MODIFICATION OF EXISTING EMPIRICAL FLOOD FORMULAE USED IN WATER RESOURCES PLANNING AND DESIGN

(FINAL DRAFT REPORT)

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PREFACE

Flood peak values are required in the design of bridges, culvert waterways, spillways for dams, and estimation of scour at a hydraulic structure. At a given location in a stream, flood peaks vary from year to year and their magnitude constitutes a hydrologic series. To estimate the magnitude of a flood peak, various methods are being adopted. Empirical formulae are commonly used in unguged catchments where an initial estimate of peak flood is required.

The empirical formulae used for the estimation of the flood peak are essentially regional formulae based on statistical correlation of the observed peak and important catchment and storm properties. To simplify the form of the equation, only a few of the many parameters affecting the flood peak are used. Most of these formulae use the catchment area as a single parameter affecting the flood peak and other factors are clubbed in a region specific constant parameter.

However, the changes in catchment conditions, river fluvial systems and change in global climate, largely affect these empirical parameters/coefficients used in these equations. Therefore, it is required to revise or modify the empirical parameters .as and when new data is available, representing the factors.

This study aims at analysing the applicability of few of the commonly used empirical equations for the three States of peninsular India, Kerala, Tamil Nadu and Karnataka. Using the peak flood series data for number of river basins of these States, an attempt was made to revise the coefficients of six Empirical equations. The study was done by Chandramohan T., M.K. Jose and N. Varadarajan of Hard Rock Regional Centre, National Institute of Hydrology, Belgaum, as a part of the Institute's work program.

DIRECTOR

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INTRODUCTION

The analysis of the peak rate of runoff, volume of runoff, and time distribution of flow is fundamental to the design of drainage facilities. Errors in the estimates will result in a structure that is either undersized and causes more drainage problems or oversized and costs more than necessary. The relationship between the amount of precipitation on a drainage basin and the amount of runoff from the basin is complex, and too little data are available on the factors influencing the rural and urban rainfall-runoff relationship to expect exact solutions.

Estimation of maximum flood discharge along with determination of maximum and minimum water levels is essential for safe and economical design of hydraulic structures. The estimation of peak discharges of various recurrence intervals is another common problem faced by engineers when designing for hydraulic structures. The size of the catchment area and the intensity of the rainfall are the major factors determining the magnitude of flood discharge. To estimate the magnitude of a flood peak the following methods are adopted:

1. Rational method,
2. Empirical equations,
3. Flood frequency studies, and
4. Unit hydrograph technique.

The use of particular method depends upon (i) the desired objective, (ii) the available data, and (iii) the importance of the project. Methods used to evaluate and analyze flood events have changed greatly. When the earliest attempts were made to analyze flood discharges, very little discharge data were available. Consequently, only simple, generalized formulas were possible. As more discharge data became available, the methods grew in both complexity and accuracy.

Empirical formulae were developed based on analysis of maximum flood records of rivers having catchment areas of particular characteristics and hydro-meteorological conditions. To simplify the form of the equation, only a few of the many parameters affecting the flood peak are used. Most of the formulae use the catchment area as a single parameter affecting the flood peak and other factors are clubbed in a region specific constant parameter. The coefficient C represents the integrated effect of the catchment losses and hence depends upon the nature of the surface, surface slope and rainfall intensity.

Each of these formulae gives better results when applied for the catchment with conditions more or less similar to those for which it was derived. The formulae frequently used are Dickens, Ryes, Khosla, Myers, Inglis, Karpov and Kanwar and Rational formula. The use of these equations depends on the accurate estimation and usage of coefficients used in these equations, which were derived during the formulation of those equations.

Standard literature gives ranges of these coefficients for different regions, land use types or for different rainfall ranges. However, these values were derived using the length of the historical data available during that time and using different unsophisticated methods along with field knowledge. These formulae did not consider rainfall characteristics directly, which, undoubtedly, play a very important role in any flood formation process. Also, the return period of the flood, which is a major factor in the selection of design floods, is not considered in any of the available empirical formulae. Thus these formulae are not useful for assessment of peak flood and its hydrograph for large / important projects where danger to life/property may be involved. Nevertheless these formulae are generally being used by many State governments for minor/medium projects with small catchment area up to around 1500 Km^2.

In this context, it is proposed to take up a study for identifying the various empirical methods used by the State Government Departments for design of hydraulic structures and to examine those equations for its present applicability. The details regarding river basins, rainfall characteristics, runoff, etc will be used to check the recommended/currently used coefficients and to modify them, if required.

Broad objectives of the study are:

- Review of various empirical formulae used by the State Departments of Peninsular India
- Collection of rainfall and discharge data and estimation of catchment related parameters for selected river basins
- Modification of coefficients by segregating the basins as per catchment size, climatic regions, elevation, etc.

- Formulation of empirical formulae for these regions to compute Return Period Flood values

The data were collected from the States of Kerala, Tamil Nadu and Karnataka and used for testing 6 commonly used empirical formulae and to modify the coefficients of these formulae. The empirical formulae considered are:

- Ryves Formula
- Rational Formula
- Riggs Formula
- Inglis Formula
- Ali Nawabjung Formula
- Creager Formula

LITERATURE REVIEW

The science of hydrology was largely empirical as physical basis for most quantitative hydrologic processes was neither well known nor data was available. During the period 1900-1930, empiricism in hydrology became more evident. During this period hundreds of empirical formulae were developed in studies by deriving regional values arrived at on the basis of statistical correlation of limited observed flood peaks.

Estimation of magnitudes of likely occurrence of flood is of a great importance for solution of a variety of water resources problems such as design of various hydraulic structures, urban drainage systems, flood plain zoning and economic evaluation of flood protection works. Whenever, rainfall or river flow records are not available at or near the site of interest, it is difficult for hydrologists or engineers to derive reliable estimates of floods. In such conditions, the regional flood frequency relationships or the flood formulae developed for the region are one of the alternative methods which may be adopted for small catchments. The choice of the methods primarily depends on the design criteria applicable to the structure and the data availability.

The basic approaches involved in flood estimation are the empirical, deterministic and probabilistic approaches. These methods are calibrated from historical flood records from gauged catchments and their relative usefulness depends on the accuracy with which they are able to predict flood sizes in ungauged catchments.

The analysis of the peak rate of runoff, volume of runoff, and time distribution of flow is fundamental to the design of drainage facilities. Errors in the estimates will result in a structure that is either undersized and causes more drainage problems or oversized and costs more than necessary. On the other hand, it must be realized that any hydrologic analysis is only an approximation. The relationship between the amount of precipitation on a drainage basin and the amount of runoff from the basin is complex, and too little data are available on the factors influencing the rural and urban rainfall-runoff relationship to expect exact solutions.

In the hydrologic analysis for a drainage structure, it must be recognized that there are many variable factors that affect floods. Some of the factors which need to be recognized and considered on an individual site by site basis are such things as:

- rainfall amount and storm distribution
- drainage area size, shape and orientation

- ground cover
- type of soil
- slopes of terrain and stream
- antecedent moisture condition
- storage potential (over bank, ponds, wetlands, reservoirs, channel, etc.)
- watershed development potential
- type of precipitation (rain, snow, hail, or combinations thereof)
- elevation

Numerous empirical formulae have been developed relating flood peak magnitude to climate and catchment characteristics such as rainfall, area and slope. Almost all of these formulae are power laws, and they include catchment area, often as the only independent variable.

A number of empirical flood formulae have been developed by various states/scientists for local/regional use. When long term and short term rainfall and runoff records are not available, the design flood is being obtained using these formulae. The value obtained from these can only be used for preliminary estimates for small catchments. The formulae developed are Dicken's, Ryve's, Nawab Jung Bahadur , W P Creager's, Jarvis f, Modified Myer's, Pettis, Boston society of Civil Engineers', Rational formula etc. Such empirical formulas do not take into account the frequency of the event, and so are deficient for use in most design procedures today.

The area of the basin was the only independent variable considered in these formulae. Also the flood estimated by these formulae does not give frequency as these formulae cannot be used with any distinction to estimate flood of various frequencies as may be required by the design criteria to be adopted for different type of structures. Further, these formulae did not consider rainfall characteristics directly, which, undoubtedly, play a very important role in any flood formation process. Thus these formulae are not useful for assessment of peak flood and its hydrograph for large/ important projects where danger to life/property may be involved. However, they can be used as a preliminary tool for the design purpose and is currently being used by many agencies for smaller catchments and for minor structures.

In most of these methods, the effect of all the other factors (climatic, managerial and edaphic) is considered as coefficient and certainly these coefficients would be different from one region to another. Therefore, it is necessary to calibrate coefficients used in these formulas with the historical data of a region in a routine manner.

The earliest empirical formulas provide only an estimate of the probable maximum flood. These equations typically take the form:

$$Q=CA^n$$

where:
Q =flood peak
C =a coefficient related to the region
A =drainage area
n =a constant

The next step in the evolution of flood analysis equations came when attempts were made to account for flood frequency.

The next improvement was to include precipitation measures in the equations. One of the most famous in this group, and still widely used, is the Rational Equation. It has the form:

$$Q=CiA$$

where:
Q =discharge
C =runoff coefficient
i =rainfall intensity
A=drainage area

This method takes frequency into account in the intensity term and assumes that rainfall frequency equals runoff frequency. The intensity is based on an intensity-duration-frequency curve. This method works well in many different regions. The biggest drawback to the Rational Method is that it is applicable only for small drainage areas.

