HYDROMETEOROLOGY OF THE DAMODAR CATCHMENT

The hydrology of the Damodar Catchment has assumed great importance in view of the large multipurpose projects being undertaken in the basin. Glass, Central Technical Power Board, Satakopan, and Bose and Nag have worked on the subject. Their main conclusions regarding rainfall are briefly given below:

(a) Glass considered that the total mean rainfall on the whole catchment producing floods generally varies from about 3' in 3 days to a maximum of about 12' in 6 days.

(b) The Central Technical Power Board assumed a rainfall of 20' in the first half of the season and 5' in the latter half with a run-off coefficient of 90 per cent.

(c) Satakopan studied the rainfall of the Damodar Catchment utilising the data from 1891-1943. His main conclusions regarding the maximum probable rainfall are as follows:

(i) A storm giving more than 13 inches of mean rainfall over the catchment may occur once in about 65 years and one giving more than 15 inches once in about 120 years.

(ii) The worst storm can give in the neighbourhood of the catchment 22 inches rainfall in 7 days, out of which 15 inches may fall in 3 days and 8 inches in one day, but the probability of such a storm occurring over the catchment itself is extremely small and that it may be neglected for all practical purposes. A storm giving 18 inches rainfall in 6 days of which 15 inches may fall in 3 days and 7 inches in a day may be assumed as the maximum that is likely to occur over the catchment.

(d) Bose and Nag find that a rain-storm of magnitude equal to or greater than 12' will occur once in 100 years and greater than 14' in 250 years. Further a storm giving 16' is likely to be equalled or exceeded only once in 1000 years.

2. The conclusions regarding maximum rainfall reached by Bose and Nag are at variance with those of Satakopan. We had also been feeling that some matters which had not been looked into required examination and some others required more detailed examination than had been done before. A detailed analysis of rainfall, utilising also the data of rainfall (1944-1956) since available, therefore appeared to be necessary.

3. The authors of this paper have recently studied in detail the hydrometeorology of the Koyana Catchment. A detailed study of the Damodar Catchment on similar lines has been made. The question regarding the minimum period for which rainfall data should be available in a monsoon country like India to obtain a fair idea of the frequency distribution and probable maximum rainfall has also been considered.

4. A summary of the main results of analysis is given below:

(i) The main surface wind directions in the catchment during June to October are either between E to S or between SW to NW.
(ii) The difference in the normal rainfall of the catchment of June to September, June to October and annual based on data up to 1940 and up to 1950 is negligible.

(iii) The mean rainfall of the catchment is 45-8" for June to September, 45-1" for June to October and 51-2" for the year.

(iv) On an average 82 per cent of the annual rainfall occurs during June to September and 88 per cent during June to October. The percentage of annual rainfall which occurs at each of the raingauges during the monsoon period differs from the average of the catchment for this period by less than 3 per cent.

(v) Rainfall in July, August and September is equally variable while the fluctuations in June and October are considerably greater.

(vi) The distributions of seasonal rainfall and rainy days (June to September and June to October) are normal.

(vii) The daily, seasonal and annual rainfall of the catchment during 1891 to 1950 have not been appreciably affected by the variations in the number of raingauge stations.

(viii) There has been no significant change in rainfall during 1891-1950.

(ix) There is a five to one chance that rainfall of June to September and June to October will lie within ± 20 per cent of the normal. The corresponding limits for June to September are 33-4" to 50-1" and for June to October 36-3" to 54-3".

(x) Frequency distribution of daily rainfall for June to October 1891-1950 and for different sub-periods (10, 15, . . . . . . . . . 60 years) have been prepared. Similar frequency tables for rainfall of 2 to 7 consecutive days have also been prepared.

(xi) Semilogarithmic curves have been fitted to the frequency distributions for 1 to 7 days and probabilities of different rainfall amounts computed.

(a) The divergence in probabilities from month to month is very marked.

(b) Probabilities obtained by using data for various periods (10, 15, 20, 30, 40, 50 and 60) differ widely.

