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Hydrometeorological study of Karanja project in Karnataka State for estimating design storm

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सार — जल ग्रहण क्षेत्र द्वारा अनुभूत संभावित अधिकतम वर्षा और विभिन्न आवर्ती अवधियों के अभिकल्प तूफान की गहराइयों के अनुमान लगाने के लिए करंजा बांध स्थल तक जलग्रहण क्षेत्र का विवस्तृत जल मौसम विज्ञान अध्ययन किया गया है। इसमें 1891–1984 अवधि की वर्षा के आंकड़ों का प्रयोग किया गया है। इससे पता चलता है कि पिछले 94 वर्षों के रिकार्ड के दौरान क्रमशः 1, 2 और 3 दिनों की अवधि में जलग्रहण क्षेत्र द्वारा 193, 258 और 312 मि. मी. अधिकतम वर्षा का अनुभव किया गया। सितम्बर 1908 और जुलाई 1965 के तेज वर्षा वाले तूफान का जो कि जल-ग्रहण क्षेत्र के आस-पास समांगी प्रदेश में आए थे, प्रसंभाव्य अधिकतम वर्षा की गहराइयों का अनुमान लगाने के लिए क्रम बदल किया गया। 1, 2 और 3 दिनों की अवधियों के लिए प्र.अ.व. क्रमशः 338, 406 और 424 मि. मी. पाई गई जो कि जल ग्रहण क्षेत्र द्वारा अनुभूत सदृश अधिकतम वर्षा गहराइयों के लगभग 1.4 से 1.8 गुणा हैं। ये अभिकल्प अनुमान हलहली में करंजा नदी के पास विद्यमान बांध के उतलव मार्ग क्षमता के पुनर्निर्धारण के लिए उपयोगी हो सकते हैं।

ABSTRACT. A detailed hydrometeorological study of the catchment upto the Karanja dam site has been made to estimate the design storm depths of different return periods and the probable maximum rainfall likely to be experienced by the catchment using rainfall data of the period 1891-1984. It has been found that the catchment experienced maximum rainfall of 193, 258 and 312 mm during 1, 2 and 3 days period respectively during the the last 94 years of record. Severe rainstorms of September 1908 and July 1965 which occurred in a homogeneous region around the catchment were transposed to estimate probable maximum raindepths (PMP). The PMP for 1, 2 and 3 days durations were found to be 338, 406 and 424 mm respectively which are about 1.4 to 1.8 times the corresponding maximum raindepths experienced by the catchment. These design estimates will be useful for the re-assessment of the spillway capacity of the existing dam across the *Karanja* river at Halhalli.

1. Introduction

A dam was constructed across the *Karanja* river at Halhalli in the Bidar district by the State Government Karnataka for utilization of its waters for irrigation. The project authorities of the dam are contemplating for improvements in the design of spillway capacity of the existing dam. The design of spillway capacity, needs an assessment of the spillway design flood based on long period flow data. Streamflow data for the *Karanja* river are available for the period 1964-1980 only and this short period of flow record is considered to be inadequate for estimating the design flood by statistical methods. The design flood could be estimated from design storm raindepths by standard hydrologic techniques. The estimates of design storm require long period rainfall and other meteorological data which are fortunately available for stations in and around the Karanja catchment. With this in view, an attempt has been made to determine design storm raindepths for different return periods and probable maximum rainfall likely to be experienced by the Karanja catchment using long period rainfall data. The estimate of probable maximum rainfall can then be used to determine probable maximum flood and the spillway capacity by reservoir routing the hydrograph of the probable maximum flood.

The location map of the Karanja river catchment is shown in Fig. 1. The catchment area of the *Karanja* river is located in the northern part of Karnataka and adjoining Andhra Pradesh at longitude 76°59′ to 77° 45′ E and latitude 17° 30′ to 18°07′ N. The river originates in the hills of Medak district of Andhra Pradesh and after flowing in a northwesterly direction through Medak district, it enters Karnataka and then flows west and northwest direction through Bidar district. The river finally joins the river *Manjra*. The catchment area upstream of the dam is about 2025 km^2 of which 562 km^2 lies in Andhra Pradesh and 1463 km^2 in Karnataka State.

2. Rainfall data used and procedure adopted

For the determination of design storm depths of different return periods a series comprising of the maximum catchment rainfall which had occurred in each year of long available record has to be constructed.

