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Estimation of PMP and Precipitations of Various Return Periods Using Statistical Approach–A Case Study for Gunderipallam Dam, Tamil Nadu, India

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Abstract: Extreme events like floods and droughts are of concern for any country in the context of the damage caused to life as well as property. For adequate management measures to minimize the extent of damage Flood inundation maps are prepared, for which the peak discharges have to be estimated. Flood inundation maps that are prepared help to carry out the Emergency Action Plans for the downstream villages. One of the main objectives for DRIP is to create Flood inundation maps for various scenarios such as PMF, SPF, and various Return Periods etc. In this study, Gunderipallam dam is selected among the 66 dams in Tamil Nadu that are considered under DRIP. The Hershfield Method is used for estimating the PMP and Extreme value distribution analysis using Easy Fit Software is used for estimating the precipitations of various return periods. The hydrograph for the PMP and Precipitations of various Return Periods can be estimated using the Hydrologic Model HEC HMS 4.1.

Keywords: *Probable Maximum Precipitation (PMP), Probable Maximum Flood (PMF), Standard Project Flood (SPF), Dam Rehabilitations and Improvement Project (DRIP), Hydrologic Engineering Center (HEC), Hydrologic Modeling System (HMS),Water Resource Department(WRD)*

1. Introduction

Flood is one of the most common hydrologic extremes frequently experienced by any country. The rainfall received in India is not uniformly distributed both in time and space. Tamil Nadu has been frequently affected by severe floods and has suffered from many flood disasters in terms of the population affected, frequency, extent of inundation and socio-economic costs. Due to rapid land use changes, encroachment and sedimentation, the rivers may not be able to carry the excessive runoff resulting from heavy rains of high intensity. As a result, the river overflows and water enters the flood plain.

1.1 Probable Maximum Precipitation

The Probable Maximum Precipitation (PMP) is defined as the greatest or extreme precipitation that is physically possible in a region as a result of severe most combinations, including rare combinations of meteorological and hydrological factors. Estimates of PMP are used for calculating the probable maximum flood (PMF) for spillways of large dams where no risk of failure can be accepted. They may also be used to determine the extent of flood plain areas at risk in extreme flood condition. If a spillway is not able to safely release the PMF, breaching of the dam wall due to overtopping can occur and cause heavy loss of lives and damages to property. Also for planning and management for hydraulic structures of medium and minor nature such as bridges, culverts, storms drainage works etc., require estimates of design rainfall of specific return periods.

1.2 Need for the Study

Tamil Nadu is one of the States in India having significant number of dams and there is a constant need to strengthen and maintain the dams important to ensure that dam structures and systems are properly maintained by regular monitoring and rehabilitation. One of the main objectives for Dam Rehabilitation and Improvement Project (DRIP) is to create Flood inundation maps for various scenarios such as PMF, SPF, and various Return Periods etc. So it is necessary to estimate the PMP and Precipitations of various Return Periods which is taken as the objective for this study.

1.3 Objectives for the Study

1) To estimate the PMP using Hershfield Approach.
2) To estimate the precipitation for various return periods like 25 year, 50 year, 100 year using extreme value distribution.
3) To estimate the PMF and Design Flood for various return periods using HEC HMS software.

2. Study Area Description

Gunderipallam dam is built across wild streams at the confluence of Kadambur hill and later downstream channel joins with Bhavani River, a tributary of Cauvery. It is an earthen dam constructed in the year 1978. The Gunderipallam Reservoir Watershed lies between 11°30’ and 11°40’N Latitude and 77°20’ and 77°30’E Longitude. The catchment area of Gunderipallam Reservoir is 72.23 Sq.km. The entire catchment lies in the steep hilly slope of Guttiyalattur

Reserved Forest area in Sathyamangalam Forest which is influenced by both monsoons. The location of study area is shown in figure 2.1.