Multiple regression is a technique that relates different flood flow frequencies directly to a stream’s physical and climatological characteristics. One equation can be developed for each return period of interest for each region. Riggs (1973) provides a good background on regression techniques. The regression model typically used in flood frequency analysis is in the form:

$$Q_n = aA^bB^cC^d$$

where:

Qn= is the discharge for return period n

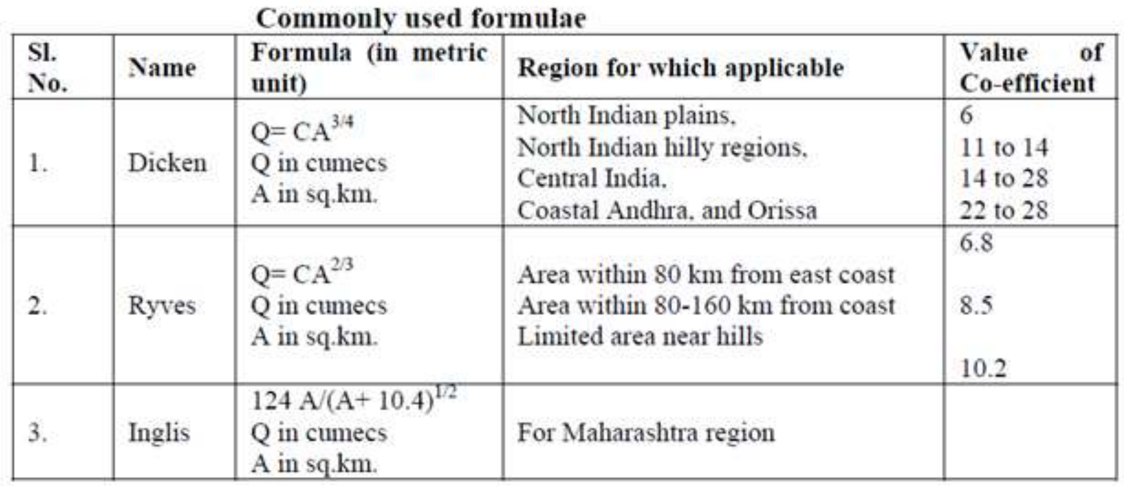
a, b, c, d are the parameter estimates of the model

A, B, C are the basin characteristics.

To perform a regression analysis, discharges are first estimated for certain return periods at gauging stations. These estimates are then used as dependent variables in the regression analysis. The independent variables are the physical and climatological watershed characteristics.

The most recently developed methods are statistically based and offer the advantage of being derived from actual stream flow records. The stream flow data can be fitted to a probability distribution. Based on this distribution, peak flows for a given exceedence probability can be estimated by relating the measured peak flow to watershed characteristics.

Some of the commonly used formulae are given in the table below.



Commonly used formulae

Sl. No.	Name	Formula (in metric unit)	Region for which applicable	Value of Co-efficient
1.	Dicken	$Q = CA^{3/4}$ Q in cumecs A in sq.km.	North Indian plains. North Indian hilly regions. Central India. Coastal Andhra. and Orissa	6 11 to 14 14 to 28 22 to 28
2.	Ryves	$Q = CA^{2/3}$ Q in cumecs A in sq.km.	Area within 80 km from east coast Area within 80-160 km from coast Limited area near hills	6.8 8.5 10.2
3.	Inglis	$124\, A/(A + 10.4)^{1/2}$ Q in cumecs A in sq.km.	For Maharashtra region	

Rational Formula:

It is developed due to attempts made to estimate the design flood (which was earlier considered to be the peak rate of runoff) that would occur due to storm rainfall of a given frequency and specified duration. The Rational Formula expressed in terms of the following equation:

$$\mathbf{Q = 0.278\ CIA}$$

where:

Q is the peak discharge in cumec

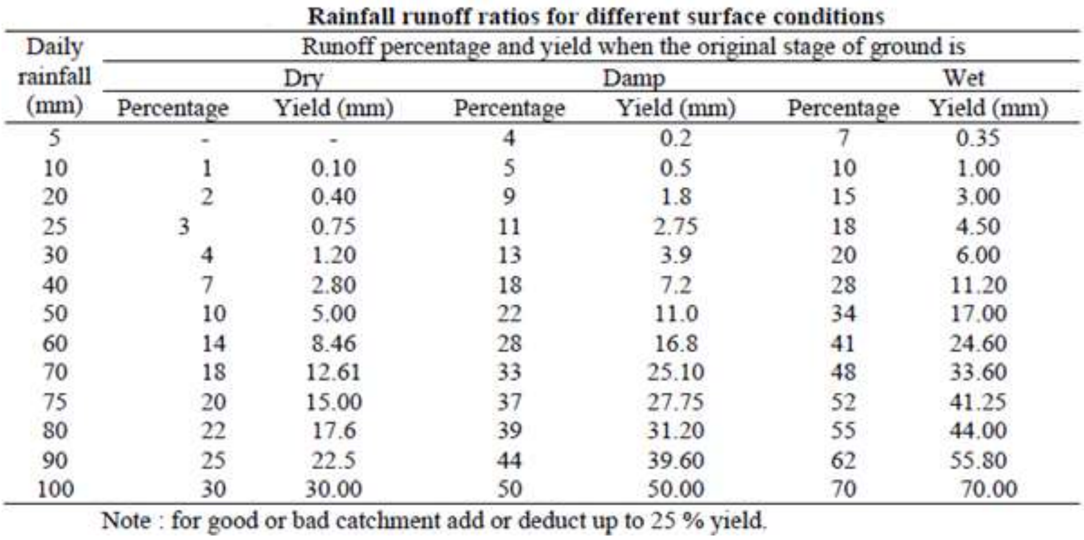
I is the uniform rate of rainfall intensity for a duration equal to or greater than the time of concentration (T_c) in mm/hr

A is the drainage area in Sq.Km.

This formula owing to its simplicity is still widely used in many countries including USA and India especially for small bridges draining small areas and for urban drainage. Intensity of rainfall can be obtained from Rainfall Intensity- Duration-Frequency curves, if the information is available.

Strange Table:

Strange evolved some ratios between rainfall and runoff based on data of Maharashta, India. He accounted for the geological conditions of the catchment as good, average and bad, while surface condition as dry, damp and wet prior to rain. The values recommended by him are given in Table below.



Rainfall runoff ratios for different surface conditions

Daily rainfall (mm)	Runoff percentage and yield when the original stage of ground is					
	Dry		Damp		Wet	
	Percentage	Yield (mm)	Percentage	Yield (mm)	Percentage	Yield (mm)
5	-	-	4	0.2	7	0.35
10	1	0.10	5	0.5	10	1.00
20	2	0.40	9	1.8	15	3.00
25	3	0.75	11	2.75	18	4.50
30	4	1.20	13	3.9	20	6.00
40	7	2.80	18	7.2	28	11.20
50	10	5.00	22	11.0	34	17.00
60	14	8.46	28	16.8	41	24.60
70	18	12.61	33	25.10	48	33.60
75	20	15.00	37	27.75	52	41.25
80	22	17.6	39	31.20	55	44.00
90	25	22.5	44	39.60	62	55.80
100	30	30.00	50	50.00	70	70.00

Note : for good or bad catchment add or deduct up to 25 % yield.

Dicken's Formula:

$$Q = C.\ A^{3/4}$$

where:

Q = discharge m3/s

A = Area in sq.km

C = 6 for North-Indian Plains

= 11-14 North-Indian Plains

= 14-28 Central India

= 22–28 Coastal Andhra & Orisa

UPIRI Formula:

Developed to find the coefficient C in Dicken’s Formula (Developed by Irrigation Research Institute, Roorkee based on frequency studies on Himalayan Rivers).

$$C = 2.342 \log (0.6T) \times \log (1185/P) + 4$$

where:

P = [(a+b)/(A+a)] X 100

a = perpetual snow area(sq.km)

A+a = Total catchment area (sq.km)

Ryve’s Formula:

$$Q = C.\ A^{2/3}$$

where:

Q = discharge m3/s

A = Area in sq.km

C = 6.8 for areas within 80 km from east coast

= 8.3 for areas 80-2400 km from coast

= 10.2 limited areas near hills

Graig Formula:

$$Q = 10\ c.v.\ I \times \ln (4.97\ L)$$

where:

C = Coefficient of discharge

V = Velocity in m/sec

I = rainfall in cm

C = 0.12 to 0.18

Inglis and De Souza’s Formula (1946):

Inglis and De Souza used data from 53 stream gauging sites in Western India. He studied catchments in western ghats and plains of Maharashtra, and gave the following relationships

For ghat areas

$$Q = 0.85\ P - 30.5$$

For Plains

$$Q = 254\ (P - 17.8)\ P$$

where:

Q = runoff (cm)

P = precipitation (cm)

Inglis Formula:

$$\mathbf{Q = 124\ A/(A+10.4)^{0.5}}$$

where:

Q in cumec and A in sq.km.

Ali Nawabjung Formula:

$$\mathbf{Q = C\ (0.386x\ 0.95-(1/14)\ logA)}$$

where C value varies from 49 to 60, Lower value for South India and higher values for North India

OR

$$\mathbf{Q = C\ A'^{\ (0.92 - (1/14)\ \log A)}}$$

where A' = 0.39 A

Creager Formula:

$$Q = C(0.386A)^{0.804(0.0386A)^{-0.048}}$$

where, Q in cumec and A in sq.km.

For North/South India

$$Q = 46CA^{0.894A^{-0.048}}$$

G.C. Khanna Formula:

Used for Hilly Areas > 1600 sq.km.

$$\mathbf{Q = 0.42\ A}$$

where, Q in cumec & A in sq.km.

Rigg's Formula:

For return period floods:

$$Q_t = a\ A^b\ B^c\ C^d$$

where Q_t is in cumecs, A , B, C … are catchment characteristics

Boston Society Formula:

$$Q = C.R.A$$

where:

Q in cumec

A in sq.km.

R = average runoff for catchment from worst storm(cm/day)

C = 0.20 TO 50

Binnie's percentages (1872) (taken from Hydrology Part III 1978):

Sir Alexander Binnie measured the runoff from a small catchment (16 km^2) near Nagpur during 1869 and 1872, developed curves of cumulative runoff against cumulative rainfall (for annual rainfall of 500 to 800 mm) and established percentages of runoff from rainfall. These percentages have been used in the Madhya Pradesh and Vidarbha regions of Maharashtra for the estimation of mean annual flow.

Khosla (1949*)* Formula:

Khosla developed a relationship for monthly runoff:

$$Rm = Pm - Lm$$

$$Lm = 0.48\ Tm \text{ for } Tm > 4.5\ 0C$$

where:

Rm = Monthly runoff in cm

Pm = Monthly rainfall in centimeters (cm)

Lm = Monthly losses in centimeters

Tm = Mean monthly temperature of the catchment in ^oC.

He supplied provisional values of losses for different temperatures. Annual runoff can be estimated as a sum of monthly values. Khosla's formula is indirectly based on the water-balance concept and the mean monthly temperature is used to reflect the losses due to evapotranspiration. The formula has been used on a number of catchments in India and is found to give fairly good results for the annual yield for use in preliminary studies.

