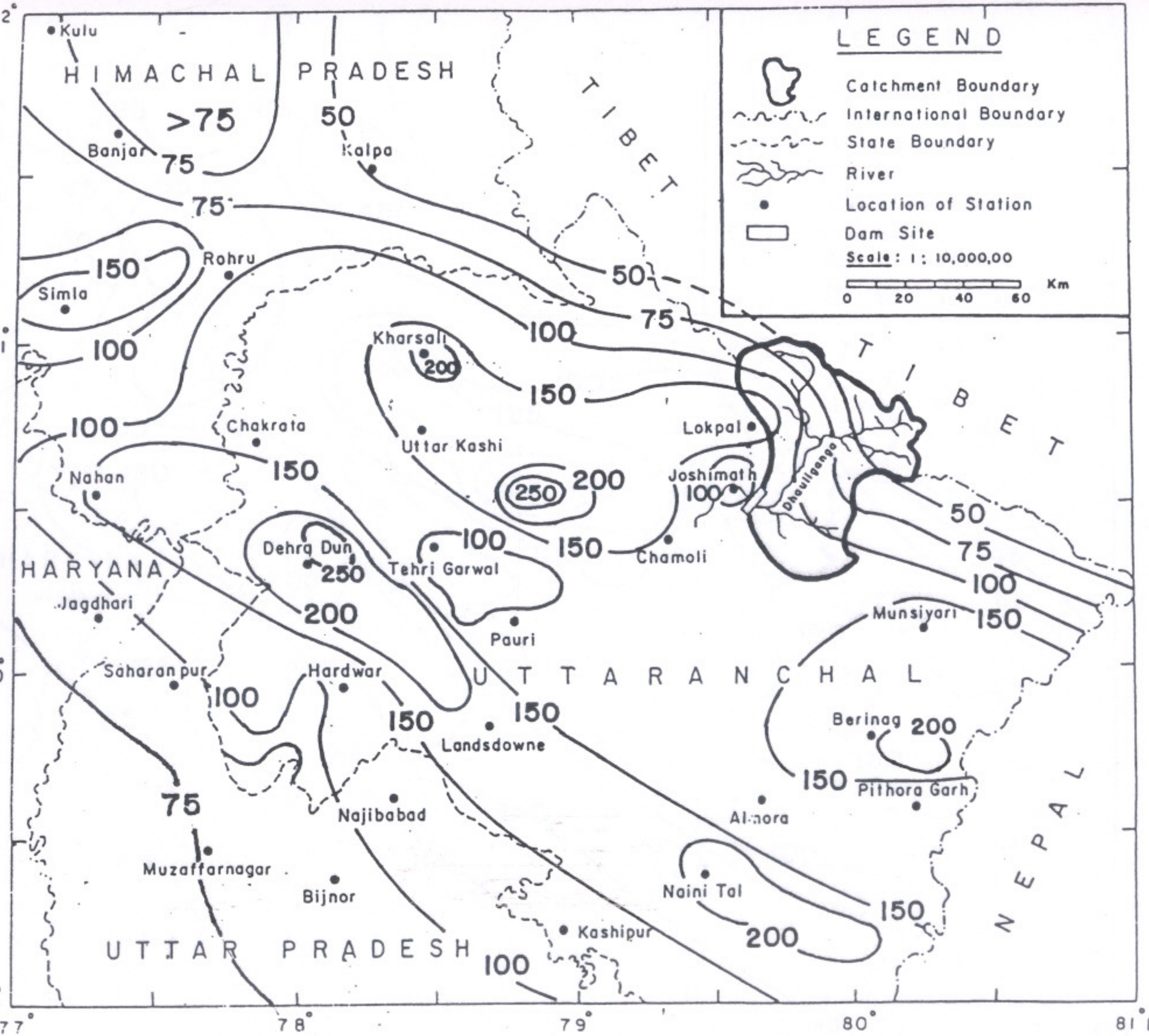


Fig.4 : Spatial patterns of mean annual rainfall in and around the catchment (in cm)

