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ABSTRACT

A significant part of northern India is covered by the Himalayas, where a number of major Indian rivers originate. In the present study, a detailed analysis of rainstorms that affected the northwest region of the Himalayas has been made to assess the orographic effect of the Himalayas on precipitation in this region during the 135 years from 1875 to 2010. The study showed that the northwest Himalayas have experienced five most-severe rainstorms whose rain depths have not been surpassed so far. These severe rainstorms caused heavy to very heavy rainfall over the region that led to tremendous destruction to crops, communications, and livestock. Severe rainstorms have not occurred during the 2001–10 decade. It is also noticed that severe floods in this region have not occurred because of a “break monsoon situation” in the middle or eastern Himalayas.

1. Introduction

Precipitation provides the basic input for hydrological studies. However, it varies greatly in space and time within a range of mountains and also from one mountain range to another. The hydrological processes cannot be properly estimated until distribution of precipitation is known. The mountainous environment in comparison to the plain areas has a strong impact on precipitation distribution. In the mountainous regions, orography provides necessary uplift to the moisture-laden currents striking against a mountain or chain of mountains, which results in copious rainfall on the windward side of the mountains.

The Himalayas have a profound effect on the climate of the Indian subcontinent and the Tibetan Plateau. Review of studies on precipitation distribution over the Himalayas due to heavy rain spells has shown that a good number of studies have been carried out regarding different aspects of Himalayan climatology. Studies made by Dhar and colleagues (Dhar 1962; Dhar and Narayan 1965, 1966; Dhar and Bhattacharya 1975; Dhar et al. 1975; Dhar and Rakhecha 1976; Dhar et al. 1984, 1986, 1987; Dhar and Nandargi 1991) have shown that such studies are very important for planning, design, and operation of water resources and hydroelectric power projects in the region.

In the present study, an attempt has been made to study the severe rainstorms that occurred over the northwest Himalayan region during the past 135 years from 1875 to 2010.

2. The study region and data used

The northwest Himalayan region—which extends over most of the hill states of the western Himalayas including Jammu and Kashmir (J&K), Himachal Pradesh, Himalayan parts of Punjab–Haryana, and most regions of Uttaranchal state (see Fig. 1)—has been considered in the present study.

In the northwest Himalayan region considered, daily rainfall data of more than 150 stations, whose elevations vary from 300 to 4100 m MSL, and the data from the adjoining plains numbering about 350 stations were used for this study. This study is based upon the data of a 135-yr period from 1875 to 2010. The daily rainfall data have been obtained from various sources, namely

(i) monthly, seasonal, and annual reports, daily rainfall summary, weekly rainfall report, etc. of the India Meteorological Department (IMD) and the data from National Climate Data Center (NCDC), IMD, Pune;
(ii) rainfall records from the project authorities such as National Thermal Power Corporation (NTPC),
The national hydroelectric power corporation (NHPC), central water commission (CWC), New Delhi, working in the Himalayas for construction of irrigation systems and hydroelectric power projects in different river basins; (iii) the forest departments of the Himalayan states (1975–2000); (iv) the rainfall registration authorities of Punjab, Haryana, Himachal Pradesh, Uttar Pradesh, J&K, and Rajasthan supplied daily rainfall data of the rain spell for the concerned districts of their respective states; and (v) daily rainfall data available in volumes at IITM, Pune, for different provinces since 1871.

On the basis of this data and the scrutiny of past studies carried out over the northwest Himalayas, a list of heavy to very heavy rain spells that occurred over the regions has been compiled and the same has been used for further analysis.

3. Meteorological systems responsible for causing heavy rainfall over the northwest Himalayan region

The northwest India and the northwest Himalayan regions are particularly prone to vagaries of severe weather situations causing severe floods, disruption of communications, loss of human lives, etc. every year. This region is particularly influenced by western disturbances that originate from extratropics in the Mediterranean and Caspian seas and travel to Indian region mostly during winter season, giving snowfall, rainfall, and chilly weather conditions. On average, five to seven western disturbances move over the northwestern region of India during the winter months. An equal number of induced lows form to their south and move east and northeastward, giving heavy to very heavy rains over the plains of Punjab, Haryana, and Uttar Pradesh.