UP Irrigation Research Institute (1960) formulae:

Uttar Pradesh Irrigation Research Institute, Roorkee, has developed the following relationships between runoff and precipitation:

Himalayan rivers

Ganga Basin at Hardwar (23,400 km^2),	$R = 5.45\ P^{0.60}$
Yamuna Basin at Tajewala (11,150 km^2)	$R = 0.354\ P^{0.11}$
Sharda Basin at Banbassa (14,960 km^2)	$R = 2.7\ P^{0.80}$

Bundelkhand area rivers (in Uttar Pradesh State)

Garai Basin at Husainpur (290 km^2)	$R = 0.58\ P - 2.8$
Ghori Basin at Ghori (36 km^2)	$R = P - 62.3$
Ghaghar Basin at Dhandraul (285 km^2)	$R = 0.38P$
Sukhra Basin at Sukhra (15 km^2)	$R = 0.47\ P - 2.8$
Karamnasa Basin at Silhat (518 km^2)	$R = 0.49\ P$

where: R is runoff in centimeters and P is rainfall in centimeters.

UPID's formula*:*

The Uttar Pradesh Irrigation Department (UPID) developed the following correlation between rainfall and runoff for Rihand River:

$$\mathbf{R = P - 1.17\ P^{0.86}}$$

where R and P are runoff and rainfall in centimeters.

A Rational relationship was developed by Narsimaiya et. Al. (!991) to derive rainfall – runoff relationship for Subernarekha river basin taking into account antecedent rainfall effect, land use, elevation and catchment slope.

Kothyari (1995) used data from 31 non-snow fed catchments in India with areas less than 1,515 km^2 in the States of Uttar Pradesh, Madhya Pradesh, Bihar, Rajasthan, West Bengal and Tamil Nadu – to develop a simple method for the estimation of monthly runoff for the monsoon months of June to October in the following form:

$$R(I) = K(I)[1 + K(I)^{N(I)-1}\{1 - K(I-1)\}P(I-1) / P(I)]P(I)$$

where:

R(I) = monthly runoff during the Ith month

P(I) = monthly areal rainfall during the Ith month

K(I) and n(I) are parameters for the Ith month with K(I)<1.0 and n(I)>1.0.

The values of the exponent n(I) were found to vary significantly in Damodar (Bihar), Barakar (Bihar), Mayurakshi (West Bengal), Chambal (Madhya Pradesh), Lower Bhawani (Tamil Nadu) and Ram Ganga River (Uttar Pradesh) during any one month and the coefficient K was found to be related to T, FA and A according to equation given below as it represents the loss from the total rainfall.

$$K = 260.9\ T^{-2.02}\ FA^{-0.05}\ A^{0.05}$$

where:
T is temperature in ^{o}C
A is the catchment area in km^2
FA is the percentage of forest area.

The values computed by the model were then compared with the corresponding observed values of runoff. This comparison revealed that the proposed method produces results with an error less than 25% for 90% of the data points. However, an error of less than 50% resulted for the arid catchments from the Chambal Basin (Madhya Pradesh).

Envelope Curves:

Another class of empirical flood formulae attempts to predict maximum flood peak magnitude for a given catchment. They take the form of an envelope curve or line on a logarithmic plot of flood peak magnitude against relevant catchment area for a suite of basins.

Envelope curves or lines provide a rudimentary but nevertheless useful summary of flood experience, and they are best employed to supply a preliminary estimate or a rough check on other estimates provided, for instance, from rainfall-runoff models and flood frequency analysis. Strictly speaking, they should be developed and used only in homogeneous flood regions – where all catchments have similar climatological and physiographic characteristics, and where any effects of changing climate are insignificant during the time period of interest.

In early fifties, Kanwar Singh and Karpov collected data of various Indian Rivers and drew two envelope curves one to suit basins of southern India and the other for those of northern and central India.

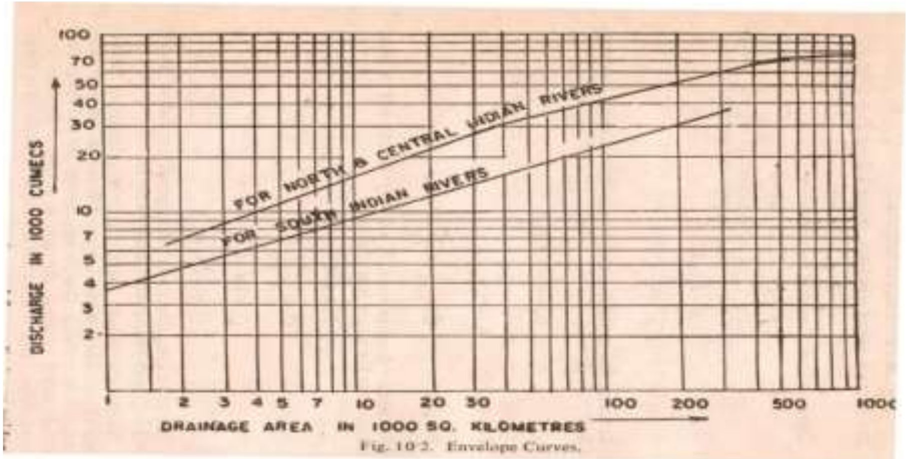


Fig. 10·2. Envelope Curves.

Further, the PMF values for a number of projects estimated by CWC and other organizations during the period 1980-91 have been utilized for developing envelope curves for PMF peaks. Three curves were developed as Upper envelope curves, Average line and lower envelope curves.

The curves correspond to the following equations:

Upper envelopes $Q_u = 1585\ A^{0.35}$
Average Lne $Q_{av} = 398\ A^{0.425}$
Lower envelope $Q_l = 100\ A^{0.5}$

where Q is PMF in cumecs and A is catchment area in Sq.km.

These curves have been recommended to be used for prioritising the existing large dams for further detailed investigations for dam safety assurance.

Telvari, evaluated the efficiency of some empirical methods such as Creager, Horton and Fuller for estimating the peak of flood flow rate in Karkhe watershed in Iran and concluded Fuller method is the most proper method for estimating the highest amount of flood flow rate in most basins and sub-basins in study area due to considering ground traits, quantitative morphological, vegetation and climate. Yazdani et al. evaluated two methods one of which was based on watershed area and another one was based on watershed physiographic and precipitation characteristics, in order to find an acceptable method for estimating peak flow in basins. Among areabased methods, Horton method and among the methods which are based on watershed physiography and precipitation characteristics, graphical approach of SCS had the lowest error.

Zare et al., estimated flood peak flow rate in various return period using empirical methods in Tolbane watershed in Gorgan. In this study five methods including Fuller, Kreager, Dicken, Alinavaz and rives which were based on watershed area, were used for estimating flood peak flow rate. Sanginabadi and Abolghasemi determined and evaluated flood flow rate and mean annual flow rate equations of Qazvin province rivers. Results showed that, the first involved parameter in flood and mean flow rate equations of these rivers is type of climate. Radmehr and Araghinezhad conducted a comparison between corrected empirical method and statistic model in predicting flow on Lar River in entry station of Lar dam. In this research, two methods including statistic and corrected empiricalmethod were used to predict monthly flow.

Azari and Behnia studied the application of methods Creager, Dicken and SCS artificial hydrograph in estimating flood peak flow rate of Bartaj watershed. Comparison of calculated results by Kreager and Dicken method with observed values in stations showed that, Kreager method had a higher accuracy with a correlation coefficient of 0.84 between calculated values and observed values, lower relative error (0.31) and lower amount of maximum relative error (1.7). Tagus et al. (2008) in testing the relationship between maximum flow rate and flow rate using Fuller empirical formula in south eastern Spain by linear regression method, found that, observed peak flow rate values and estimated values have a proper appropriateness. Alcazar and Palau (2010) regionalized flow regimes in a Mediterranean watershed. Totally 51 physical and hydrological variables were measured and collected in 45 stations, and the variables were classified within 5 groups using main components analysis. Tsanis (2010) presented an approach for sudden flood peak flow rate estimation, hydrograph and flood volume in a watershed with a few measurement stations where, few flood hydrological characteristics have been known. In this research, results from 8 empirical flood estimation including Cramar, Burkli Ziegler, Faning, Dredge & Burge, Bourges, Possenti, Hyderabad, and Inglis are evaluated with measures values by hydrometric stations existing in the watershed, in Bakhtegan watershed located in Fars province.

DESIGN PRACTICES ADOPTED BY STATE GOVERNMENTS

Based on the reports and information collected from States, it has been observed that the yield estimation procedures adopted by various States are in confirmation with the Central Water Commission (CWC) and Indian Standards guidelines, in general under the constraints of data availability.

Maharashtra:

Water Resource Department has reported that the yield assessment are based on 1980 Working Group Recommendations, GOI.

PWD Handbook, Government of Maharashtra, Chapter 19 on Hydrology describes the rainfall, evaporation, transpiration, Evapotanspiration and discharge measurement related methodologies, regression and correlation analysis techniques.

Data Processing Centre at Nashik are using state of the Art methods through HYMOS, SWDES and WISDOM in data processing. The procedure of water availability study involves utilisation of observed gauge discharge / Tank gauge data. Standard procedures are used in computing basin average rainfall. Naturalization of flow is made by Water Balance method considering upstream utilizations. The yield series is developed from rainfall-runoff correlation.

The practices followed by Gujarat Water Resource Department in water availability involve the following procedures:

- Collection and checking of data
- Rainfall – Interpolation and adjustment of missing data
- Naturalization considering upstream utilizations
- Developing regression model for monsoon periods and non monsoon period
- Net yield calculation considering all upstream existing and planned utilizations.

Himachal Pradesh:

In Himachal Pradesh the design flood is generally obtained by empirical formulae/rational formula. The full channel capacity is also worked out from river sections. Approval from Central Water Commission is obtained for major projects for which the assessment is made by various standard methods as feasible on case to case basis.

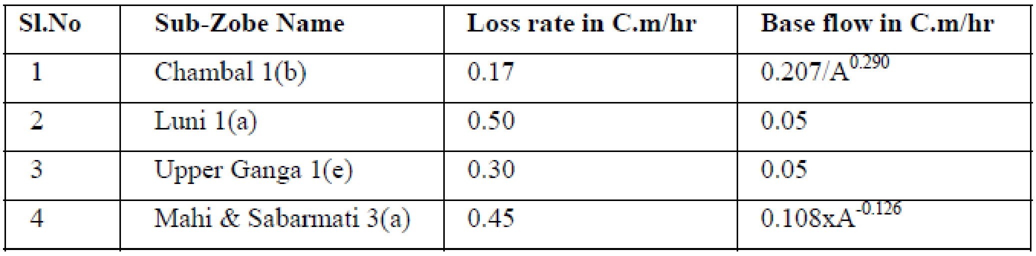
Small hydroelectric projects as run of the river schemes are developed based on the existing gauge data. In the presence of flow information available in the same or nearby homogenous basins, catchment area proportioning method is used. In the absence of any coefficient based on catchment characteristics is evolved.