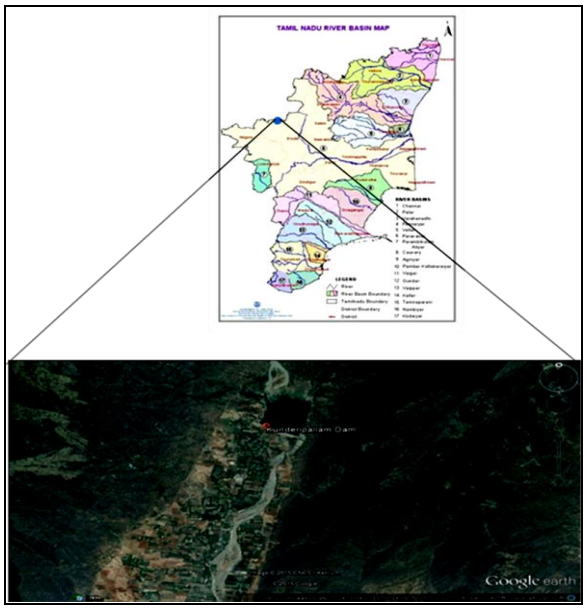

Figure 2.1 *Google Earth image of dam*

2.1 Gunderipallam Reservoir

The Government of Tamil Nadu, G.O.Ms.No.18 PWD dated 03-01-1974 has accorded administrative approval for the formation of Gunderipallam Reservoir. This reservoir is located at the foot of southern part of Western Ghats in Sathyamanagalam Forest range and at distance of 60 km North West of Erode town and 21km from Sathyamangalam of taking from Sathy Athani road at Vanipudur village. The agricultural economy of the area is solely depending on regular and periodical rain. When rain fails and drought condition prevails in the region, the economic balance will be badly affected. To improve the above condition, it has been proposed to construct Gunderipallam Reservoir, for storing the flood water of Gunderipallam stream during monsoon period and utilize the same for irrigation of other purpose during the deficit rainfall was received. Figure 2.2 shows the Plan of the dam.

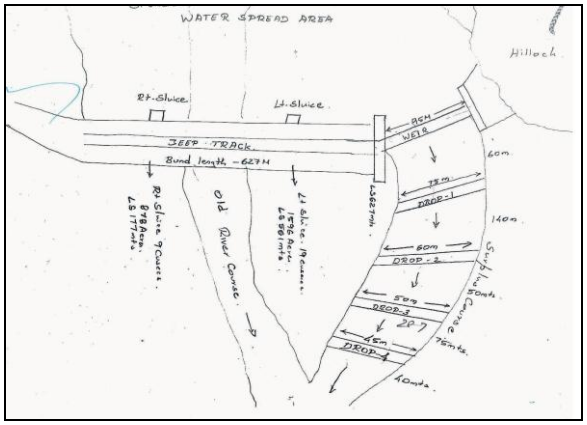

Figure 2.2 *Plan of the dam*

2.2 Hydraulic Particulars of the Dam

Reservoir

Catchment area	: 72.23 km^2.
Design flood	: 299.63 m^3/s
F.R.L.	: +300.09 m
M.W.L.	:+301.10 m
Area at F.R.L.	:0.61 km^2

Dam

Type	: Earth dam
Top of roadway	: +302.83 m
Maximum height	: 17.70 m
Length	: 627.00 m

Surplus Arrangements

Uncontrolled masonry weir on the left flank

Length	: 95.00 m
Crest	: +300.09 m
Discharge capacity	: 299.63 m^3/s

Source: WRD office, Chepauk.

3. Methodology

The methodology for the estimation of Probable Maximum Precipitation using Hershfield Technique and precipitations of various return periods using Extreme value distribution are described in figure 3.1. The precipitations for the study area are collected. Using Statistical Methods the PMP and the precipitations of various return periods are calculated. For creating the model, the Digital Elevation Model (DEM) was delineated for the study area by downloading the ASTER data. The input parameters are calculated using formulas. Then the HEC HMS model is run for simulation and peak discharge is estimated.

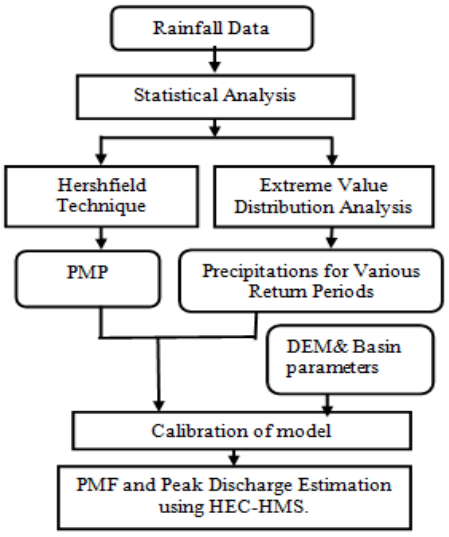

Figure 3.1 *Methodology for estimation of PMF*

4. Time Series for Gunderipallam

The Daily Rainfall Data for the Gunderipallam site has been collected from the Statistical Department, Chennai. Then the annual maximum 1-day rainfall data have separated from the data. A Time series graph is drawn is between Year Vs Annual Maximum Rainfall which is shown in fig3.4. It was found that the mean of the time series is found to be 97.76mm which is indicated by red line in the figure 4.1 and the maximum rainfall of 265mm was occurred in the year 1978.