Fig. 1. Location map of Karanja catchment

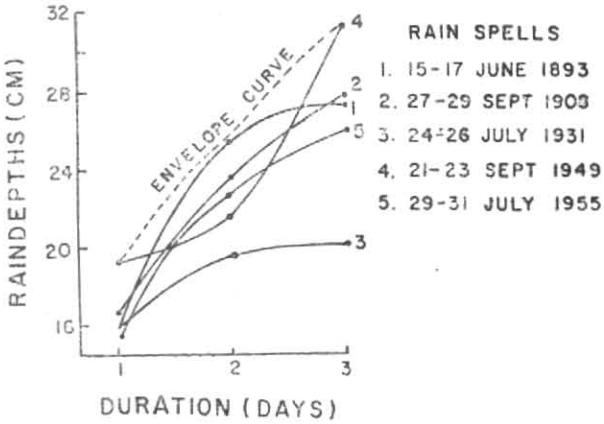


Fig. 2. Depth-duration curves of 5 highest rainspells

The determination of PMP involves comprehensive analysis of severemost rainstorms that have occurred in the meteorologically homogeneous area in and around the catchment of interest.

The Karanja catchment is inadequately gauged and there are hardly three raingauge stations namely Bidar, Humanabad and Zahirabad within the catchment. These have only 28 years of concurrent records. The short period of 28 yeras has been considered to be inadequate, for estimating design storm depths. Consequently, data of stations lying outside the catchment have also been used. It was found that Gulbarga, Sangareddy and Chincholi are the only stations close to the catchment which have long period rainfall data. The rainfall data of these three stations in combination with the stations within the catchment have been used for the detailed design storm study. A summary of the data available with period of record is shown in Table 1.

The mean catchment rainfall has been estimated by Thiessen polygon method. For this purpose, three separate sets of Thiessen polygons were constructed using a combination of stations, with concurrent rainfall data. The Thiessen weighting factors obtained for each of the Thiessen polygons are given in Table 2. The individual rainfall values were weighted by the appropriate Thiessen factor to obtain an estimate of mean catchment rainfall.

3. Rainfall characteristics of the Karanja catchment

The catchment area upstream of the damsite which is 2025 km^2 lies between Longs. 77°0′ to 77° 45′E and Lats. 17° 30′ to 17°55′N. The southwest monsoon normally sets in over this region in the 1st week of June and withdraws in the 2nd week of October. The heaviest rainfalls are not the result of the monsoon alone, but are triggered by westward or northwestward movements of depressions that form in the Bay of Bengal. During their formation and movement across India, these depressions cause heavy rain on the coastal area and the rainfall shifts westwards alongwith the depressions. The Peninsular rivers such as the *Karanja*, get heavy rainfall towards the end of August or beginning of September when the monsoon depressions move in a more southerly direction.

The mean monthly and annual rainfall of the catchment upto the damsite (Halhalli) has been worked out by the Thiessen polygon method using appropriate weighting factors. Table 3 gives the mean monthly and annual rainfall of the Karanja catchment upto the damsite.