Rajasthan:

When the observed runoff data are not available, the yield is computed using Strange’s table. The Strange’s table gives runoff for good, average and bad catchments and surface conditions viz dry, damp and wet prior to the rain.

When the observed runoff data along with the observed rainfall of any nearest G & D site is available the yield is computed using regression analysis. A relation between observed monthly rainfall and observed monthly runoff for the G & D site is generated and it is transposed over the catchment of the project using the rainfall-runoff relationship between observed rainfall of G & D site and observed rainfall for the project.

The design flood for major projects is estimated using hydrometerological approach and got approved from Central Water Commission. The categorization of projects is done as per classification given in BIS specification IS-11223-1985.The 1day, 2day, 3day SPS storms and PMP and their temporal distribution are obtained from India Meteorological Department. The infiltration losses and baseflow are generally based on Sub-Zonal reports of Central Water Commission as under.



Sl.No	Sub-Zobe Name	Loss rate in C.m/hr	Base flow in C.m/hr
1	Chambal 1(b)	0.17	$0.207/A^{0.290}$
2	Luni 1(a)	0.50	0.05
3	Upper Ganga 1(e)	0.30	0.05
4	Mahi & Sabarmati 3(a)	0.45	$0.108xA^{-0.126}$

For small projects having catchments less than 25 sq.km design flood is computed using publication “Flood estimation methods for catchments less than 25 sq.km”. Reservoir routing is done by Modified Pulse method for determining spillway capacity.

West Bengal:

For extension of streamflow records, the following methods are used:

1. Double Mass curve method
2. Correlation with catchment areas
3. Regression analysis
4. Index-station method
5. Langbeins log deviation method.

For yield assessment of Damodar river basin (19900 km^2) Dhir, Ahuja and Majumdar's Relation is adopted:

$$R = 13\,400P - 5.75 \times 105$$

where R = Runoff (cm) and P = Precipitation (cm)

For large catchments PMP atlas prepared by IITM is used. The methodology followed is generally as given in the publication of Mutreja and Pidmont and CWC manual for large projects.

Andhra Pradesh:

For design of minor irrigation structures like canals, Dicken's and Ryve's formulae are being used.

For catchment areas in upland regions:

$$Q = CA^{3/4}$$

C = 1400 for catchment area (A) = 1 sq. mile
C = 1200 for A between 1 to 30 sq. miles
C = 1060 for A between 30 to 500 sq. miles

For catchment area greater than 500 sq. miles, $Q = 7000\ A^{1/2}$

For catchment areas in deltaic tracts:

$$Q = CA^{3/4}$$

where: C = 1000

Kerala:

Ryve's Formula is being used.

Karnataka:

Strange Tables are being used.

STUDY AREA

KERALA

State of Kerala lies between 8° 18’ and 12° 48’ N and 74° 52’ and 77° 22’ E and covers an area of 38864 km^2. It is a narrow strip of land with width varying from about 30 km in the north and south to 130 km in the central portion. Though the area of the State is small, variation in physical features is very wide. It covers altitudes ranging from below sea level, in Kuttanad to about 2700 m above sea level, along Western Ghat.

Based on the topography, the State can be divided into three well-defined natural regions.

- The Lowland consists of coastal belt with backwaters and paddy fields. It has an elevation upto 8 meters and 25 % of the population lives here.
- The Midland covers central portion of the Sate with a diversity of crops like paddy, coconut, pepper, sugarcane, tapioca, and rubber. Elevation ranges from 8 to 75 m and accounts for 60 % of the total population.
- The Highland covers hilly region of the Western Ghat with dense forests. Tea, coffee, rubber, and cardamom are abundant in this region. The population is very small owing to the steep terrain and dense forest.

In the broad background of the Indian climatic patterns suggested by IMD, the seasons of Kerala have been demarcated as follows (Nair, 1987):

- Summer or hot weather season (March to May)
- southwest (SW) monsoon season (June to September)
- northeast (NE) monsoon season (October and November)
- winter or cool weather season (December to February)

The average annual rainfall over the State is about 3000 mm, which is 3 times the Indian average. Important rainy seasons in the State are South West monsoon (June-September) and North East monsoon (October-November). It receives rainfall for almost ten months in a year from both the monsoons and local systems.

The annual rainfall; for the low land region ranges from 900 mm to 3500 mm, from 1400 mm to 4000 mm for the midland region and from 2500 mm to 5000 mm in the high land region; from south to north.

There are 44 rivers flowing in the State (with minimum length of 15 km), out of which 41 originates from the Western Ghats and flow towards west (CWRDM, 1995). The other three originates from the Western Ghats and join Bay of Bengal (Kabbini, Bhavani, Pambar). Most of these rivers are ephermal, with input from rainfall, mainly during the monsoons.

TAMIL NADU

Tamil Nadu State lies between 8° 01’ and 13° 28’ N and 76° 20’ and 80° 15’ E and covers an area of 130058 km^2. Tamil Nadu is divided naturally between the flat country along the eastern coast and the hilly regions in the north and west. The broadest part of the eastern plains is the fertile Kaveri (Cauvery) River delta; farther south are the arid flatlands surrounding the cities of Ramanathapuram and Madurai (Madura). The high peaks of the Western Ghats run along the state’s western border.

The total geographical area of the State is divided into 5 major physiographic divisions of the Kurinji or mountainous region, the Mullai or forest region, the Palai or arid region, the Marudham or the fertile plains and the Neidhal or coastal region. The densely forested and wild life filled mountain chains of the Western Ghats, plateaus, intensively cultivated farmlands, fertile coastal plains are the geographical features of Tamil Nadu. Tamil Nadu being a coastal state is highly vulnerable to seasonal fluctuations in terms of rainfall, temperature, relative humidity, wind speed, etc., causing uncertainty in Agriculture production.

Tamil Nadu is mostly dependent on monsoon rains, and thereby is prone to droughts when the monsoons fail. The climate of the state ranges from dry sub-humid to semi-arid. The state has three distinct periods of rainfall:

- advancing monsoon period, south west monsoon from June to September, with strong southwest winds;
- North east monsoon from October to December, with dominant north east winds;
- dry season from January to May.

The annual rainfall of the state is about 945 mm (37.2 in) of which 48 per cent is through the north east monsoon, and 32 per cent through the south west monsoon. Since the state is entirely dependent on rains for recharging its water resources, monsoon failures lead to acute water scarcity and severe drought.

Tamil Nadu has a tropical climate with little variation in temperature during summer and winter. Summer temperatures rise above 40^0 in the plain areas. Hill stations have pleasant climate. The average rainfall ranges between 635mm and 1,905 mm. The Nilgiris and other hill areas of the State get the highest precipitation while the arid regions are located in Ramanathapuram and Tirunelveli District.

Tamil Nadu is divided into seven agro-climatic zones: north east, north west, west, southern, high rainfall, high altitude hilly, and Cauvery Delta (the most fertile agricultural zone).

The rivers of the state flow eastward from the western ghats and are entirely rain-fed. The perennial river fed by both the monsoons is the Cauvery, which flows across Tamil Nadu cutting the state in to two halves. The perennial rivers are Palar, Cheyyar, Ponnaiyar Kaveri, Meyar, Bhavan, Amaravati, Vaigai, Chittar and Tamaraparni. The non-perennial rivers are the Vellur, Noyal, Suruli, Gundar, Vaipar, Valparai and Varshali. The 760 km long Cauveri is the largest river of the state.

KARNATAKA

The study area, Karnataka State, is situated between 11° 40' and 18° 27' north latitude and 74° 5' and 78° 33' east longitude in the centre of western peninsular India, covering an area of 19.1 Mha and accounts for 5.8% of the country's total geographic area. It has a 350 km long coastline, which forms the western boundary. According to the 2001 provisional census the population of the State is 52,733,958, with a rural population of 66.02% and an urban population of 33.98%.

The state of Karnataka is part of two well-defined regions of India, namely the Deccan Plateau and the Coastal Plains and Islands and it can be further divided into four physiographic regions-the Northern Karnataka Plateau, Central Karnataka Plateau, Southern Karnataka Plateau, Karnataka Coastal Region.

The state enjoys three main types of climates:
The Tropical Monsoon climate covers the entire coastal belt and adjoining areas. The climate in this region is hot with excessive rainfall during the monsoon season i.e., June to September. The Southern half of the State experiences hot, seasonally dry

tropical savana climate while most of the northern half experiences hot, semi-arid, tropical steppe type of climate. The climate of the State varies with the seasons.

The winter season from January to February is followed by summer season from March to May. The period from October to December forms the post-monsoon season. The period from October to March, covering the post-monsoon and winter seasons, is generally pleasant over the entire State except during a few spells of rain associated with north-east monsoon which affects the south-eastern parts of the State during October to December.

The annual rainfall in the State varies roughly from 50 to 350 cm. In the districts of Bijapur, Raichur, Bellary and southern half of Gulbarga, the rainfall is lowest varying from 50 to 60 cm. The rainfall increases significantly in the western part of the State and reaches its maximum over the coastal belt. The south-west monsoon is the principal rainy season during which the State receives 80% of its rainfall. Rainfall in the winter season (January to February) is less than one per cent of the annual total, in the hot weather season (March to May) about 7% and in the post-monsoon season about 12%.

Karnataka is divided in to 10 agro climatic zones taking into consideration the rainfall pattern-quantum and distribution, soil types, texture, depth and physio-chemical properties, elevation, topography major crops and type of vegetation.

There are seven river systems in Karnataka which with their tributaries, drain the state, Krishna, Cauvery and West Flowing Rivers forms the major river systems of the State.