Normally, the southwest monsoon starts withdrawing from the northwest and adjoining regions of India from 15 September; it gets revived again in association with Bay of Bengal/Arabian Sea depressions, which move toward this region and interact with western disturbances (see Fig. 1), causing exceptionally heavy rainfall over the region, especially in J&K, sub-Himalayan regions of Himachal Pradesh, Punjab, and Uttarakhand Himalayas.

The tracks of monsoon depressions or low pressure areas from the Bay of Bengal sometimes recurve in a northerly to northeasterly direction when they travel over the central parts of the country (Dhar and Nandargi 1993c). This is mostly due to the movement of strong westerlies (western disturbances) over the extreme northwest to northeast Himalayas. The synchronization of movement of westerly waves in the extreme north with the passage of monsoon disturbances in the lower latitudes cause heavy to very heavy rainfall along the foothills of the Himalayas.

4. Selection of severe rainstorms

A severe rainstorm considered in this study is one that broadly satisfies the following criteria. These criteria were used by the authors in several of their studies of severe rainstorms of India (Dhar and Nandargi 1993a,b,c, 1995a,b):

(i) a rainstorm of a given duration should have a closed isohyetal pattern around its heavy rain center;
(ii) the heavy rain center should have received a rainfall of 20 cm or more on the day of maximum rainfall and a cumulative rainfall of 25 cm or more and 30 cm or more for the durations of the maximum second and third days of the rainstorm, respectively; and
(iii) the closed isohyetal pattern of the rainstorm on the maximum first, second, and third days of the rainstorm should have an areal extent of over 50 000 km² or more for each of the durations.
5. Severe rainstorm analysis

Following the above-mentioned criteria, the scrutiny of daily rainfall for the period of 135 years from 1875 has shown that there were five most-severe rainstorms that occurred over this region in the past. It is interesting to mention here that if we divide the entire 135-yr period into 25-yr subperiods, each subperiod has recorded one severe rainstorm (see Table 1); however, no severe rainstorms has been recorded during the present period of 2001–10. Except the 1955 rainstorm that occurred during 3–5 October, all other severe rainstorms occurred in the second fortnight of September.

As mentioned earlier, excepting September 1924, all these rainstorms were associated with the interaction of monsoon disturbances from the Bay of Bengal and western disturbances from the northwest region moving over the study region at the same time. It is also to be mentioned here that the September 1947 rainstorm was in association with a disturbance that originated from the Arabian Sea. These rainstorms were subjected to the depth–area–duration (DAD) method of rainstorm analysis and it was found that these severe rainstorms occurred over an area of more than 100 000 km². However, their DAD rain depths are given for standard areas up to 50 000 km² in Table 2 for comparison and their DAD curves are shown in Fig. 2.

It is seen from Table 2 and Fig. 2 that for 1- and 2-day durations, the 17–18 September 1880 rainstorm (see Fig. 3) is definitely much more severe than all the other 3-day-duration rainstorms. The rainstorms of September 1924, October 1955, and September 1988 are more or less similar in severity, yielding almost the same rain depths for the 3-day duration. The rainstorm of September 1947

### Table 1. Distribution of most-severe rainstorms during 1875–2010 over the northwest Himalayas.

|--------------|-----------|---------|---------|---------|-----------|

### Table 2. Average rain depths (cm) for 1-, 2-, and 3-day durations of most-severe rainstorms that occurred over northwest Himalayas.