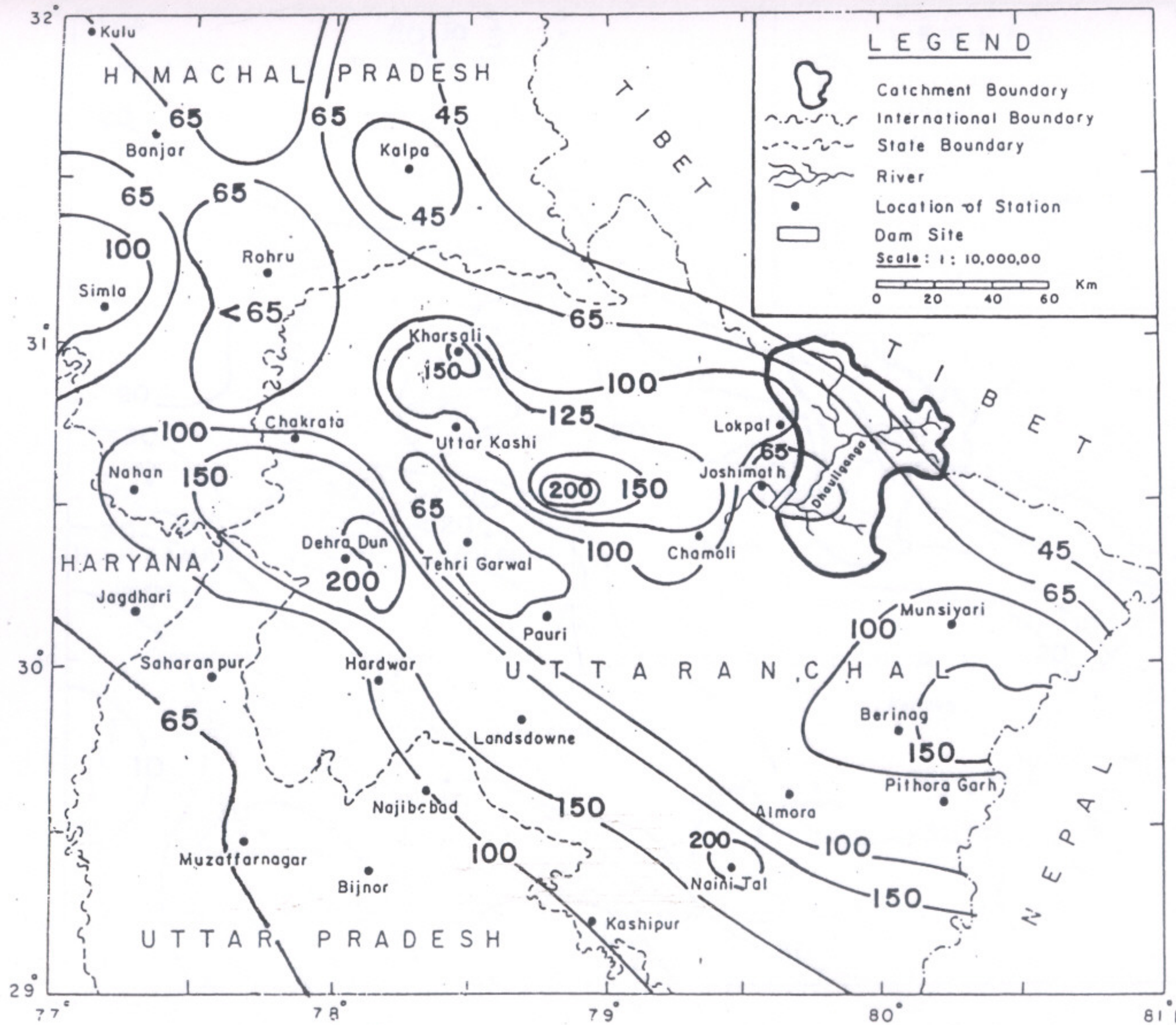


**Fig.5 : Spatial patterns of mean monsoon ( June–Sept.) rainfall in and around the catchment (in cm)**

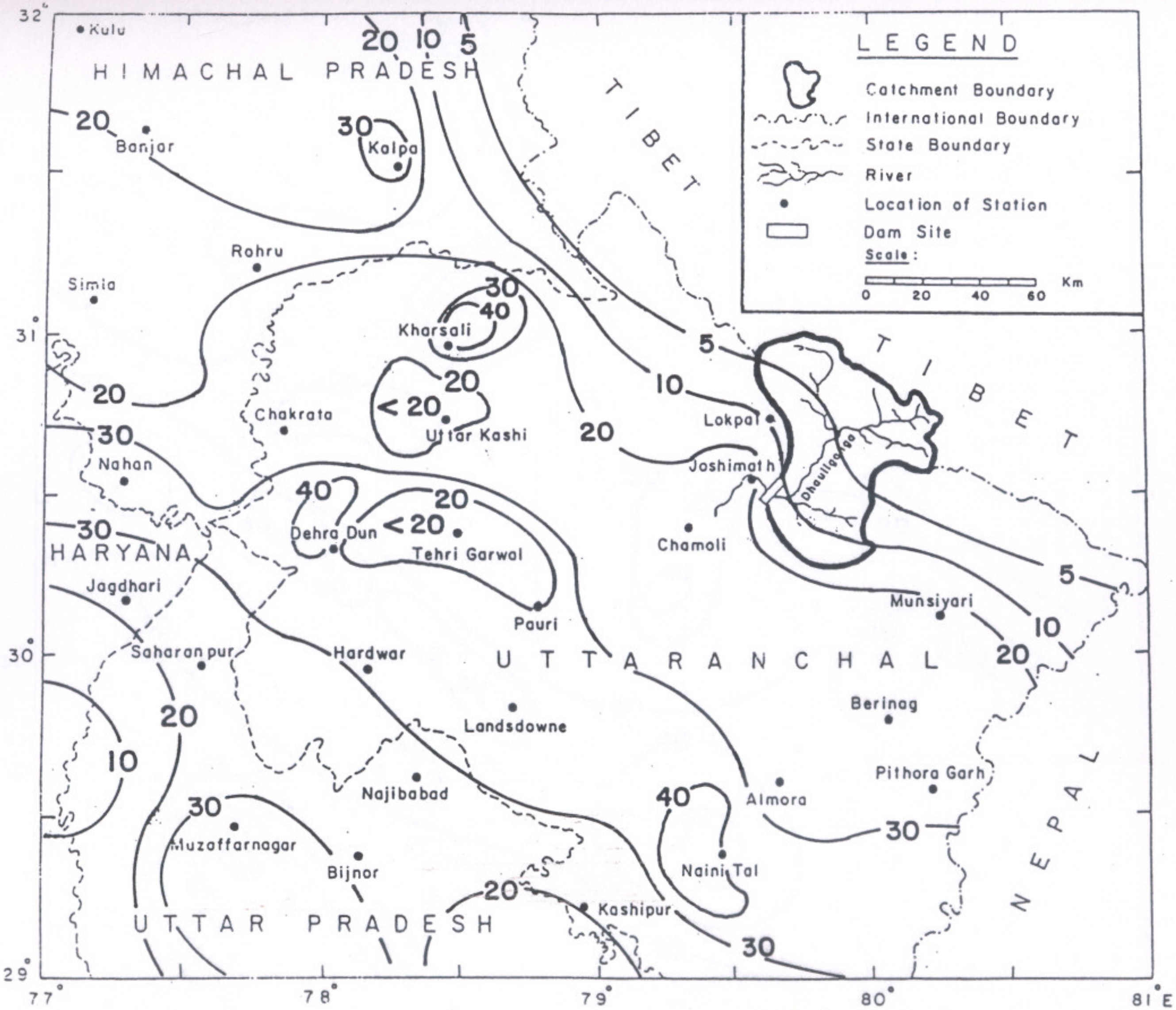


**Fig.6 : Spatial patterns of highest 1–day rainfall in and around the catchment (in cm)**

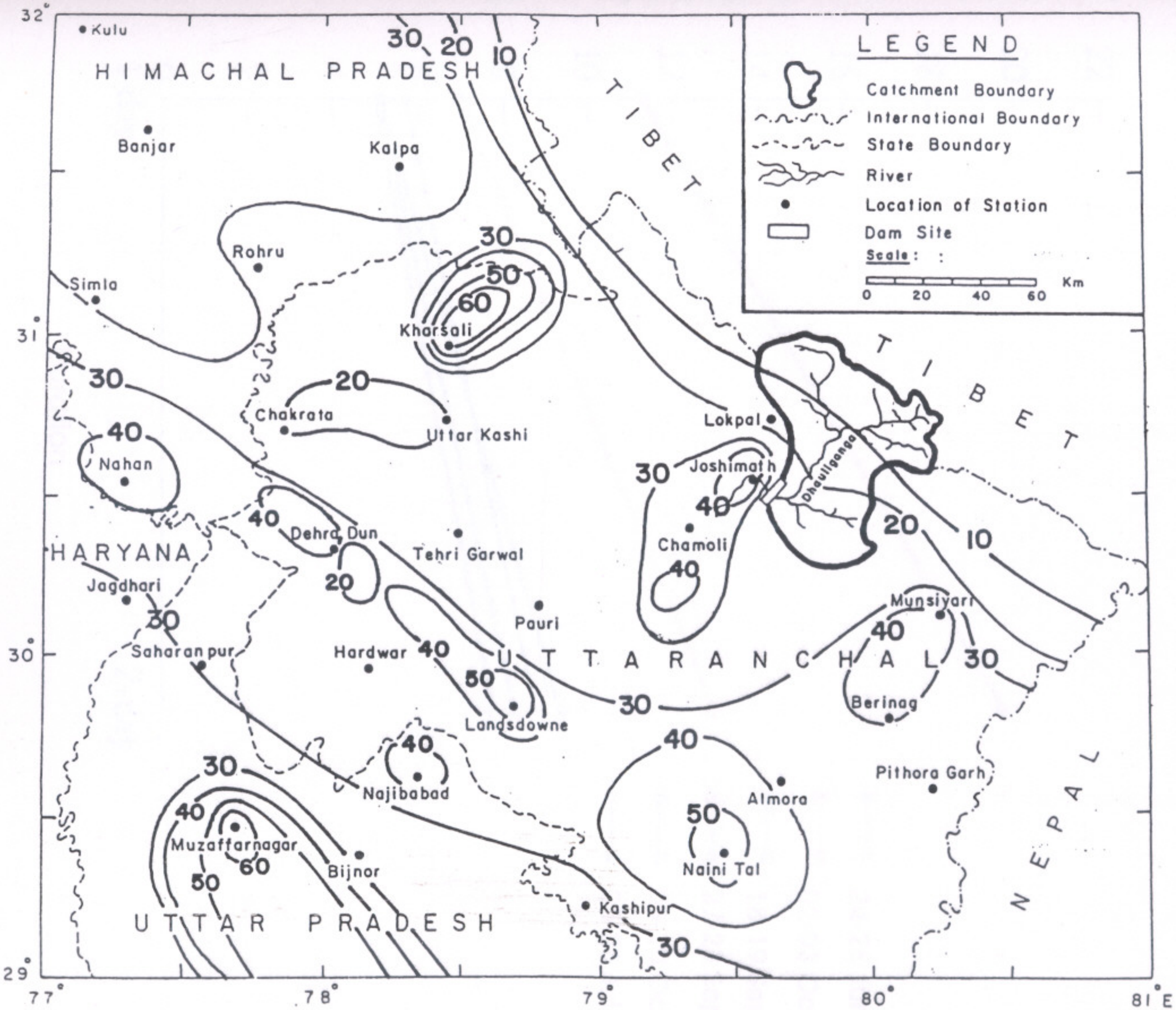


**Fig.7 : Spatial patterns of highest 2–day rainfall in and around the catchment (in cm)**

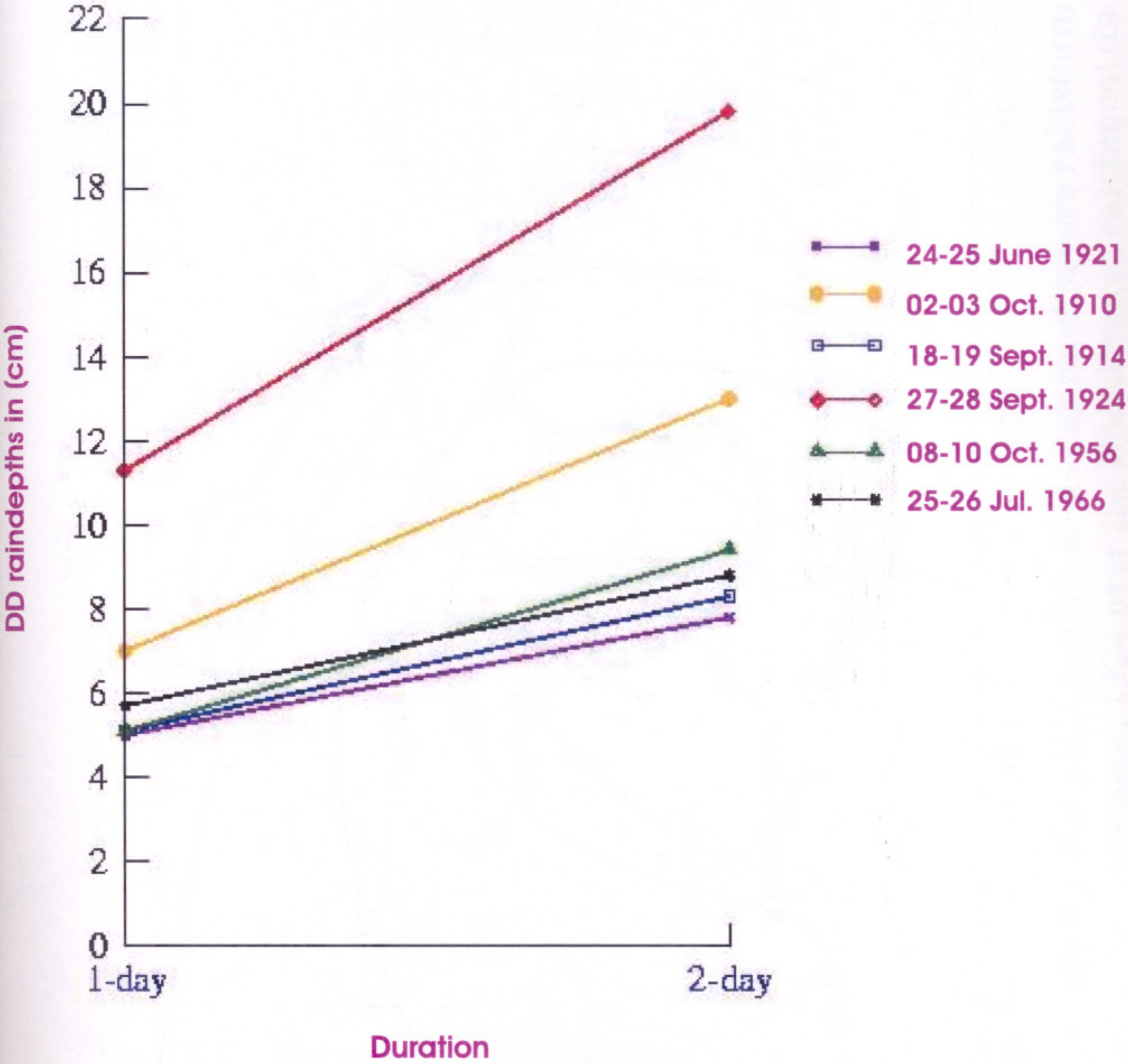


Fig. 8 : Envelope DD curves for severe rainstorm over Dhauliganga catchment

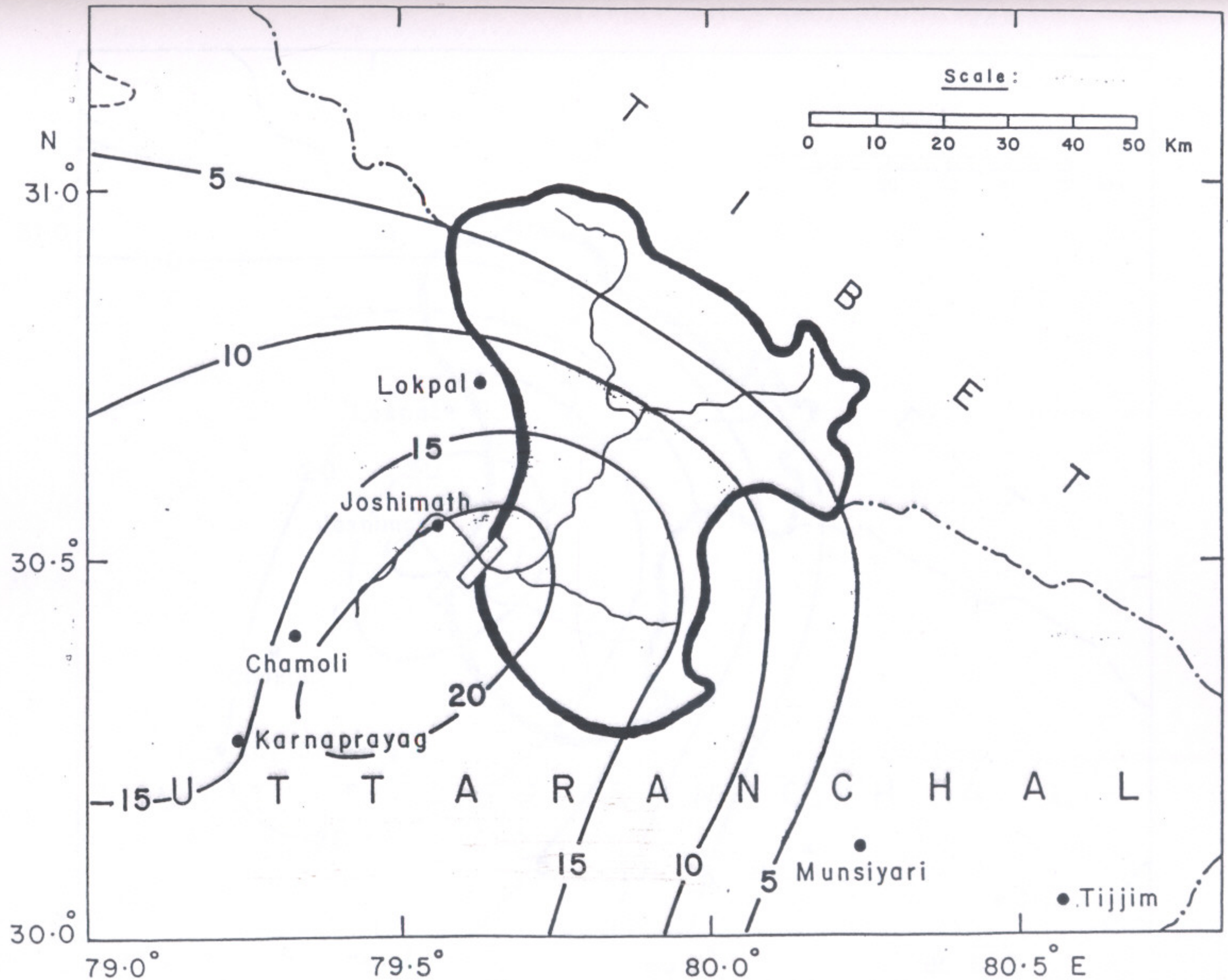


**Fig.9 : Isohyetal pattern of 1–day most severe rainstorm of 28 Sept. 1924 over the Dhauliganga catchment (in cm)**

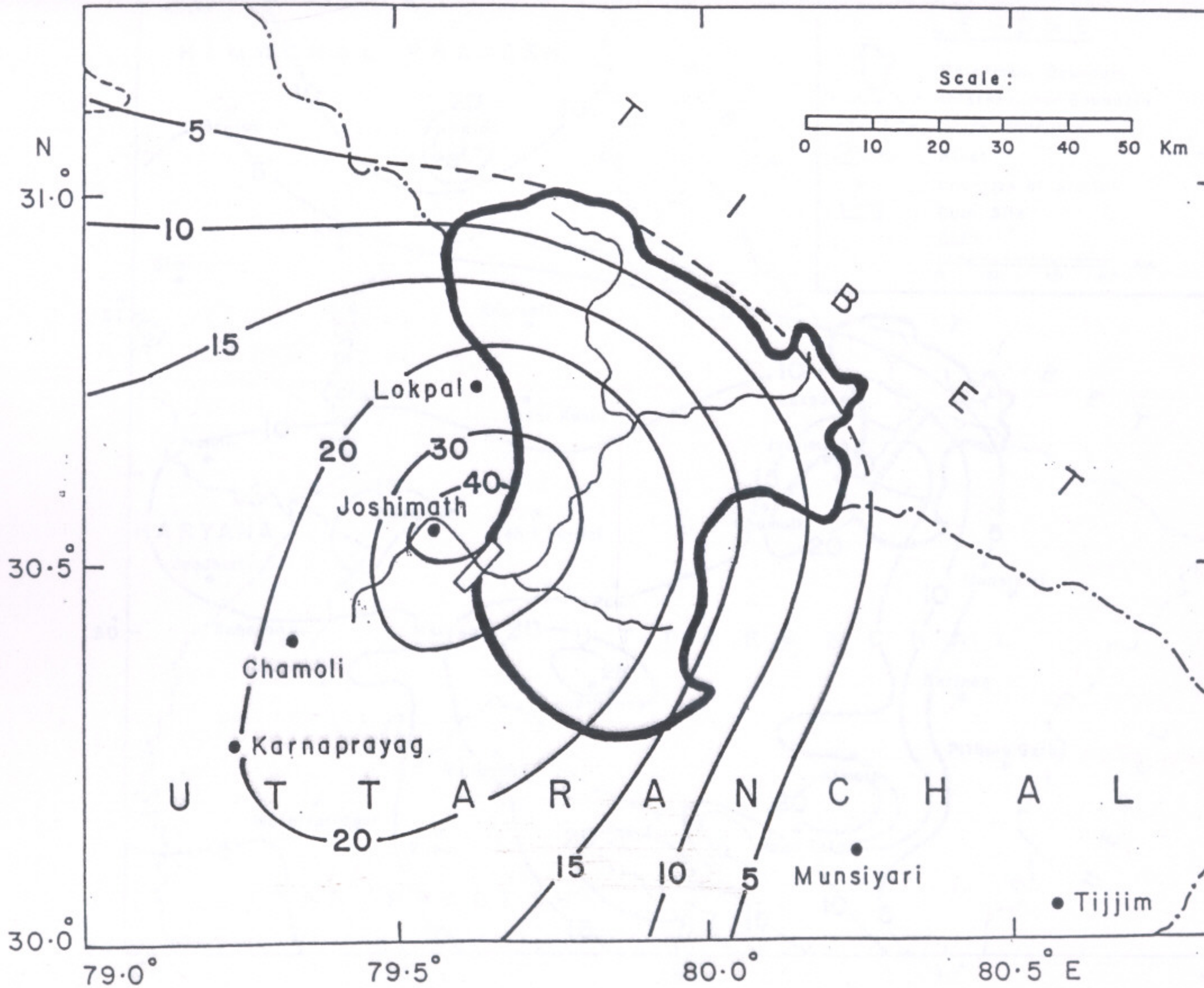


**Fig.10 : Isohyetal pattern of 2–day most severe rainstorm of 27–28 Sept. 1924 over the Dhauliganga catchment (in cm)**

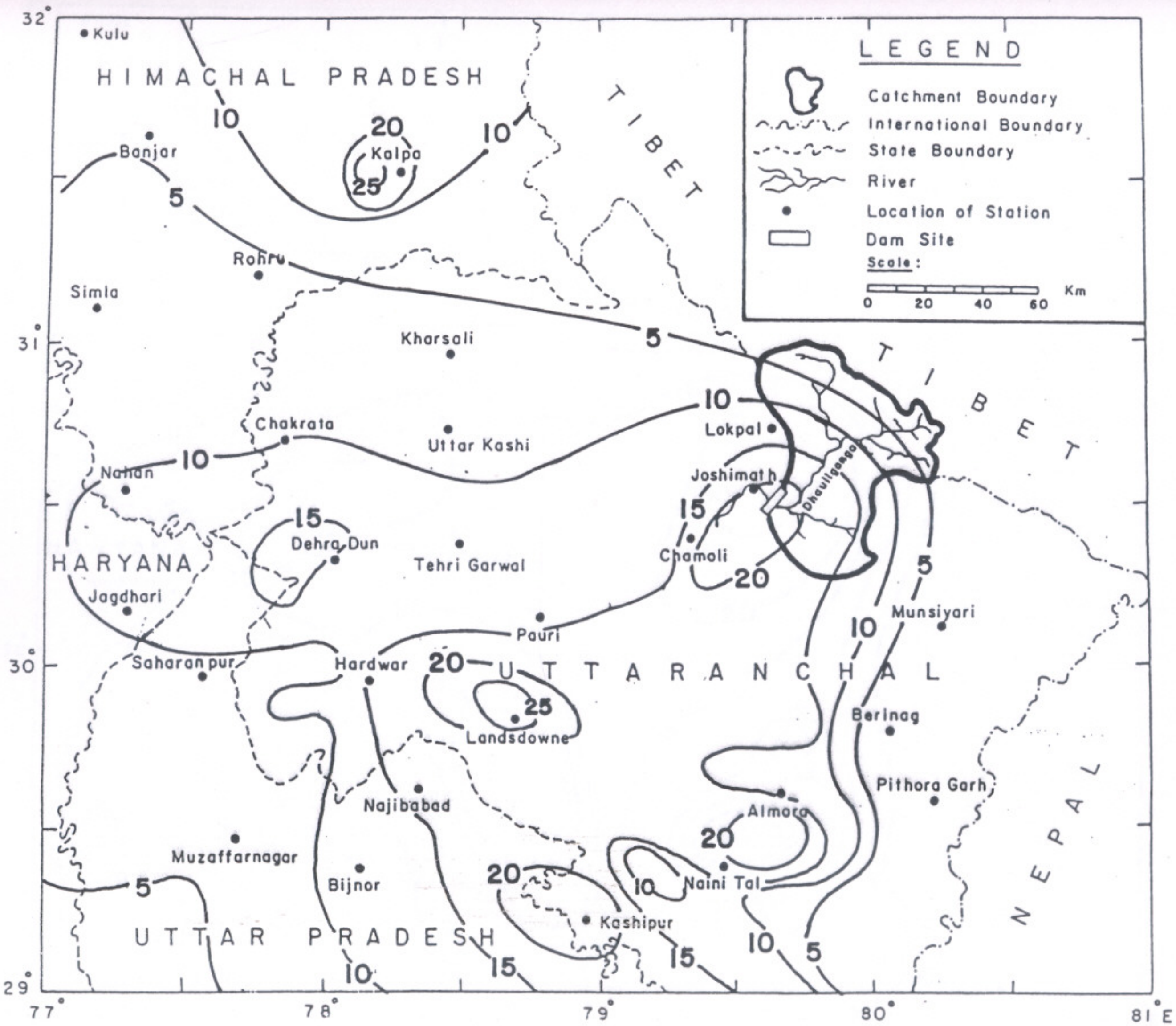


**Fig.11 : 1–day isohyetal pattern of 28 sept 1924 rainstorm over and near the Dhauliganga catchment (in cm)**

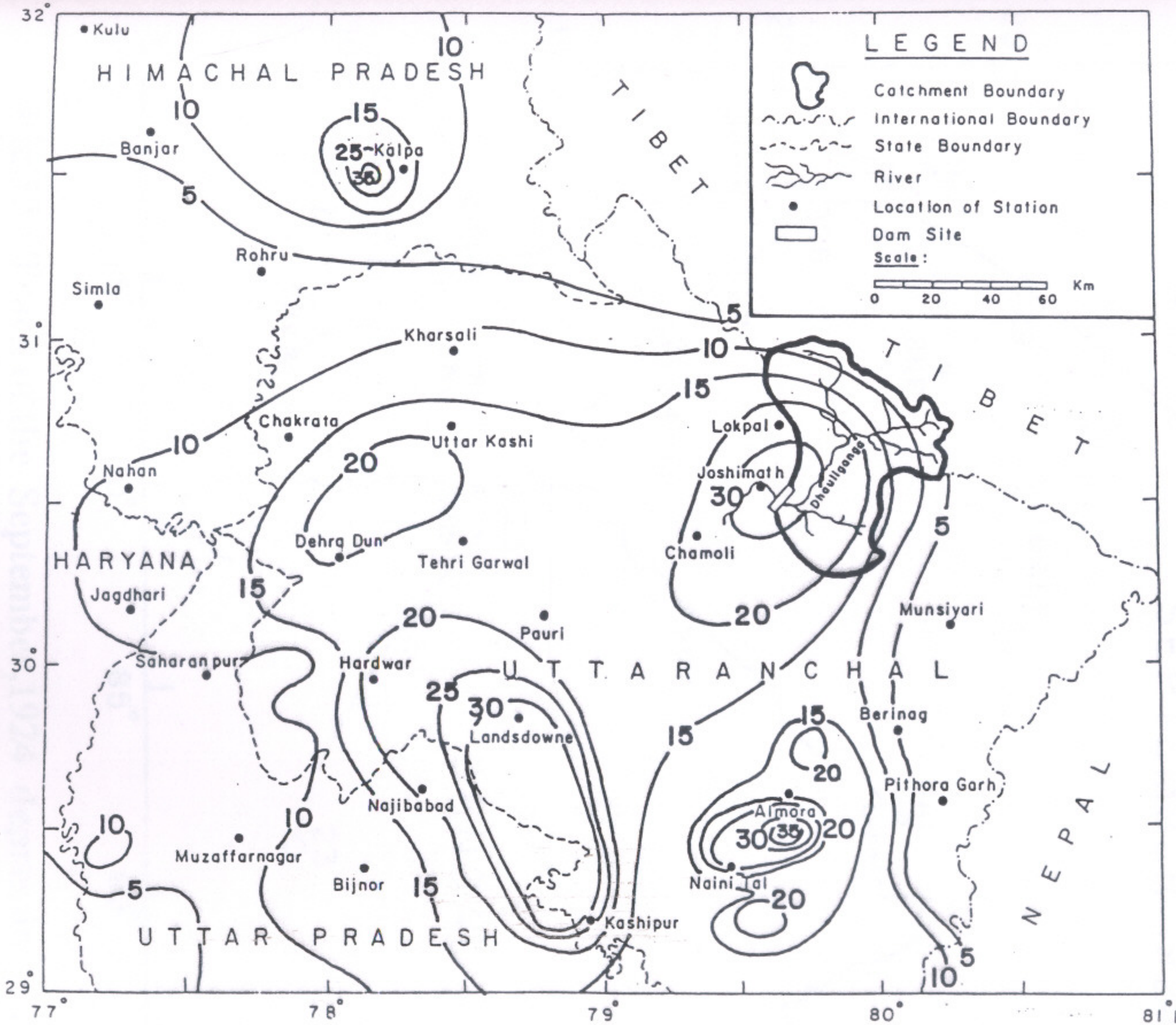