RIVER GAUGE SITES SELECTED FOR THE STUDY

The present study aims at reviewing effectiveness of the current practices in selection of various coefficients in empirical flood formulae commonly used in India, especially pertaining to the Peninsular India. Therefore, the States of Kerala, Tamil Nadu and Karnataka are selected for this study. Gauged river basins of different sizes and characteristics are selected and the gauge data are used to investigate the applicability of number of empirical formulae for the region and for the revision of the empirical coefficients.

After referring the available literature on empirical flood formulae, six commonly used formulae were used for this study. They are, Rigg's formula, Creager formula, Ryves formula, Rational formula, Inglis formula and Ali Nawab Jung formula. These formulae were used to evolve empirical equations for Return Period floods.

The data used were of gauge sites from three States, which are given in the tables 1, 2 & 3.

Table 1: River Gauges of Kerala

River	Gauge Site	Latitude	Longitude	Catch Area (sq.km)	Av Mons P (mm)
Vamanapuram	Ayilam	08 42 55	76 51 15	540	970.8
Valapatanam	Perumannu	11 58 10	75 35 15	1070	2713
Pulanthode	Pulamanthole	10 53 50	76 11 50	790	1688.8
Periyar	Neeleeswaram	10 11 00	76 30 00	4234	2348.6
Payaswini	Erinjipuzha	12 29 00	76 08 50	957	2993.9
Muvattupuzha	Ramamangalam	09 50 00	76 28 00	1208	2348.6
Meenachil	Kidangoor	09 40 30	76 36 20	615	1968
Manimala	Kallooppara	09 24 10	76 39 50	731	1661.9
Pamba	Malakkara	09 19 45	76 39 50	1713	1837.3
Kallada	Pattazhy	09 04 00	76 45 40	1210	1661.9
Kaliyar	Kalampore	09 59 25	76 31 51	405	2348.6
Kadalundi	Karathode	11 03 25	76 03 20	750	2033.1
Chalakkudy	Arangilay	10 08 00	76 18 00	1342	2198
Chaliyar	Kuniyil	11 15 00	75 50 00	1876	2033.1
Bharathapuzha	Kumbidi	10 51 00	76 02 00	5755	1688.1
Bharathapuzha	Ambalapalayam	10 36 00	76 59 00	950	240
Achankoil	Thumpamon	09 13 40	76 42 00	810	1661.9

Table 2: River Gauges of Tamil Nadu

River	Gauge Site	Latitude	Longitude	Catch Area (sq.km)	Av. Mon. P (mm)
Bharathapuzha	Ambaramapalayam	10 36 00	76 59 00	950	233.1
Palar	Avaramkuppam	12 40 00	78 30 00	3300	442
Cauvery	Nellithurai	11 19 00	76 54 00	1475	233.1
Vaigia	Paramakudi	09 32 48	78 35 00	6796	136.1
Bhavani	Savandapur	11 30 00	77 30 00	5776	250.6
Cauvery	Thengumarahada	11 32 00	76 55 00	1370	1060
Vaigia	Theni	09 58 00	77 28 00	1200	305.4
Ponniyar	Vazhavachanur	12 04 00	78 59 00	10781	442
Ponniyar	Villupuram	11 52 00	79 28 00	12900	433
Amaravathi	Nallamaranpatty	10 55 00	77 55 00	9080	295.1
Tabraparni	Muruppanadu	08 44 00	77 50 00	4380	92.6
Vaippar	Irrukkankudi	09 20 00	77 59 00	3721	181.8
Ponniyar	Gummanur	12 32 00	78 10 00	4620	361

Table 3: River Gauges of Karnataka

River	Gauge Site	Latitude	Longitude	Catch Area (sq. km.)	Av Mon P (mm)
Cauvery	Biligundlu	12 10 48	77 43 48	36682	286.7
Nethravathy	Bantwal	12 53 04	75 02 35	3184	3303.4
Kabini	Kollegala	12 11 21	77 06 00	21082	304
Harangi	Kudige	12 30 09	75 57 43	1936	1716
Hemavathy	M.H.Halli	12 49 06	76 08 00	3050	980.7
Bandigaduhalla	Muthanakere	11 50 00	76 07 00	1260	304
Malaprabha	Cholachguda	15 52 43	75 43 16	9373	427.3
Krishna	Galgali	15 25 00	75 25 00	22560	365.9
Krishna	Huvinhedgi	16 29 25	76 55 23	55150	478.2
Kagna	Malkhed	17 12 12	77 09 23	7650	640.1
Ghataprabha	Mudhol	16 19 00	75 12 00	6734	365.9
Tungabhadra	Oollenur	15 28 00	76 42 00	33018	478.2
Manjira	Saigaon	18 03 00	77 03 00	9960	908.6
Bhima	Yadgir	16 44 15	77 07 31	69863	640.1
Shimsha	T.K.Halli	12 25 00	77 11 36	7890	286.7
Kabini	T.Narasipura	12 13 48	76 53 46	7000	342.1
Haridra	Byaladahalli	14 26 00	75 46 47	2300	280
Tungabhadra	Harlahalli	14 49 50	75 40 33	14582	478
Tungabhadra	Honnali	14 14 18	75 39 30	7075	1787.1
Varada	Marol	14 56 20	75 37 05	4901	478
Tunga	Shimoga	13 56 08	75 34 41	2831	1787.1

METHODOLOGY

The main objective of the present study was to test the applicability of few commonly used flood formulae with the available daily runoff records from three southern States. Therefore, the first step was to extract the flood peak values from the runoff records. When the data records are about 40-45 years, it is enough to identify the maximum peak flood values for each year from the data sheets. However, many of the gauge sites selected does not have a proper length of data records. In such cases, another method used in flood data arrangement is the partial-duration series. This procedure uses all peak flows above some threshold value. So in the present study, partial duration series of flood peaks was extracted by keeping 3 to 4 times standard deviation as the cut off value of the peak flood value. By following this procedure, each of the gauge sites yielded 50 to 80 flood peak values.

The various steps involved in the study are:

- Collection of gauge data for all the river basins within the above 4 States.
- Processing of the runoff data for each of the gauge sites to extract partial duration flood series.
- Estimation of Return Period floods for each of the river basin using L-moment approach.
- Segregation of the river basins in terms of climatic/geographic regions, size, etc.
- Collection/computation of catchment characteristics such as catchment area, geomorphological characteristics, slope, land use/land cover pattern, etc.
- Testing of empirical formulae which are commonly being used within the individual regions using the discharge data and catchment characteristics.
- Modification of empirical coefficients to suit the local conditions and its verification by dividing the data set into two portions.
- Modify the existing equations to compute different Return Period Floods.

To evaluate various equations, statistical standards including mean square errors, oriental coefficient and mean difference were used. The empirical equation with lower RMSE, BIAS and MD would be the most suitable method. Statistical standards used for checking the accuracy of the equations, are explained as below:

Mean difference:

$$\bar{D} = 1/n\left[\sum_{i=1}^{n}(r_1 - r_2)\right]$$

where, r1 is the first observed peak flow rate, r2 is the first estimated peak flow rate, n is number of statistical years, D is mean difference per unit (r)

BIAS:

$$BIAS = \frac{1}{n}\sum_{i}^{n}\frac{Eo - Ee}{Eo}$$

In this equation, E_0 and E_e are observed values and estimated values of peak flow rate, respectively.

RMSE:

Low amount of RMSE represents lower error and model accuracy. RMSE tends to zero is suitable.

$$RMSE = \left|\frac{1}{n}\sum_{i=1}^{n}\frac{(Qi - Qo)^2}{Qi}\right|^{1/2}$$

In equation, Qi and Qo are observed values and estimated values of peak flow rate, respectively.

ESTIMATION OF Q_T (RETURN PERIOD FLOOD)

As described above, partial duration flood series were derived for all the gauge sites. EV-I distribution has been identified as the robust distribution for analyzing the peak flow; hence, this distribution was used in the present study. The flood peaks obtained were used to derive the parameters of the Extreme Value Type I distribution. The model parameters were estimated using the L-moments. Flood values for different return periods were estimated using the fitted model.

L-moments are a recent development within statistics (Hosking, 1990). In a wide range of hydrologic applications, L-moments provide simple and reasonably efficient estimators of characteristics of hydrologic data and of a distribution's parameters. Zafirakou-Koulouris *et al*. (1998) mentioned that like ordinary product moments, L-moments summarize the characteristics or shapes of theoretical probability distributions and observed samples. Both moment types offer measures of distributional location (mean), scale (variance), skewness (shape), and kurtosis (peakedness). Hosking and Wallis (1997) state that L-moments are an alternative system of describing the shapes of probability distributions. Historically they arose as modifications of the probability weighted moments (PWMs).

For example, the first four L-moments are related to the PWMs using;

$\lambda 1 = \beta 0$

$\lambda 2 = 2\beta 1 - \beta 0$

$\lambda 3 = 6\beta 2 - 6\beta 1 + \beta 0$

$\lambda 4 = 20\beta 3 - 30\beta 2 + 12\beta 1 - \beta 0$.

These L-moments were used to estimate the parameters of EV-I distribution and using them, the flood values for various Return Periods were calculated.

MODIFICATION OF COEFFICIENTS FOR THE EMPIRICAL FORMULAE

Six standard empirical formulae were selected for the study;

- Ryves/Dickens Formula
- Rational Formula
- Inglis Formula
- Riggs Formul
- Ali-Nawabjung Formula
- Creager Formula

1. Ryves and Dickens Formula:

Ryves and Dickens formula takes the form of a power relation between runoff (Q) and catchment area (A) in the form;

$$Q = C A^b$$

The value of ‘b’ is 0.75 for Dickens formula and 0.67 for Ryves formula. C depnds on many factors such as size of the catchment, location of the catchment, etc. The return period flood values were used here to estimate the values of the coefficients ‘C’ and ‘a’ for each of the States.

2. Rational Formula:

The rational method is found to be suitable for peak flow prediction in small size (< 50 km^2) catchments. It finds considerable application in urban drainage designs and in the design of small culverts and bridges.

Consider a rainfall of uniform intensity and very long duration occurring over a basin. The runoff rate gradually increases from zero to a constant value. The runoff increases as more and more flow from remote areas of the catchment reach the outlet. Designating the time taken for a drop of water from the farthest part of the catchment to reach the outlet as time of concentration (tc), it is obvious that if the rainfall continues beyond tc, the runoff will be constant and at the peak value. The peak value of runoff is given by:

$$Qp = C\ I\ A \qquad \text{for } t > tc$$

where C = coefficient of runoff, A = area of the catchment and I = intensity of rainfall.