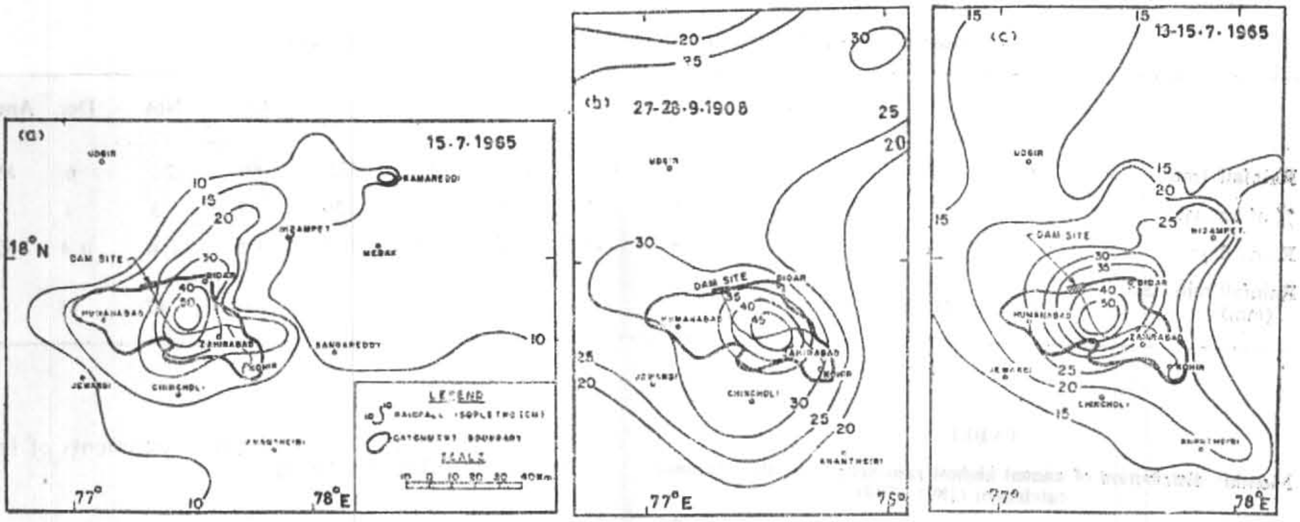
The mean annual rainfall of the catchment has been estimated as 898 mm. About 80% of the annual total is received during the southwest monsoon season of June to September. Further the months of July to September are seen to be the rainiest ones with each having about 11 rainy days whereas June has about 7. Table 3 shows that the months of June to November excepting September get rainfall per rainy day of the same order of 17 mm whereas September gets 22 mm. Large number of rainy days and higher values of rainfall per rainy day in September shows that rainstorms of severe nature with longer durations are more likely to occur in this month.

4. Design storm analysis

Design storm of a catchment is defined as that maximum average depth of rainfall which is adopted for derivation of the design flood. The determination of design storm involves comprehensive analysis of all the major rainstorms that have occurred within or near the catchment. The estimate of maximum average depth of rainfall is then obtained by depth duration (DD) or depth area duration (DAD) analysis.

4.1. *Analysis of heavy rainspells over the Karanja catchment*

An attempt has been made to find out those rainstorms which gave maximum rainfall over the Karanja catchment. For this purpose, daily rainfall data of stations within the catchment were examined for the period 1891 to 1984 and one heaviest rainspell, actually experienced by the catchment was selected, for each year.



Figs. 3 (a-c). 1-day (July 1965), 2-day (Sep 1908) and 3-day (Jul 1965) isohyetal patterns

TABLE 1

Summary of rainfall data available

S. No.	Station	Record available
1	Bidar	1891-1984
2	Chincholi	1950-1984
3	Gulbarga	1891-1984
4	Humanabad	1957-1984
5	Sangareddy	1891-1984
6	Zahirabad	1957-1984

TABLE 2

Thiessen polygon network and their weighting factors

	Stations	Period	Weighting factor
Set 1	Bidar	1891-1949	0.92
	Gulbarga		0.04
	Sangareddy		0.04
Set 2	Bidar	1950-1956	0.66
	Chincholi		0.30
	Gulbarga		0.02
	Sangareddy		0.02
Set 3	Bidar	1957-1984	0.23
	Chincholi		0.01
	Gulbarga		0.01
	Humanabad		0.36
	Sangareddy		0.01
	Zahirabad		0.38

Heavy rainfall over this catchment has been found to occur in spells of 2 to 3 days durations. For each rainspell mean catchment rainfall depth for 1, 2 and 3-day durations upto the damsite (area 2025 km^2) were computed by the Thiessen polygon method using appropriate weighting factors of stations with concurrent records.

The frequency of occurrence of 94 annual highest rainspells in different months over the Karanja catchment is given in Table 4. Table 4 shows that the majority of heavy rainspells have occurred in the month of September. Besides the monsoon season, heavy rainspells have also occurred in the post monsoon months of October and November, but their frequency is comparatively less.

The average catchment rainfall depth of the ten highest rainspells during the 94-year period are given in Table 5 for 1, 2 and 3-day durations.

4.2. *Depth duration (DD) analysis*

With a view to obtain the enveloping or maximum raindepths experienced by the catchment, the raindepths for 1, 2 and 3-day durations were plotted as depth duration (DD) curves for each year (Fig. 2). In this way 94 DD curves were drawn for the 94 rainspells and the enveloping curve was then drawn. The enveloping depth-duration curve gives the maximum depth of rainfall over the catchment for different durations. The envelope rainfall depths are given in Table 6.