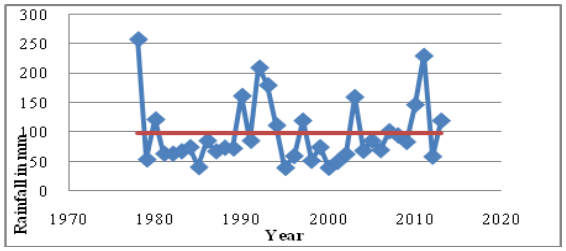

Figure 4.1*One Day Annual Maximum Rainfall series for gunderipallam*

4.1 Estimation of PMP by Hershfield Method

Statistical method used for estimating point PMP at a station or over an area is based upon the assumption that information regarding extreme rainfall is contained in the long rainfall records of that station/area. Hershfield (1961) for the first time used the statistical method for the estimation of PMP for USA. Preliminary appraisal of this technique in Canada (Bruce and Clark, 1966) and in USA (Myers, 1967), has shown that the PMP estimates obtained by this approach are closely comparable to those obtained by the conventional moisture maximization and storm transposition methods. The World Meteorological Organization (WMO) in their various manuals and technical publications (World Meteorological Organization, 1969, 1970, 1986) have also recommended this method for estimation of point PMP for those river basins whose daily rainfall data are available for a long-period of time. Hershfield technique was also described in the dam safety report for Cauvery basin for estimation of PMP

The Hershfield Method is described in equation 4.1,

$$X_{PMP} = \overline{X} + \sigma \times K_m \qquad (4.1)$$

Where,

X_{PMP} = PMP estimate for a station,
$\overline{X}$ = mean of the annual extreme series,
σ = standard deviation of the annual extreme series and
K_m= Frequency factor for PMP.
Frequency factor 'K_m' is obtained by equation 4.2.

$$K_m = (X_{max} - \overline{X_{n-1}}) / \sigma_{n-1} \qquad (4.2)$$

Where,

X_{max} = largest value of the annual extreme series,
$\overline{X_{n-1}}$= mean of the annual maximum series omitting the largest value from the series,
σ_{n-1}= standard deviation of the annual extreme series omitting the largest value from the series.

Table 4.1 *Parameters of Hershfield Equation*

S No	Parameters	Estimated values
1	$\overline{X}$	97.66 mm
2	σ	54.388 mm
3	X_{max}	258 mm
4	$\overline{X_{n-1}}$	90.07 mm
5	σ_{n-1}	43.41 mm

By substituting the values from table 4.1, the frequency factor is estimated as 3.895. Then the K_m value is substituted in chow's equation. The result of chow's equation is PMP. The estimated PMP for Gunderipallam is 310 mm which lies in the range of 200-800 mm in PMP atlas of the Cauvery basin flood estimation report.

4.2 Estimation of Parameters for Best Fit Distribution

Many methods are available for parameter estimations, which include the method of moments(MM), maximum likelihood estimation (MLE), the least squares method (LS), L-moments and generalized probability weighted moments (GPWM).The MLE method is considered in this study because it provides the smallest variance as compared to other methods. Statistical Software EasyFit is used to determine the best fit distribution for the annual maximum rainfall series for the Gunderipallam site. Goodness of Fit is the common test to determine the best fit distribution. It was found that Log Pearson type III distribution is selected based on the minimum error. The results are shown in table 4.2.

Using the Frequency factor table for the log Pearson type 3 Distribution, the frequency factors for various return periods are estimated and substituting these factors in chow's equation, the precipitations are estimated which is shown in Table 4.3.

Table 4.2 *Results of Goodness of Fit Test*

SL NO	DISTRIBUTIONS	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
1	Log Pearson Type III	0.08928	1	0.29647	1	1.2269	2
2	Normal	0.22441	4	2.1189	4	12.091	4
3	Log Normal	0.10745	2	0.3109	2	0.6654	1
4	Gumbel Maximum Value	0.16211	3	0.9743	3	8.4225	3

Table 4.3 *Precipitations for various Return Periods*

Return Periods (Years)	Frequency Factors K_t	Rainfall (mm)
25	2.146	214
50	2.743	247
100	3.330	279

4.3 Model Description

The Geospatial Hydrologic Modeling Extension (HEC-GeoHMS) is a software package for use with the ArcView Geographic Information System. GeoHMS uses ArcView and Spatial Analyst to develop a number of hydrologic MODELLING inputs. Analyzing digital terrain information, HEC-GeoHMS transforms the drainage paths and watershed boundaries into a hydrologic data structure that represents the watershed response to precipitation. The Basin model is prepared by processing the DEM in HEC-GeoHMS.