In the present study, since the rainfall intensity values are not available, an average rainfall intensity value (mm/hr) was estimated as the ratio of average monsoon rainfall (mm) and the duration of monsoon rainfall (days converted to hrs). For this purpose, number of rainy days (monsoon) for Kerala is assumed to be 85, 65 for Karnataka and 35 for Tamil Nadu.

3. Inglis Formula:

The general form the Inglis Formula is;

$$Q = 124\ A/(A+10.4)^{0.5}$$

For the present study, the formula is considered in the form of;

$$Q = C\ A/(A + a)^{b}$$

where C is taken as a regional coefficient, which is constant for all return period floods for an individual State or Region. C depends on climatic and geographical situations and characteristics of the basin. The coefficients “a’ and ‘b’ changes for each return period floods.

4. Creager Formula:

The Creager formula is;

$$Q = C(0.386A)^{0.804(0.0386A)^{-0.048}}$$

However, for this study, the formula is converted to;

$$Q = CA^{(aA)^b}$$

where C is the regional coefficient and 'a' and 'b' are the empirical coefficients for individual return period floods.

5. Ali Nawabjung Formula:

Ali Nawabjung formula calculates peak flood as;

$$\mathbf{Q = C\,A'^{\,(0.92 - (1/14)\log A)}}$$

where A' = 0.39 A

In this study, the formula was taken the form as;

$$\mathbf{Q = C\,A^{(a - (1/b)\log A)}}$$

6. Riggs Formula:

Riggs formula uses multiple regression analyses of return period discharge with catchment characteristics, as given below, where A, B, C, … are the catchment characteristics.

$$\mathbf{Q_t = a\,A^b\,B^c\,C^d}$$

Catchment characteristics considered for the study are Catchment area and the average monsoon rainfall. The formula takes the form as;

$$\mathbf{Q_t = C\,A^a\,P^b}$$

RESULTS AND DISCUSSIONS

The daily discharge data from the three States Kerala, Tamil Nadu and Karnataka were analysed to extract partial duration flood series for each of the gauge sites. These data series were used to calculate Floods for different return periods. These Return Period flood values were then used in the statistics software Systat for the testing and modification of coefficients of six commonly used empirical formulae. Return period flood values for gauge sites from Kerala, Tamil Nadu and Karnataka are given in Tables 4, 5 & 6. The simple fitting of power function to Discharge and Catchment Area is shown in Figures 1, 2 & 3. It can be seen from the figures that the power fitting gives good correlation between flood value and catchment area, for Kerala and Tamil Nadu gauge sites.

Table 4: Return Period Floods (cumecs) for Gauge Sites, Kerala State

Gauge Site	Q2	Q5	Q10	Q25	Q50	Q100	Q200	Q500	Q1000
Ayilam	233.9	330.4	394.2	474.9	534.7	594.1	653.3	731.4	790.4
Perumannu	1210.2	1436.0	1585.5	1774.3	1914.4	2053.5	2192.1	2374.9	2513.1
Pulamanthole	609.1	793.5	915.6	1069.9	1184.3	1298.0	1411.2	1560.5	1673.4
Neeleeswaram	1722.4	2056.6	2278.0	2557.6	2765.0	2970.9	3176.1	3446.8	3651.3
Erinjipuzha	656.7	800.2	895.3	1015.3	1104.4	1192.8	1280.9	1397.1	1485.0
Ramamangalam	942.0	1043.6	1110.9	1195.9	1259.0	1321.6	1384.0	1466.3	1528.5
Kidangoor	402.8	481.1	532.9	598.4	647.0	695.2	743.3	806.7	854.6
Kallooppara	456.8	544.1	601.8	674.8	729.0	782.7	836.3	907.0	960.4
Malakkara	776.7	885.9	958.1	1049.4	1117.1	1184.4	1251.4	1339.7	1406.5
Pattazhy	572.4	867.9	1063.5	1310.7	1494.0	1676.0	1857.4	2096.6	2277.4
Kalampore	304.2	347.9	376.9	413.4	440.6	467.5	494.3	529.7	556.5
Karathode	465.2	558.4	620.1	698.0	755.8	813.2	870.3	945.8	1002.8
Arangilay	686.5	778.6	839.6	916.6	973.8	1030.5	1087.0	1161.6	1218.0
Kuniyil	1569.7	1863.6	2058.2	2304.1	2486.5	2667.5	2847.9	3085.9	3265.7
Kumbidi	1765.3	2051.0	2240.2	2479.2	2656.5	2832.5	3007.9	3239.2	3414.1
Ambalapalayam	98.8	155.8	193.5	241.2	276.6	311.7	346.7	392.8	427.7
Thumpamon	450.4	537.6	595.4	668.3	722.5	776.2	829.8	900.4	953.8

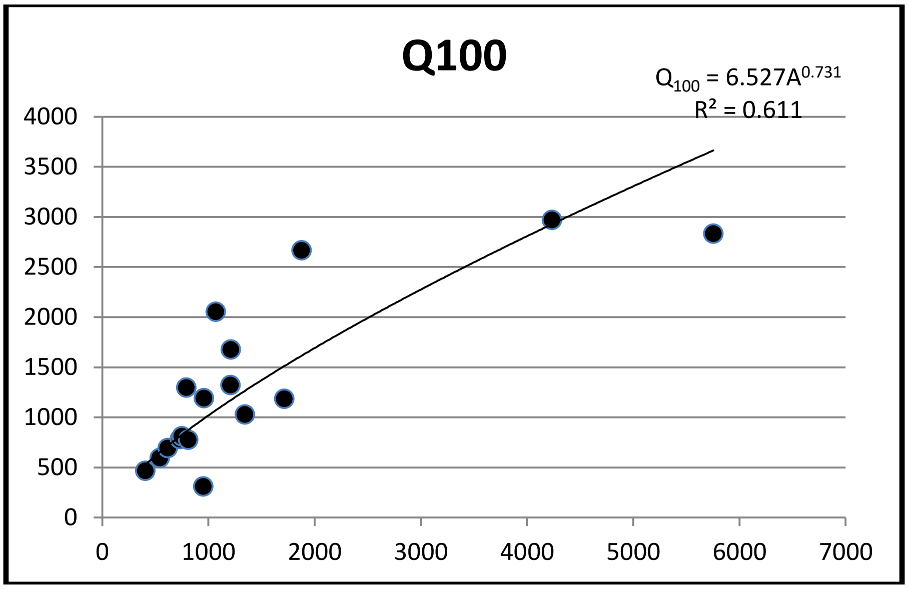


Figure 1: Relation between Q_{100} and Catchment Area for Kerala State

Table 5: Return Period Floods (cumecs) for Gauge Sites, Tamil Nadu State

Gauge Site	**Q2**	**Q5**	**Q10**	**Q25**	**Q50**	**Q100**	**Q200**	**Q500**	**Q1000**
Ambaramapalayam	128.3	188.3	228.0	278.2	315.5	352.4	389.3	437.8	474.6
Avaramkuppam	108.9	153.3	182.6	219.8	247.3	274.6	301.9	337.8	365.0
Nellithurai	622.1	824.7	958.9	1128.5	1254.3	1379.1	1503.5	1667.7	1791.7
Paramakudi	704.9	1032.7	1249.8	1524.0	1727.5	1929.4	2130.6	2396.0	2596.7
Savandapur	468.6	699.6	852.6	1045.9	1189.2	1331.6	1473.3	1660.4	1801.8
Thengumarahada	169.7	253.1	308.4	378.2	430.0	481.4	532.6	600.2	651.3
Theni	201.3	289.2	347.4	421.0	475.6	529.8	583.8	655.0	708.8
Vazhavachanur	747.2	1125.7	1376.3	1692.9	1927.8	2160.9	2393.2	2699.7	2931.3
Villupuram	1108.0	1521.4	1795.2	2141.0	2397.5	2652.2	2905.9	3240.7	3493.7
Nallamaranpatty	1417.9	2459.5	3149.2	4020.6	4667.0	5308.7	5948.0	6791.5	7429.0
Muruppanadu	857.1	1284.0	1566.7	1923.9	2188.8	2451.8	2713.9	3059.6	3320.9
Irrukkankudi	343.3	507.7	616.6	754.1	856.1	957.4	1058.3	1191.4	1292.0
Gummanur	241.2	360.0	438.6	537.9	611.5	684.7	757.5	853.6	926.3