<table>
<thead>
<tr>
<th>Rainstorm</th>
<th>Storm center (district)</th>
<th>Area in hundreds of km²</th>
</tr>
</thead>
<tbody>
<tr>
<td>24 Sep 1988</td>
<td>Nawanshahr (Jullundur)</td>
<td>51.4 51.0 49.0 46.9 43.4 37.0 31.8 27.6 20.6</td>
</tr>
<tr>
<td>24-25 Sep 1988</td>
<td>Nawanshahr (Jullundur)</td>
<td>64.9 63.3 59.5 56.2 52.0 45.3 42.8 38.8 31.5</td>
</tr>
<tr>
<td>24-26 Sept 1988</td>
<td>Basohli (Kathua)</td>
<td>81.1 80.9 79.7 78.0 74.7 66.2 62.0 54.1 41.5</td>
</tr>
<tr>
<td>5 Oct 1955</td>
<td>Aliwal (Ambala)</td>
<td>49.5 48.0 45.7 45.0 43.8 40.5 35.5 28.9 19.9</td>
</tr>
<tr>
<td>4-5 Oct 1955</td>
<td>Batala (Gurdaspur)</td>
<td>69.1 67.7 65.5 63.5 61.2 55.7 51.0 43.8 32.5</td>
</tr>
<tr>
<td>3-5 Oct 1955</td>
<td>Batala (Gurdaspur)</td>
<td>82.6 81.0 75.3 69.7 63.9 58.4 53.4 47.2 38.4</td>
</tr>
<tr>
<td>26 Sep 1947</td>
<td>Dadupur (Ambala)</td>
<td>30.5 29.9 28.6 27.3 26.0 23.5 20.8 17.7 14.9</td>
</tr>
<tr>
<td>26-27 Sep 1947</td>
<td>Dadupur (Ambala)</td>
<td>40.6 40.4 39.1 38.4 37.1 34.2 30.8 25.8 21.0</td>
</tr>
<tr>
<td>25-27 Sep 1947</td>
<td>Dadupur (Ambala)</td>
<td>56.3 55.3 51.0 48.4 45.8 42.4 38.2 32.6 26.8</td>
</tr>
<tr>
<td>29 Sep 1924</td>
<td>Lansdowne (Garhwal Himalayas)</td>
<td>35.1 34.9 33.8 32.9 31.0 27.1 25.0 23.0 18.5</td>
</tr>
<tr>
<td>28-29 Sep 1924</td>
<td>Lansdowne (Garhwal Himalayas)</td>
<td>59.4 58.2 57.1 56.0 54.0 49.5 44.5 38.8 33.8</td>
</tr>
<tr>
<td>28-30 Sep 1924</td>
<td>Lansdowne (Garhwal Himalayas)</td>
<td>77.5 76.8 75.5 74.0 70.9 63.5 55.8 49.0 41.0</td>
</tr>
<tr>
<td>18 Sep 1880</td>
<td>Nagina (Bijnor)</td>
<td>82.3 82.0 80.0 77.5 73.6 62.8 51.5 40.5 26.3</td>
</tr>
<tr>
<td>17-18 Sep 1880</td>
<td>Nagina (Bijnor)</td>
<td>104.1 103.5 100.0 99.1 95.9 86.8 76.8 63.0 41.4</td>
</tr>
</tbody>
</table>
is somewhat less severe than all the remaining four rainstorms. Figure 4 shows the 3-day isohyetal pattern of 24–26 September 1988 rainstorm.

5. Conclusions

This paper has brought out the fact that heavy to very heavy rainfall occurs in the northwest Himalayas during the withdrawal phase of the monsoon season in association with the western disturbances moving over this region. The five cases discussed in this paper have yielded the highest rain depths and can safely be utilized for estimating probable maximum precipitation (PMP) values or for design storm studies of the river basins in this region. However, it may be said that of all the five most-severe rainstorms, the rain depths yielded by the 2-day September 1880 rainstorm have not been surpassed during the last 135 years!

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FIG. 2. One- to three-day DAD curves of most-severe rainstorms over the northwest Himalayas.

FIG. 3. Two-day isohyetal pattern of 17–18 Sep 1880 rainstorm over the northwest Himalayas.
REFERENCES