Depth duration analysis has shown that the rainstorm of 1949 produced the maximum rainfall over the Karanja catchment for 1 and 3 days durations whereas for 2 days duration maximum rainfall was caused by the rainstorm of 1893. Table 6 shows that maximum 1, 2 and 3-day rainfall are about 21, 29 and 35 per cent respectively of the mean annual catchment rainfall. This shows that more than a third of the annual rainfall over the Karanja catchment can occur in the course of 3 days. Similar results have been obtained in the design

TABLE 3

Mean monthly and annual rainfall for the Karanja catchment upto the damsite

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Rainfall (mm)	6	9	12	25	25	126	202	165	235	60	27	6	898
% of annual	1	1	1	3	3	14	22	18	26	7	3	1	
Rainy days	0.5	0.8	1.1	2.1	2.4	7.4	11.5	10.0	10.7	3.6	1.6	0.4	52.1
Rainfall/rainy day (mm)	12	11	11	12	10	17	18	17	22	17	17	15	

TABLE 4

Monthly distribution of annual highest rainspells over the Karanja catchment (1891-1984)

	May	Jun	Jul	Aug	Sep	Oct	Nov	Total
Frequency	1	10	21	22	29	8	3	94
% of the total	1	11	22	23	31	9	3	

TABLE 5

Ten highest raindepths experienced by the catchment

S. No.	Rainfall (mm) 1-day	2-day	3-day
1	193	258	312
2	171	235	277
3	166	224	269
4	160	214	259
5	158	202	258
6	153	195	233
7	146	194	226
8	135	185	212
9	133	180	206
10	132	180	204

TABLE 6

Envelope raindepths experienced by the Karanja catchment upto the damsite

Storm duration	Envelope raindepths (mm)	% of mean annual catchment rainfall	% of 3-day catchment rainfall
1-day	193 (1949)	21	62
2-day	258 (1893)	29	83
3-day	312 (1949)	35	100

TABLE 7

Design raindepths (mm) for different return periods

Duration	100-yr	1000-yr	10,000-yr
1-day	199	267	335
2-day	263	351	438
3-day	312	417	521

storm studies of a number of river catchments of India (Dhar and Rakhecha 1979).

5. Frequency analysis of catchment rainfall

In order to determine the design raindepths of this catchment, for different return periods, the annual maximum catchment raindepths for 94 years period for 1, 2 and 3-day durations have been subjected to Gumbel distribution. The theoretical relationships for estimating design raindepths for different return periods for 1 to 3 days durations are as follows :

$$R_1 = 8.0 + 3.8\ k_T \quad (1)$$

$$R_2 = 11.0 + 4.9\ k_T \quad (2)$$

$$R_3 = 13.0 + 5.8\ k_T \quad (3)$$

where R_1, R_2, R_3 are the maximum catchment raindepths (cm) for 1, 2 and 3-day durations respectively and

$$k_T = -[1.1 + 1.795 \log_{10} \log_{10} \{T/(T-1)\}].$$

Using above equations, maximum raindepths for 100 1,000 and 10,000 years return periods for 1, 2 and 3-day durations have been computed. The raindepths for different return periods are given in Table 7.

It can be seen that the envelope or maximum raindepths obtained from the depth-duration envelope curve (*vide* Table 6) almost correspond with the 100-year values estimated by frequency analysis method. Design storm studies in respect of the Mahi catchment upto Kadana (Dhar *et al.* 1975) and the Bhima upto Ujjaini (Dhar *et al.* 1970) have shown that envelope raindepths have comparatively low return period of about 100 years.

6. Estimation of Probable Maximum Precipitation (PMP)

Probable maximum precipitation (PMP) has been defined as the greatest depth of precipitation for a given duration that is physically possible over a catchment or a drainage area. Estimates of PMP are used in the design of all hydraulic structures, which in the event of failure would cause large loss of life and property. The basic procedure in determining PMP estimates over a

TABLE 8

DAD and transposed raindepths (mm) of the severemost rainstorms over the Karanja catchment

Rainstorm period	1-day		2-day		3-day	
	DAD	Transposed	DAD	Transposed	DAD	Transposed
27-29 Sep 1908	275	254	388	369	407	373
13-15 Jul 1965	325	282	345	315	389	353