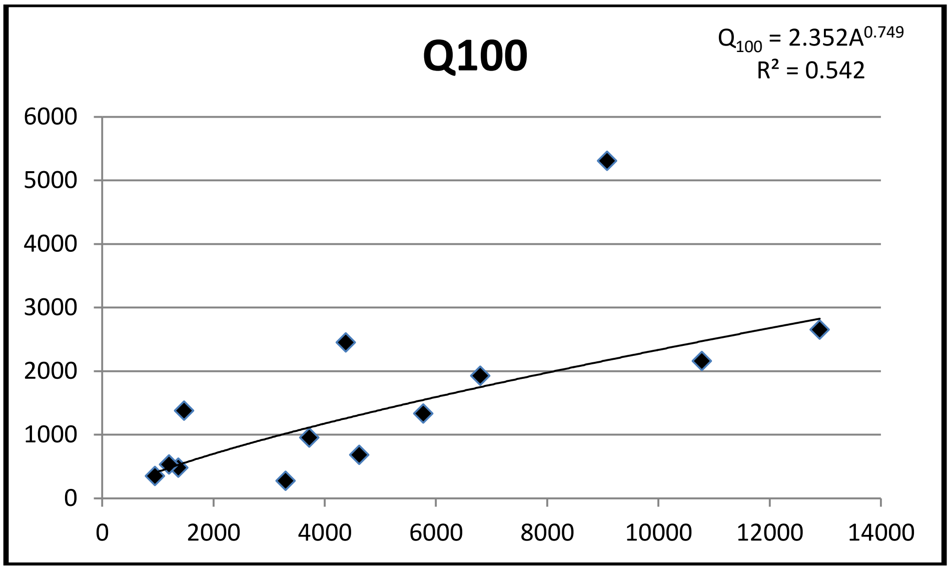


Figure 2: Relation between Q_{100} and Catchment Area for Tamil Nadu State

Table 6: Return Period Floods (cumecs) for Gauge Sites, Karnataka State

Gauge Site	Q2	Q5	Q10	Q25	Q50	Q100	Q200	Q500	Q1000
Biligundlu	3355.9	3973.6	4382.5	4899.2	5282.5	5663.0	6042.1	6542.2	6920.2
Bantwal	4750.5	5521.7	6032.3	6677.4	7156.0	7631.0	8104.4	8728.8	9200.8
Kollegala	3329.9	4033.1	4498.7	5087.0	5523.4	5956.6	6388.3	6957.7	7388.1
Kudige	1429.7	1606.0	1722.7	1870.2	1979.6	2088.2	2196.4	2339.1	2447.0
M.H.Halli	739.7	998.7	1170.2	1386.9	1547.7	1707.2	1866.2	2076.0	2234.5
Muthanakere	1273.1	1486.9	1628.6	1807.5	1940.2	2072.0	2203.2	2376.4	2507.3
Cholachguda	1254.5	1664.1	1935.3	2277.9	2532.1	2784.4	3035.8	3367.4	3618.1
Galgali	9895.4	11311.3	12248.6	13433.0	14311.7	15183.9	16052.8	17199.3	18065.8
Huvinhedgi	1274.1	1682.3	1952.5	2294.0	2547.3	2798.7	3049.3	3379.8	3629.6
Malkhed	1095.5	1393.9	1591.4	1841.0	2026.2	2210.0	2393.1	2634.7	2817.3
Mudhol	1345.2	1656.0	1861.8	2121.8	2314.6	2506.1	2696.8	2948.5	3138.7
Oollenur	3934.4	4955.2	5631.1	6485.1	7118.6	7747.4	8374.0	9200.6	9825.3
Saigaon	2139.3	2512.2	2759.1	3071.0	3302.4	3532.2	3761.0	4063.0	4291.2
Yadgir	6639.8	7741.6	8471.0	9392.7	10076.5	10755.2	11431.4	12323.6	12997.8
T.K.Halli	562.6	695.8	783.9	895.3	977.9	1060.0	1141.7	1249.5	1331.0
T.Narasipura	1457.7	1747.8	1939.8	2182.5	2362.5	2541.2	2719.2	2954.1	3131.6
Byaladahalli	175.3	196.8	211.1	229.1	242.5	255.8	269.0	286.5	299.7
Harlahalli	3501.0	4156.3	4590.2	5138.4	5545.1	5948.8	6351.0	6881.6	7282.7
Honnali	2695.4	3141.7	3437.2	3810.6	4087.6	4362.6	4636.5	4998.0	5271.1
Marol	1196.4	1309.5	1384.4	1479.0	1549.2	1618.9	1688.3	1779.9	1849.1
Shimoga	3029.6	3936.4	4536.7	5295.2	5858.0	6416.5	6973.1	7707.3	8262.2

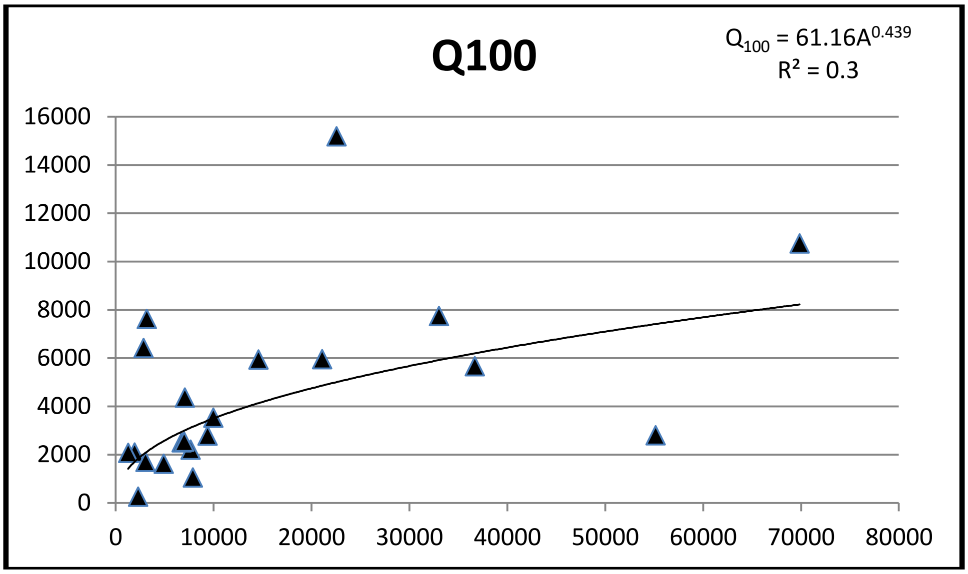


Figure 3: Relation between Q_{100} and Catchment Area for Karnataka State

Six Empirical Formulae; Ryves, Rational, Inglis, Riggs, Ali Nawabjung and Creager, were tested with the available peak discharge series and Return Period flood values for each of the gauge sites. Equations were applied in Systat software and the coefficients were obtained for each of the States. To evaluate the accuracy of the empirical coefficients, mean square errors, oriental coefficient and mean difference were used. The empirical coefficients with lower RMSE, BIAS and MD were extracted. The empirical coefficients are separated into two; C, representing a regional coefficient, which is kept constant for the individual equations for all the Return Period floods. The coefficients ‘a’ and ‘b’ are considered changing from each of the return period flood peaks. The empirical coefficients for all the equations considered for each of the three States are given in Tables 7, 8 & 9.

Table 7: Empirical Coefficients for Kerala

Emp. Formula	**Coefficients**	**Return Period Flood**						
		Q2	**Q5**	**Q10**	**Q50**	**Q100**	**Q200**	**Q500**
CREAGER	C	2	2	2	2	2	2	2
	a	19	17	14	10	9	8.5	7.5
	b	-0.02	-0.02	-0.016	-0.012	-0.011	-0.01	-0.008
RIGGS	C	4	4	4	4	4	4	4
	a	0.35	0.37	0.40	0.44	0.45	0.47	0.48
	b	0.35	0.35	0.34	0.34	0.31	0.30	0.28
RYVES	C	9	9	9	9	9	9	9
	a	0.60	0.61	0.64	0.66	0.67	0.68	0.71
RATIONAL	C	0.60	0.63	0.70	0.78	0.82	0.84	0.87
INGLIS	C	20	20	20	20	20	20	20
	a	8	9	12	15	16	18	19
	b	0.5	0.49	0.47	0.45	0.44	0.43	0.41
ALI NAWAB	C	1.6	1.6	1.6	1.6	1.6	1.6	1.6
	a	1.05	1.07	1.11	1.15	1.18	1.20	1.21
	b	18	17	15	14	13	11	10

Table 8: Empirical Coefficients for Tamil Nadu

Emp. Formula	**Coefficients**	**Return Period Flood**						
		Q2	**Q5**	**Q10**	**Q50**	**Q100**	**Q200**	**Q500**
CREAGER	C	5	5	5	5	5	5	5
	a	110	104	101	100	99	97	96
	b	-0.041	-0.038	-0.037	-0.033	-0.031	-0.028	-0.025
RIGGS	C	3	3	3	3	3	3	3
	a	0.40	0.42	0.43	0.44	0.45	0.48	0.49
	b	0.33	0.32	0.30	0.29	0.26	0.25	0.24
RYVES	C	7	7	7	7	7	7	7
	a	0.54	0.59	0.60	0.62	0.65	0.66	0.69
RATIONAL	C	0.29	0.31	0.32	0.36	0.38	0.42	0.46
INGLIS	C	25	25	25	25	25	25	25
	a	10	11	12.5	13	15	16	18
	b	0.59	0.57	0.54	0.53	0.50	0.48	0.45
ALI NAWAB	C	1.2	1.2	1.2	1.2	1.2	1.2	1.2
	a	0.95	0.98	0.99	1.02	1.04	1.08	1.11
	b	19	18	16	15	13	12	10

Table 9: Empirical Coefficients for Karnataka

Emp. Formula	Coefficients	Return Period Flood						
		Q2	**Q5**	**Q10**	**Q50**	**Q100**	**Q200**	**Q500**
CREAGER	C a b	4 24 -0.03	4 22 -0.028	4 21 -0.027	4 20 -0.025	4 19 -0.022	4 17 -0.021	4 14 -0.018
RIGGS	C a b	11 0.34 0.42	11 0.36 0.41	11 0.37 0.40	11 0.39 0.38	11 0.40 0.36	11 0.42 0.35	11 0.45 0.33
RYVES	C a	14 0.53	14 0.54	14 0.55	14 0.57	14 0.58	14 0.61	14 0.62
RATIONAL	C	0.62	0.63	0.64	0.66	0.68	0.69	0.72
INGLIS	C a b	55 11 0.58	55 15 0.575	55 16 0.56	55 18 0.54	55 19 0.525	55 21 0.51	55 22 0.50
ALI NAWAB	C a b	2.2 1.20 10.5	2.2 1.24 9	2.2 1.26 8.5	2.2 1.29 8	2.2 1.33 7	2.2 1.35 6.25	2.2 1.40 5.5

Various empirical flood peak flow rate estimation methods were compared with the return period floods. With regard to comparison standards, for the best standard, a low rank and for the worst method a high rank was considered in each standard. By putting these standards in the table, the method which has had the lowest rank in all standards can be considered as the most proper method. Considering the conducted evaluation, the ranks for the three standards (RMSE, BIAS and MD), are shown in Tables 10, 11 & 12.

From the Table 10, it can be seen that the Creager, Ryves and Inglis formulae produces larger errors and hence the empirical formulae best suited for Kerala are:

- Riggs
- Rational
- Ali Nawabjung

Table 11 gives the rankings given to each of the six formulae based on the statistical test, for Tamil Nadu. It can be seen from the table that the following equations can be applied with better accuracy for the State of Tamill Nadu:

- Inglis
- Ali Nawabjung
- Creager

Similarly, from Table 12, it can be seen that the empirical formulae which can be used with better prediction efficiency, for Karnataka State are:

- Inglis
- Ali Nawabjung
- Creager

Table 10: Ranking of Empirical Methods wrt Various Statistical Tests (Kerala)

Statistical Standard	Creager	Riggs	Ryves	Rational	Inglis	Ali Nawabjung
MD	5	2	6	1	4	3
RMSE	5	1	5	4	6	2
BIAS	5	2	4	3	6	1

Table 11: Ranking of Empirical Methods wrt Various Statistical Tests (Tamil Nadu)

Statistical Standard	Creager	Riggs	Ryves	Rational	Inglis	Ali Nawabjung
MD	2	6	5	4	1	3
RMSE	3	5	6	2	1	4
BIAS	3	6	5	4	2	1

Table 12: Ranking of Empirical Methods wrt Various Statistical Tests (Karnataka)

Statistical Standard	Creager	Riggs	Ryves	Rational	Inglis	Ali Nawabjung
MD	2	4	5	6	3	1
RMSE	1	5	4	6	3	2
BIAS	2	5	6	4	1	3

The comparison of the return period flood values (obtained using the observed discharge data) with the estimates using the empirical formulae is shown in Figure 4, 5 & 6. However, these figures gives only Q values for a particular return period and for a single gauging station, just for illustration purpose.