4.3.1 HEC-GeoHMS Pre-processing

Initially DEM for the delineated study area is created by downloading ASTER data 30x 30m resolution in the ArcGIS which is shown in figure 4.2. It is observed that the maximum and minimum elevation is found to be 1461 m and 240 m.

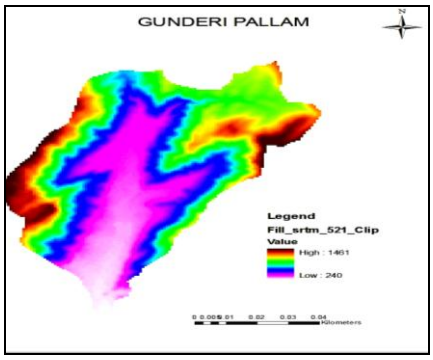

Figure 4.2 *DEM for Gunderipallam*

Then the terrain pre-processing steps are carried out gives the following output as shown in figure 4.3.

Figure 4.3 *Flow Accumulation map*

4.4 Peak Flood Estimation Using Hec-Hms

The Hydrologic Modeling System (HEC-HMS) is designed to simulate the precipitation- runoff processes of dendritic drainage basins. Hydrographs produced by the program are used directly or in conjunction with other software for studies of water availability, urban drainage, flow forecasting, future urbanization impact, reservoir spillway design , flood damage reduction, floodplain regulation, and systems operation.

4.5 Input Parameter Estimation for the Basin Model

1) Initial and constant method: based on the soil type of the study area 3.81 mm/hr and 7.6 mm/hr is chosen as the initial and constant loss value.
2) Baseflow method: The constant baseflow for Cauvery basin is given as 0.05 cumec/km^2 for the study area considered the baseflow is calculated as 3.5 cumecs as per Flood Estimation Report 3(i) (CWC)
3) To estimate the design flood for the catchment Snyder's Unit Hydrograph method was chosen. The input parameters are calculated based on the Flood Estimation Report 3(i) for Cauvery basin by CWC shown below.

4.5.1 Snyder's SUH

1) Length of the longest main stream in the watershed= 17 Km
2) Centroid of the catchment area= longitude: 77.381417; latitude: 11.607291
3) Length of the longest main stream from a point opposite to the centroid of the catchment= 6.5 Km
4) $T_c=0.01947*(L^{0.77})*(S^{-0.0385})$
$=0.01947*(17000^{0.77})*(0.03676^{-0.0385})$
=2.09 hours
5) Time to peak tp=0.553(L*Lca/sqrt(Se)) $^{0.405}$ =0.71 hrs

4.5.2 Meteorological Model

Time series data for every half an hour interval is found using IMD one-third rule formula is given as $P_t=P_{24}$ (t/24) $^{(1/3)}$ to convert one day rainfall to hourly rainfall which is given as input to HEC-HMS.

5. Results and Discussion

Using Hershfield equation, the PMP for Gunderipallam is estimated as 310 mm which is shown in table 4.1. Easy Fit software helps to determine the best fit distribution. Log Pearson type III is selected as the best fit for the time series data. The frequency factors are estimated using the distribution tables and the precipitations are shown in table 4.3.

For modeling process the precipitations and the basin parameters are the main input for the model. In HEC-HMS model, parameters tab is used for the incorporating the input parameters. In order to calibrate the input parameters of the model, the precipitations for the past flood events in 1978, 1999, 2001, 2003 and 2012 are given as input in

meteorological model. The simulated discharge for these flood events is compared with the actual discharge. A linear trend line is drawn which is shown in figure5.1. The graph shows that the root mean square value of 0.97 which means that the model is predicting the discharge with a minimum error of 3%.

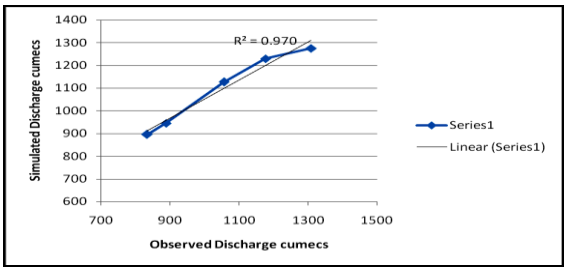

Figure 5.1 *Scatter plot for observed vs simulated discharge*

Once the model is calibrated, the precipitations of PMP and various return periods are given as input to model. The basin parameters are unchanged and the simulation run is created for various precipitation scenarios. The peak discharges are shown in table 5.1and the hydrographs for various scenarios are shown in figures from 5.2 to 5.5.