TABLE 9

Parameters used for moisture adjustment factor

Rainstorm period	Storm dew point (°C)	Precipitable water (mm)	Maximum dew point (°C) for Karanja catchment	Precipitable water (mm)	Maximisation factor
27-29 Sep 1908	23.7	71	24.4	78	1.10 (78/71)
13-15 Jul 1965	23.1	69	25.2	83	1.20 (83/69)

basin is the adjustment of precipitation values from observed severe rainstorms for maximum moisture. When the sample of severe rainstorms over the basin is not adequate, the record of storms is increased by transposition of major storms from meteorologically homogeneous area surrounding the basin. *Manual of Hydrometeorology* (India Met. Dep. 1972) has described the method of transposition of storms from one area to another. Its greatest usefulness is in setting a definite absolute lower limit for PMP.

An estimate of probable maximum precipitation likely to be experienced by the Karanja catchment has been obtained by a study of major storms that were experienced in the homogeneous area in and around the catchment. An examination of severemost rainstorms has shown that in the past, two severemost rainstorms have occurred in the homogeneous area in and around the catchment during the 94-year period. The dates of occurrence of these two storms are :

(*i*) 27-29 September 1908 (Centred at Ibrahimpatnam) and

(*ii*) 13-15 July 1965 (Centred at Nizamsagar).

It is fortunate that the recorded storms of 27-29 September 1908 and 13-15 July 1965 have been analysed in detail (Dhar *et al.* 1982). It was then concluded that July 1965 rainstorm gave maximum raindepths upto an area of 2000 km² for 1-day duration and Sep 1908 contributed for 2-day & 3-day durations. From a meteorological view point there is every reason to expect that the storms of 1908 and 1965 can occur over the Karanja project (Gadgil and Iyanger 1980).

The isohyetal patterns of these two storms were then transposed over the Karanja project so as to achieve the maximum average raindepths over the catchment. The transposed raindepths alongwith DAD raindepths for an area of 2025 km² upto the existing damsite for different durations are given in Table 8.

The transposed 1-day pattern for July 1965, 2-day pattern for September 1908 and 3-day pattern for July 1965 are shown in Figs. 3 (a, b & c) respectively.

It can be seen from the Table 8 that the July 1965 was severemost for 1-day duration whereas Sep 1980 was for 2 and 3-day durations. The transposed raindepths for these rainstorms are about 90% of DAD raindepths for different durations.

7. Storm maximisation

In evaluating PMP for the Karanja catchment, the transposed raindepths are adjusted by the moisture maximisation factor. The moisture adjustment factor is a ratio between the maximum moisture observed over the catchment during the period when the storm occurred to the moisture observed in the storm. During storms the use of surface dew points at a number of stations measured in the warm moist air gives satisfactory estimates of moisture available in the atmosphere. The corresponding values of maximum total moisture in the Karanja catchment within 15 days of the storms and the total moisture that occurred during the storms of 27-29 Sep 1908 and 13-15 July 1965 have been computed from their respective surface dew point temperatures. The maximum 24-hour persisting dew point temperature for the Karanja catchment in July and September months have been found to be 25.2°C and 24.4°C respectively from the 5 representative stations lying in the path of the moisture inflow. The storm dew point temperatures for September 1908 and July 1965 storms have been found to be 23.7°C and 23.1°C respectively.

Table 9 shows the values of parameters used for evaluating the moisture adjustment factor, where the dew points are expressed in their 1000 mb equivalents.

The maximisation factors obtained for the September 1908 rainstorm and for the July 1965 rainstorm have been found to be 1.10 and 1.20 respectively. Dhar and Mhaisker (1968) worked out moisture maximisation factor of the order of 2 to 26 per cent for the southern-half of Indian Peninsula.

7.1. *Estimates of Probable Maximum Precipitation (PMP) for different durations*

The following estimates of PMP have been obtained by adjusting transposed raindepths (Table 8) by the appropriate maximisation factor:

1-day, PMP - $282 \times 1.20 = 339$ mm (1965 rainstorm)

2-day, PMP - $369 \times 1.10 = 406$ mm (1908 rainstorm)

3-day, PMP - $353 \times 1.20 = 424$ mm (1965 rainstorm)

The PMP for 1, 2 & 3 days durations were found to be about 1.4 to 1.8 times the corresponding maximum raindepths experienced by the catchment.

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