**Fig.12: 2–day isohyetal pattern of 27–28 sept 1924 rainstorm over and near the Dhauliganga catchment (in cm)**

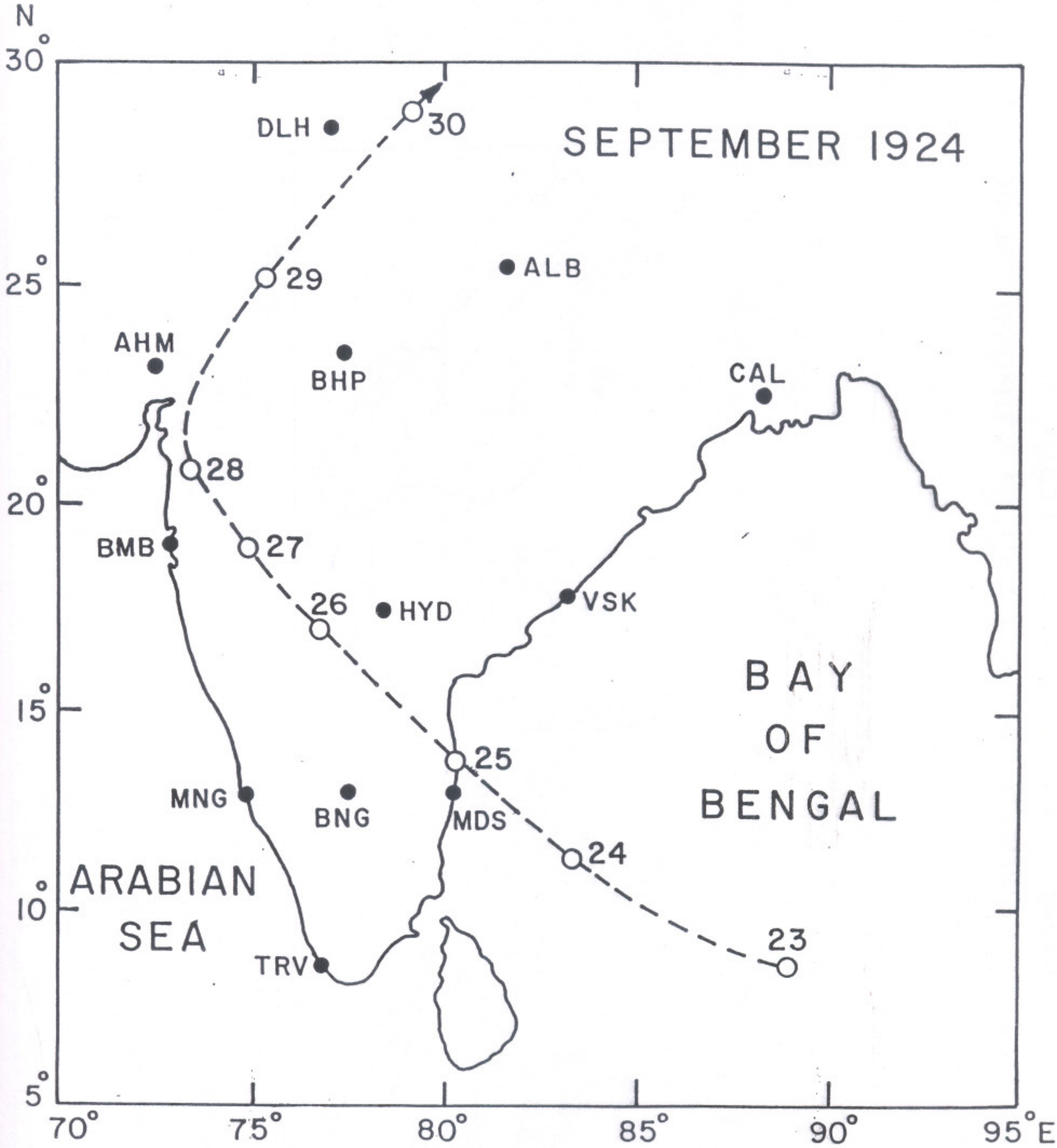


**Fig.13 : Track of the September,1924 depression which caused heavy rainfall over the catchment**

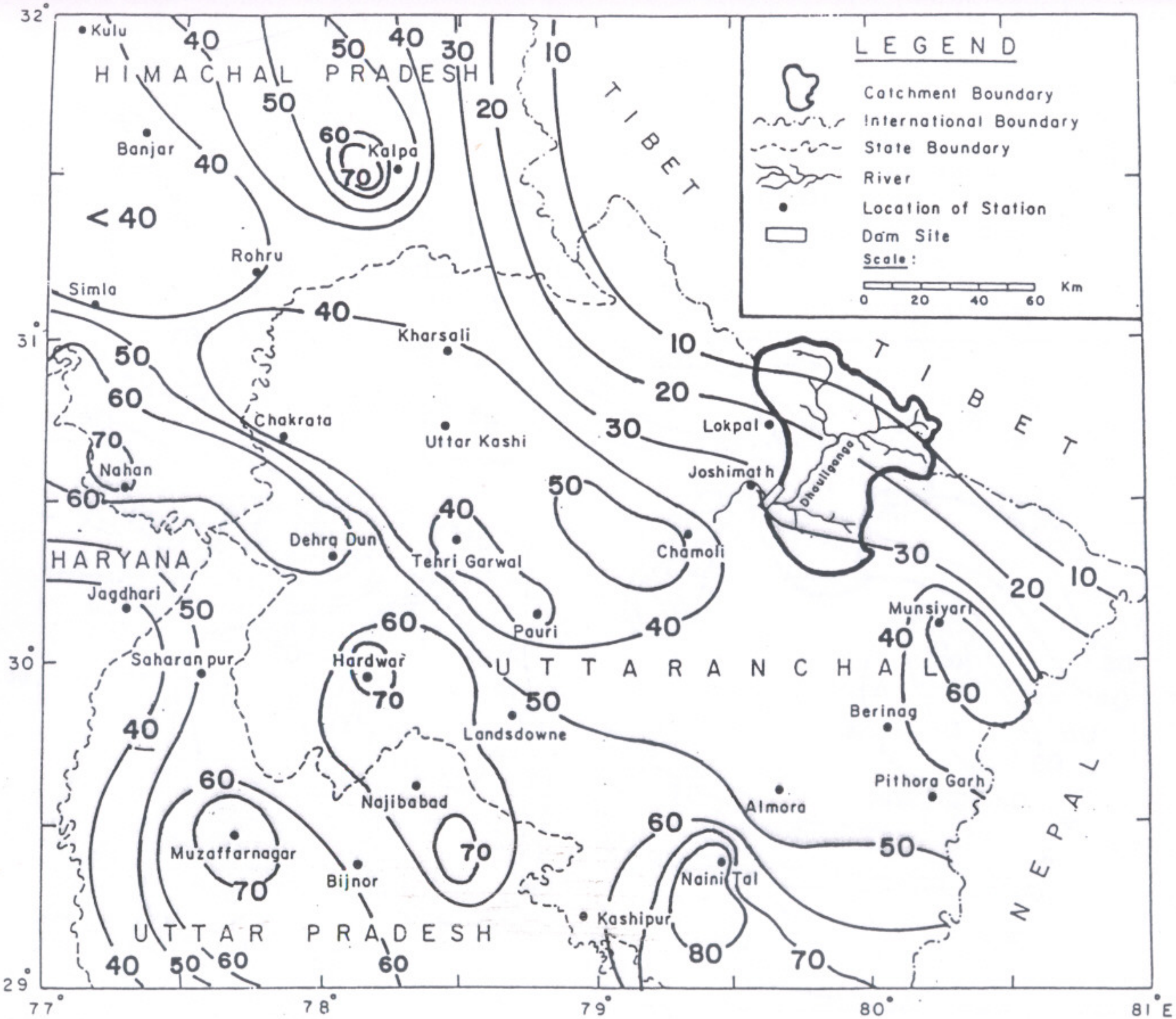


**Fig.14 : Spatial patterns of 1-day PMP by statistical method over and near the catchment (in cm)**

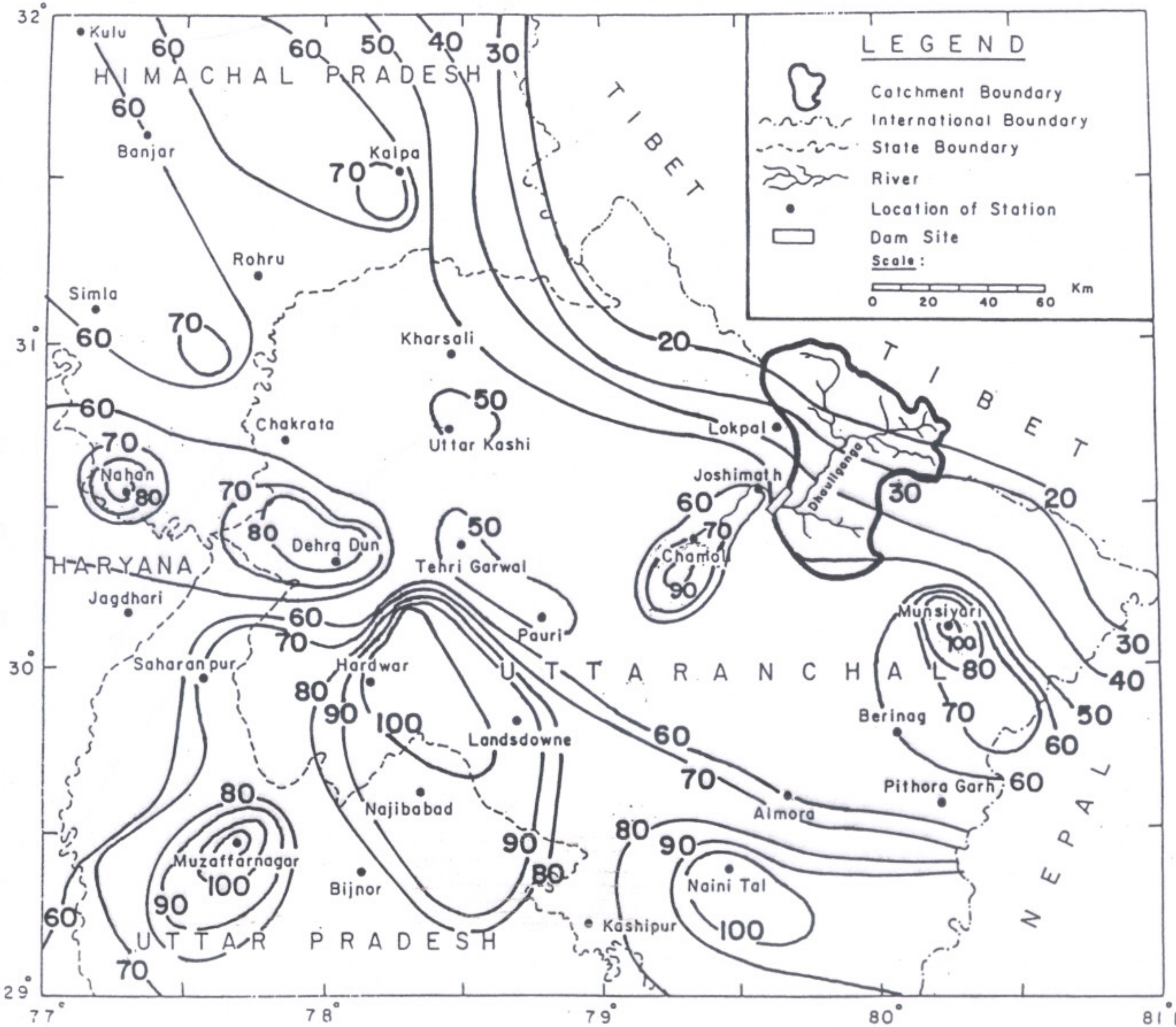


**Fig. 15 : Spatial patterns of 2–day PMP by statistical method over and near the catchment (in cm)**

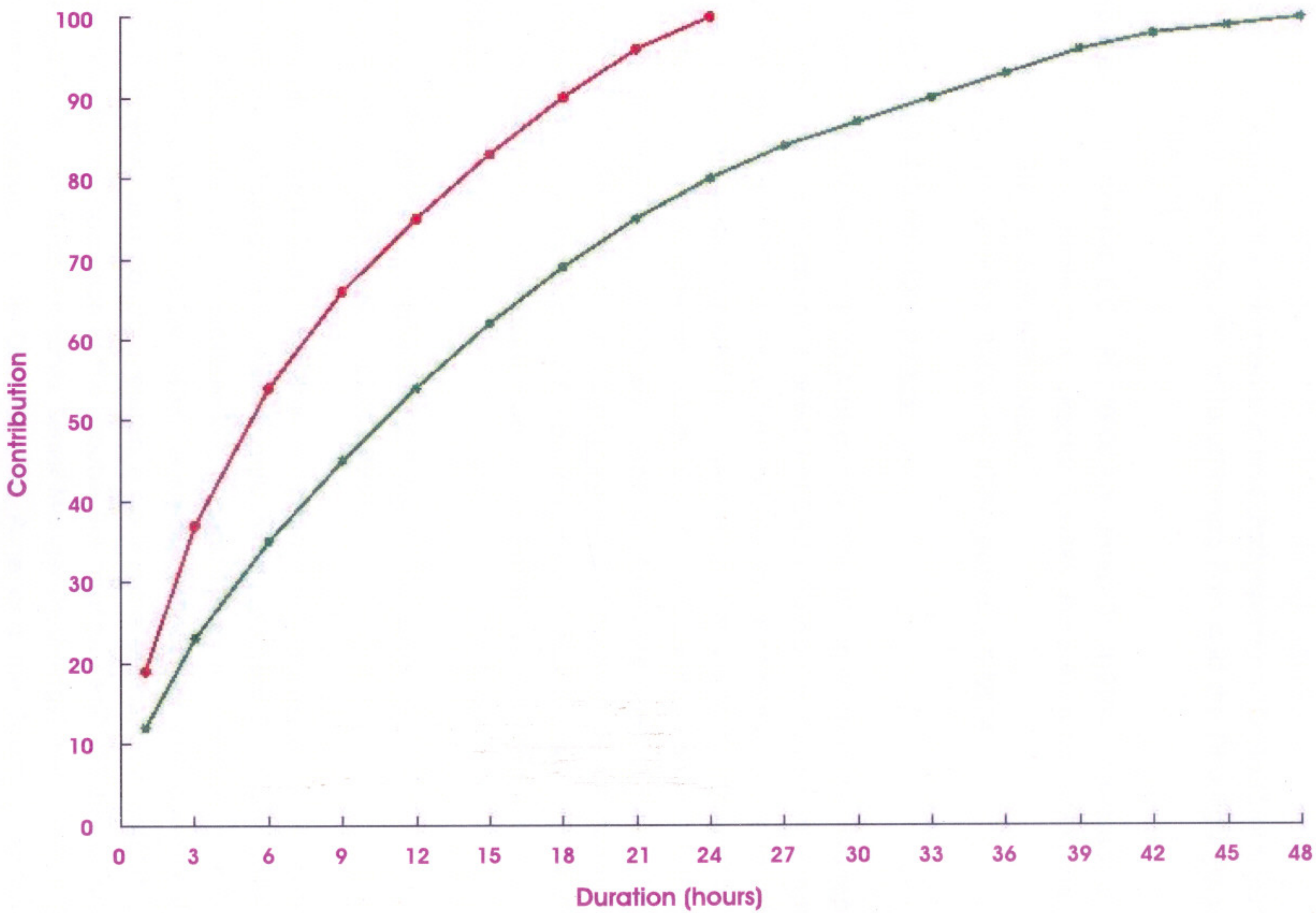


Fig. 16 : Average Time Distribution (%) for 24-hour and 48-hour extreme rainfall

**ANNEXURE- I**

**Subject :** Replies to the comments on final draft reports on " Design Storm Studies over the Bhagirathi upto Loharinag Pala and the Dhauliganga upto Tapovan"

**Reference :** a) Letter No. CC : PEC/0000.999 dated 21-01-2004 addressed to Shri. M.S. Shitole, Joint Director, CWPRS, Pune from Mr. S.M.Khare, Dy. GM (PE-Civil), NTPC, Noida.

b) FAX Letter No. IITM/HY/NTPC-Projects dt. 4/2/2004