(c) Even in this catchment where rainfall is mainly during the monsoon months, data of at least 50 or 60 years are required for obtaining an idea of probable occurrence of rainfall of different amounts.

(d) The probable amounts of rainfall occurring once in about 1000 years based on data for the period 1891 to 1950 are as follows—

<table>
<thead>
<tr>
<th>Days</th>
<th>Inches</th>
<th>Days</th>
<th>Inches</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7-7</td>
<td>5</td>
<td>17-2</td>
</tr>
<tr>
<td>2</td>
<td>12-3</td>
<td>6</td>
<td>17-2</td>
</tr>
<tr>
<td>3</td>
<td>14-6</td>
<td>7</td>
<td>18-2</td>
</tr>
<tr>
<td>4</td>
<td>15-3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(e) A small difference in the rainfall amounts in higher ranges introduces big difference in probability values.

(xvii) A study has been made of the differences in probability values by using truncated distributions. The main result is that probability values differ considerably depending upon the assumptions made in preparing the frequency tables and the method of obtaining probability. As far as possible complete distributions should be used.

(xviii) The highest rainfall that has occurred over the catchment in one to seven days during the years 1891 to 1950 is as follows—

<table>
<thead>
<tr>
<th>No of days</th>
<th>Inches</th>
</tr>
</thead>
<tbody>
<tr>
<td>One day</td>
<td>9-91</td>
</tr>
<tr>
<td>Two days</td>
<td>7-40</td>
</tr>
<tr>
<td>Three days</td>
<td>9-21</td>
</tr>
<tr>
<td>Four days</td>
<td>10-68</td>
</tr>
</tbody>
</table>

(xix) The highest rainfall during a day at any station in the catchment during 1891 to 1950 was 12-8" at Kodarma on 1 August 1917.

(xx) Estimates of probable maximum rainfall have also been obtained by (1) using Gumbel's method for rainfall data of 5, 6 and 7 days separately, (2) by using truncated distributions of the form used by Satakopan and (3) considerations of moisture content and movement of air.
(xxii) The distribution of daily rainfall during storm periods of five to seven days has been examined and it is found that—

(a) On occasions of five day rainfall exceeding 7.5" generally more than 75 per cent of the rainfall had occurred in three consecutive days.

(b) On occasions of six day rainfall exceeding 9" generally more than 75 per cent of the rainfall had occurred in three days.

(c) On occasions of seven day rainfall exceeding 10", generally about 75 to 70 per cent of the rainfall had occurred in three days, and about 90 per cent of the rainfall in five days.

(xxii) Depth area curves have been drawn for some selected storms in the catchment.

(xxiii) A study has been made of storms in the neighbourhood of the catchment and the question of transposition of storms has been considered. Even on occasions when the tracks of the storms were over or near the catchment, much heavier rainfall than over the catchment fell in its neighbourhood. This would suggest that while transposing storms in their neighbourhood to the catchment the magnitude of the storms is likely to be affected.

(xxiv) The maximum probable rainfall in one to seven days is as follows—

<table>
<thead>
<tr>
<th>Days</th>
<th>Rainfall in inches</th>
<th>Days</th>
<th>Rainfall in inches</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7.5</td>
<td>5</td>
<td>17.0</td>
</tr>
<tr>
<td>2</td>
<td>12.0</td>
<td>6</td>
<td>17.5</td>
</tr>
<tr>
<td>3</td>
<td>14.0</td>
<td>7</td>
<td>18.0</td>
</tr>
<tr>
<td>4</td>
<td>16.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(xxv) Frequency distribution of average daily discharges at Rhondia based on data from 1934 to 1948 has been prepared for the months June to October. The highest average daily discharge during the period was 521500 cusecs on 10 October 1941 and the peak discharge on this date was 634000 cusecs. The highest peak discharge was 640000 cusecs on 12 August 1935.

(xxvi) A daily average discharge of 100000 cusecs is likely to be exceeded once in about 850 years.

(xxvii) High discharge at Rhondia (exceeding 200000 cusecs) on any date is very highly correlated with the rainfall recorded on the date and the preceding two days. This is also true of peak discharges.