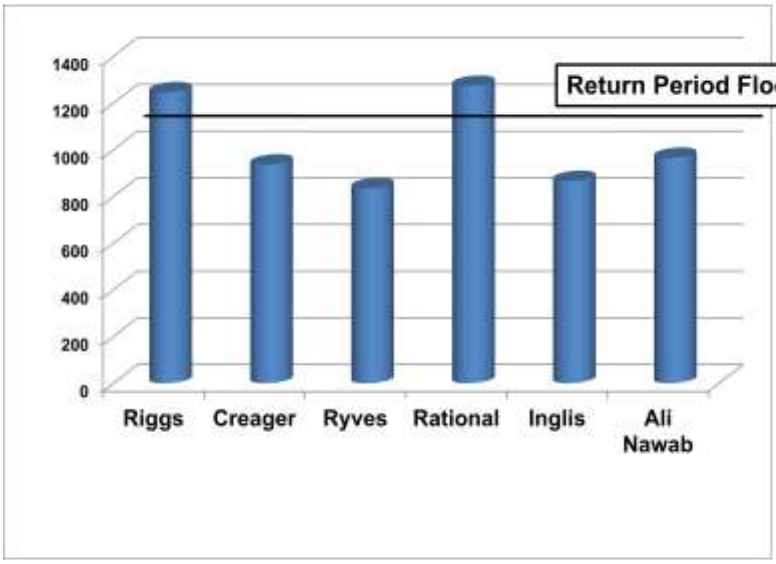


Figure 4: Comparison of Performance of Empirical Formulae (Kerala)

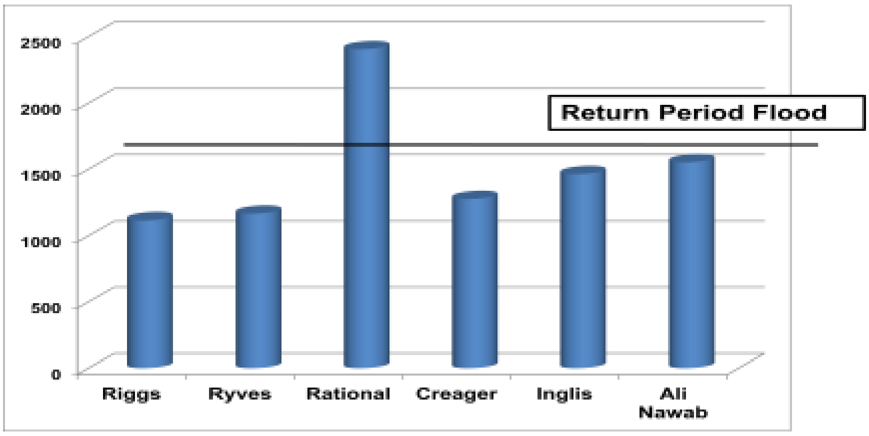


Figure 5: Comparison of Performance of Empirical Formulae (Tamil Nadu)

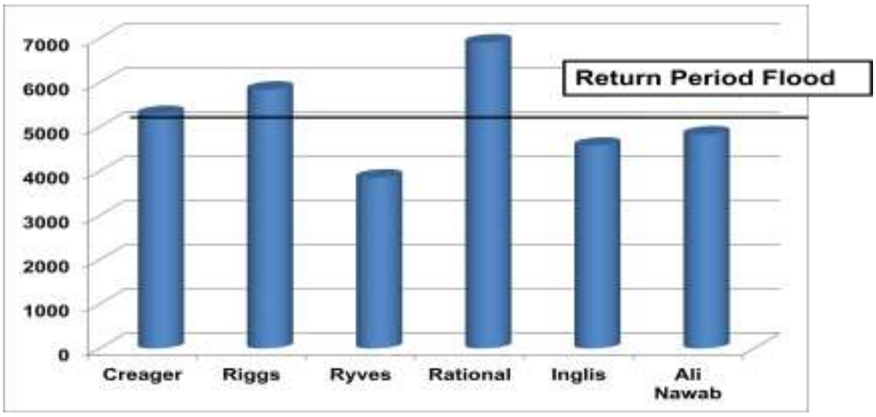


Figure 6: Comparison of Performance of Empirical Formulae (Karnataka)

CONCLUSIONS

Empirical flood formulae are commonly used in water resources planning and management, where historical data is not adequately available for other methods such as flood frequency analyses or unit hydrograph techniques; or where an initial estimate of flood value for a Return Period is required. Most of the equations use catchment area as the variable for the calculation of peak flood value. However, it is very important to note that the coefficients used in such equations are site specific and evaluated with very few observations or data duration. Therefore, regular testing of these equations is required to revise the empirical coefficients, as and when more and more data is available.

In the present study, six commonly used Empirical Formulae were tested using the observed flood peak values and return period flood values for gauge sites (covering different agro-climatic regions and varying catchment areas) in three southern States of India, Kerala, Tamil Nadu and Karnataka. For statistical comparison of the results from empirical runoff estimation methods with observed data, some statistical indexes such as RMSE, BIAS and MD were used.

Six Formulae; Rational, Riggs, Ryves, Inglis, Creager and Ali Nawbjung, were tested with the estimated flood values for different Return Periods. Ranks were assigned to each of these equations based on the statistical tests for standard prediction errors. It is found that Ali Nawabjung formula gives comparable predictions for the gauge sites from all the three States. Inglis and Creager formulae are also yielding better predictions for Tamil Nadu and Karnataka, wheras, for the gauge stations from Kerala, Riggs and Rational formulae gives better estimates.

REFERENCES

Alcázar, J. and Palau, A. 'Establishing environmental flow regimes in a Mediterranean watershed based on a regional classification'. Journal of Hydrology. 388. pp. 41–51. 2010.

Borujeni, S. C. and Sulaiman, W. N. 'Development of L-moment based models for extreme flood events', Malaysian Journal of Mathematical Sciences'. Vol. 3 (2), pp. 281-296. 2009.

Bridges and Wayne, C. 'Techniques for estimating magnitudes and frequencies of floods on natural flow streams in Florida'. U.S. Geological Survey Water Resources Investigations Report 82-4012. Tallahassee. FL. 1982.

Fill, H.D. and Steiner, A.A. 'Estimating instantaneous peak flow from means daily flow data'. Journal of Hydrologic Engineering. 8(6): pp. 365-369. 2003.

Gholami, Sh, 'The survey of empirical methods using in instantaneous maximum discharges determining'. M Sc Thesis. University of Tehran. 1991.

Griffiths, G.A. and McKerchar, A.I. 'Dependence of flood peak magnitude on catchment area'. Journal of Hydrology (NZ). 47 (2). pp. 123-131. 2008.

Hosking, J. R. M. 'L-moments: Analysis and estimation of distributions using linear combinations of order statistics', J. Royal Stat. Soc., Series B, **52**, pp.105–124. 1990.

Hosking, J. R. M. and Wallis, J. R. Regional Frequency Analysis – An Approach Based on L-moments, Cambridge University Press, New York. 1997.

Inglis, C. C. and De Souza. 'A critical study of runoff and floods of catchment of the Bombay Presidency with a short note on loss from lakes by evaporation'. Bombay PWD Technical paper No. 30. 1930.

Jha, R. and Smakhtin, V. 'A review of methods for Hydrological estimation at ungauged sites in India'. IWMI Working Paper No. 130. 2008.

Khosla, A. E. Analysis and utilization of data for the appraisal of water resources, The Central Board of Irrigation and Power Journal. 1949.

Kothyari, U. C. 'Estimation of monthly runoff from small catchments in India'. Journal of Hydrological Sciences. 40: pp. 533-541.1995.

Ponce, Victor M. Engineering Hydrology: Principles and Practices. Prentice Hall. Englewood Cliffs. NJ. 1993.

Rakesh Kumar, Chatterjee, C., Sanjay Kumar, Lohani, A.K. and Singh, R.D. 'Development of regional flood frequency relationships using L-moments for Middle Ganga Plains, Subzone 1(f) of India'. Water Resources Management **17: pp.** 243–257. 2003.

Riggs, H.C. 'Regional analysis of stream flow characteristics'. Techniques of Water Resources Investigations. Book 4. Chap B3. U.S. Geological Survey. Washington DC. 1973.

Rohina, A., Fard, A. B., Kazemi, N., Abadi, K. and Mohammadi A. ‘Evaluating empirical methods of flood flow rate estimation in Bakhtegan watershed - Iran’. International Journal of Advanced Biological and Biomedical Research. Volume 1. Issue 4. Pp. 450-458. 2013.

Salajegheh, A. and Dastorani, J. ‘Determining of regional coefficients of Fuller's empirical formula to estimate maximum instantaneous discharges in Dasht Kavir basin, Kalshour Sabzevar, Iran’. BIABAN Journal. Vol 11. No 1. pp. 53-59. 2006.

Smithers, J C. ‘Methods for design flood estimation in South Africa’. Water SA. Vol. 38. No. 4. 2012.

Taguas, E.V., Ayuso, J.L., Pena, A., Yuan, Y., Sanchez, M.C., Giraldez, J.V. and Pérez, R. ‘Testing the relationship between instantaneous peak flow and mean daily flow in a Mediterranean Area Southeast Spain’. Catena. 75. pp 129–137. 2008.

Telvari, A. ‘Calibration and comparison of instantaneous maximum discharge estimation empirical methods in Karkheh basin’. Soil Conservation and Watershed Management Institute. 1998.

Zafirakou-Koulouris, A., Vogel, R. M., Craig, S. M. and Habermeier, J. ‘L-moment diagrams for censored observations’, Water Resour. Res. **34**(5), pp. 1241–1249. 1988.