Query No.1 : The detailed storm studies :

Kindly refer to Section 10 (a & b) and Section 10.1 in each of the two reports submitted to you. It is clearly mentioned that DAD analysis is not applicable in such orographic region and DD method is the most appropriate technique. Details of DD method are given in each report. List of severe rainstorms affected the respective catchment and their average rain depths for 1 & 2-day durations are given in Table 7 of each report. DD curves of those severe rainstorms are given in Fig. 8 of each report. Isohyetal patterns of 1 and 2-day durations of most severe rainstorm which contributed envelope rain depths (SPS) are also given in each report. It is, therefore, implied that all the details about the detailed storm studies are already included in the report.

Query No.2 : Details of convolution within single bell of 24-hour or two bells of 12 hours are not given

The above technique of the time distribution analysis using two bells (12 hours each) (mentioned by you) has been recently introduced from CWC authorities but details of which are not yet available in any published form. It is to be mentioned here that WMO Manual No.332 (1986), entitled, "Manual for estimation of PMP" which is referred to as a standard reference book in the estimation of PMP, there is no mention about application of the "Double Bell arrangement" for the estimation of design flood. Mr. Shankracharya, Senior Manger (Hydrology) from NHPC, Noida in a letter addressed to the Director, IITM, Pune and the Director General of Meteorology (DGM), IMD, New Delhi with reference to the above technique by CWC, New Delhi has reported that " CWC official now agrees that double bell technique is not a distribution, but an agreement ".

**ANNEXURE- II**

**Subject :** Replies to the comments on final draft reports on " Design Storm Studies over the Bhagirathi upto Loharinag Pala and the Dhauliganga upto Tapovan"

**Reference :** a) E-mail from Mr. S.M.Khare dated 10-3-2004

b) D.O. Letter No. IITM/HY/NTPC-projects dated 18/3/2004