(xxviii) The regression formula between rainfall of July to October with the corresponding seasonal flow expressed in inches is:

\[ D = 0.65 R - 8.68 \]

Using this formula discharges have been computed from 1891 to 1950. The highest and lowest discharge during July to October according to this formula are:

- Highest 1917 = 5621200 cusecs or 11148800 Acre feet.
- Lowest 1918 = 1794460 cusecs or 3559040 Acre feet.

(xxix) The influence of temperatures on monsoon seasonal run-off is not significant.

(xxv) The CCs of discharge on any day at Asansol with discharge of the following day (i.e., with a lag of one day) at Rhondia are very highly significant.

(xxvi) The rainfall of the catchment on any day is highly correlated with the discharge at Asansol on the following day.

(xxvii) Discharge of the Damodar river at Rhondia on any day is very highly correlated with the following:

(a) Rainfall of preceding day (0.73)

(b) Rainfall of preceding two days (0.80)

(c) Rainfall of preceding day and discharge of preceding day (0.82)

The regression formulae are:

(a) \[ D = 0.3979 \times D_{-1} + 5.7958 \times R_{-1} + 0.4275 \]

\[ (D \text{ in } 10,000 \text{ cusecs}) \]

(b) \[ D = 4.35 (R_{-1} + R_{-2}) + 0.9703 \]

\[ (D \text{ in } 10,000 \text{ cusecs}) \]

(c) \[ D = 71.70 R_{-1} + 14.6757 \]

\[ (D \text{ in } 1000 \text{ cusecs}) \]
A detailed account will be published separately as a Memoir of the India Meteorological Department.

Meteorological Office, Poona
S. K. PRAMANIK
K. N. RAO
January 11, 1952

REFERENCES
1. Glass, E. L., Selections from the records of the Bengal Government relating to Damodar Flood Control Project.

SUPERIOR MIRAGE OF LIGHTNING STREAKS

Unusual displays of lightning streaks extending several thousands feet into the cloudless air above the top of cumulonimbus clouds have been reported occasionally. A survey of these accounts reveals the following features:

1. The cumulonimbus cloud from which the flashes extended upwards was in a very active condition.

2. The cloud was frequently illuminated by the normal lightning flashes from inside or opposite sides, indicating that lightning activity was confined more to the opposite side of the cloud away from the observer.

3. The unusual flashes started from the top of the cumulonimbus cloud (but below the top of the anvil) and extended several thousands feet (3000 ft or more) above the anvil top into the clear sky. In these reports there was nothing to show that the flashes reached very high up to the ionosphere.

4. The unusual flashes looked like a “series of streamers extending from a single point at the centre of the anvil and spreading out like a fountain” or like an uprooted tree in an inverted position with the roots spreading out at the top.

5. The cumulonimbus cloud responsible for the display, happened to be situated far away; in one case the lower part was below the horizon.

6. The unusual flashes were purple in colour.

In Fig. 1 an attempt has been made to give a rough picture of the phenomenon as reported by different observers.

For an explanation of the phenomenon let us consider what happens inside a cumulonimbus cloud in an active condition. It is well known that a region of well marked inversion exists in the upper layers of these clouds. Some actual values of deviations of temperatures inside a cumulonimbus cell as compared with the temperatures outside in the clear air are obtainable from the results of the U. S. Thunderstorm Project. In ideal cases, for an active cell in the mature stage, the contrast in temperatures between the regions inside and outside was found to be practically negligible, up to 15,000 ft, but near 20,000 ft, the temperature inside the cloud was as much as 4°C higher than that of the environment.

Temperature inversions in the upper air have been known to give rise to the phenomenon known as “Superior Mirage”. Humphreys has reproduced some illustrations showing images of a distant object appearing inverted over the object itself, as in Fig. 2. The unusual lightning streaks appear to be examples of similar phenomenon. Due to the presence of the inversion, the densities inside the cloud decrease in an irregular manner with the height, with the