Table 5.1 *Peak Discharge for Various Scenarios*

Scenarios	Return Periods (Years)	Peak Discharge (Cumecs)
I	PMP	1571.7
II	25	1035.8
III	50	1219.9
IV	100	1398.5

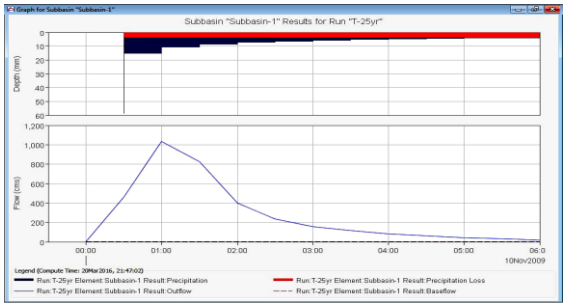

Figure 5.2 *Hydrograph for 25 yr return period*

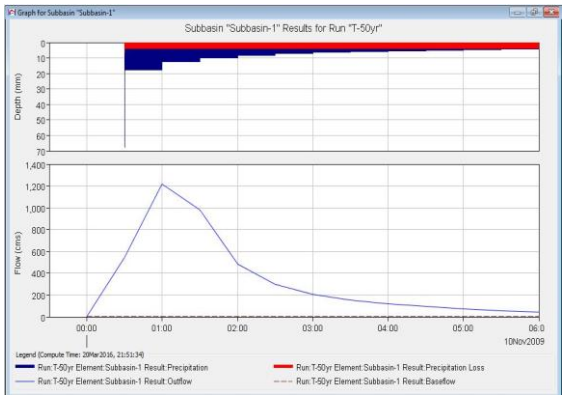

Figure 5.3 *Hydrograph for 50 year return period*

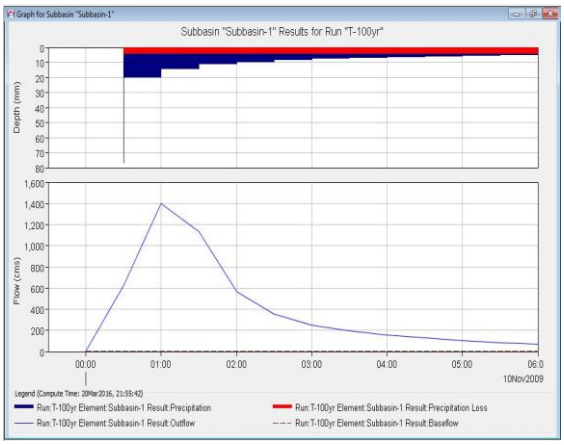

Figure 5.4 *Hydrograph for 100yr return period*

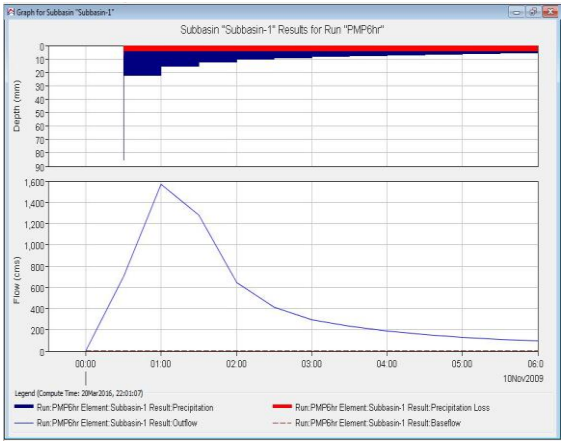

Figure 5.5 *Hydrograph for PMP*

6. Conclusion

- In the present study, it is found that the probable maximum precipitation is 310 mm and its respective probable maximum flood is estimated as 1571.7 cumecs.
- The discharge over the surplus weir is found to be 5 times more than the safe discharge capacity over surplus weir. So, surplus weir found to be unsafe during floods.
- The present study can be extended by developing the flood inundation maps for peak discharges of various return periods.
- De-silting process is the most important process to be carried out to increase the storage capacity of the reservoir.
- The bund structure can be strengthening by ground improvement techniques.

7. Acknowledgment

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