Query No.1. CATCHMENT AREA PLAN :

The Catchment maps are prepared using the Survey of India base maps (1961) in the scale of 1:1 million. Location of barrage sites and area of each catchments was provided by NTPC project authorities.

Query No. 2. SHOWING THE CONTOUR LINES AND ITS INTERVAL :

Topographical features shown in and around the two catchments in our studies were taken from the Digital Elevation Model (DEM) data prepared by the US Geological Survey with a resolution of 30 seconds. Intervals of contours shown over and near the two catchments were made as per the suitability and for better presentation. Intervals of contour lines can be adjusted as per the requirements. We would, however, like to inform that NTPC authorities were requested to provide topo sheets for the study regions but the same could not be made available to us. In the Project meeting held at CWPRS, Pune on 29 Jul., 2003, NTPC representative has informed us that catchment boundaries / satellite imageries available with IITM may be used.

Query No.3. EXISTING AND PROPOSED PROJECTS :

As the project authorities entrusted to study the two catchments mentioned above, we critically looked into and examined the two catchments upto their respective barrage sites only.

Query No.4. LOCATION OF RAIN GAUGES, HYDRO METEROLOGICAL STATIONS IN AND AROUND CATCHMENT AREA :

Details of the rainfall data used in the studies have been given along with their sources in Table Nos. 1 to 3 of each report. Station locations are shown on the Survey of India base maps (1961), used for further analysis.

Query No. 5. DIGITISED DATA OF TOPOSHEET

Same as reply given against Query No.2.

Query No. 6. RAINFALL DATA COLLECTED FROM IMD (RAW / PROCESSED)

As per the terms and conditions of IMD, any raw rainfall data obtained from NDC, IMD, Pune can not be supplied to any third party. This point has been made clear to the project authorities from time to time. However, a copy of analysed/ processed data to the possible extent has been given in separate Annexures.

Query No.7. DETAILS OF COMPUTATION FOR SLOPE

Computation of slope analysis has not been attempted in our study as it was not included in the objectives of the project work plan.

Query No. 8. 24-HR STORM VALUE FOR 25, 50, 100 YR. RETURN PERIOD FOR PROJECT CATCHMENT (AREAL VALUES)

It is not clear from the mail that whether 24-hr storm value means the 1-day storm value. If so, then carrying out frequency analysis for estimating areal values of different return periods for the two catchments under study, it is necessary to have annual maximum rainfall series of 1, 2 and 3-day durations for the entire catchment. In the present case, there were no rainfall stations inside the two catchments, as such extreme rainfall series for the catchment as a whole and working out estimates of maximum 1-day rainfall for the required return periods are not possible.