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ABSTRACT

The computation of flood magnitude and its likely occurrence to design different hydraulic structures are major challenges to the research community. The present study has been carried out to identify the homogeneous regions in the Mahanadi basin in Chhattisgarh part (data from 26 gauge/discharge sites) of India using conventional and clustering-based homogeneity tests and then computation and identification of probability weighted moment and L-moment based best regional distributions for different regions. Different simple to complex distributions like Extreme Value-I, Generalized Extreme Value, Logistic, Generalized Logistic, Generalized Pareto, Normal and Log-normal, Wakeby-4, and Wakeby-5 was used in the analysis through standardizing procedure to compute regional distributions. The best-fit distribution selected by simulating several series and compute L-kurtosis along with the L-moment ratio diagram.

The homogeneity analysis confirmed that this basin can broadly be divided into two different homogeneous regions with 15 and 11 stations in the first (Region-1) and second (Region-2) regions respectively. The GEV distribution was found best suited for Region-1 while the Generalized Pareto worked well for Region-2. To make results more convenient for field application, catchment area-based equations were converted in the form of Dicken's or Ryve's formulae for these regions to estimate flood quantiles of any return period.

Keywords: Flood quantiles, regional flood frequency modeling, homogeneity, distributions, L-moments

1.0 INTRODUCTION

The flood is an instantaneous hazard resulting from a relatively high flow that may overtop the banks of a stream and cause widespread loss of life (Hallegatte et al. 2013), properties, crops, and important installations. The flood quantile estimation is required for flood plain zoning, evacuation, construction of structures, flood forecast, and land-use management (Kidson and Richards 2005). The flood frequency analysis is carried out on annual and peak over threshold values with at-site, at-site regional, and regional only mode based on data availability proved its usefulness in designing structures and flood hazard mapping. The at-site flood frequency has limited applicability in FFM because of extrapolation from a shorter period of records to get flood quantiles of longer return periods (Lettenmaier and Potter 1985). In the regional FFM (RFFM), the data from multiple sites in a region are pooled to get a longer series and a best-fit distribution is obtained to suit the region (Castellarin et al. 2005). The RFFM is especially useful in the case of limited and no data availability may suffer from multiple sources of uncertainties including stationarity of the series, serial & spatial correlation, sampling variability (different length of series for different stations), heterogeneity of catchments, models, parameters, data, and operational errors (Yen 2002; Hailegeorgis and Alfredsen 2017). Therefore, RFFM should be applied after carefully investigating homogeneity, unbiased modeling, and efficient criterion for the selection of best-fit distribution.

Fang et al. (2007) used peak over threshold sampling method where the number of exceedances was considered to follow Poisson (Po) distribution and fitted Generalized Pareto (GP) and exponential (Ex) distributions in three different combinations and found that the Po-Ex/GP model performed better than both other models. Mishra et al. (2009) used regional flood frequency analysis on simulated flood data of Nepal using L-moments for the determination of parameters of six different distributions on annual flood series obtained from the application of the SimHyd hydrologic simulation model and found GEV and Log-Normal as the most suited distributions with superiority of regional approach over the commonly used method of Water and Energy Commission Secretariat (WECS). Asad et al. (2013) applied Gumbel and Powel’s distributions for an international river Dudhkumar passes through Bhutan, India, and Bangladesh and found significant differences in results from both these distributions. Odry and Arnaud (2017) presented a comparison of wide-range of flood frequency methods based on statistical and simulation techniques using k-fold cross-validation for deciding the number of ungauged catchments in a set of 1535 catchments where donor catchments (where data available) were used for calibration and target catchments (with less/no data) for validation. Romali and Yusop (2017) computed peak flow for different average recurrence intervals in the Segamat river of Malaysia using Log-Pearson, Log-Normal, Generalized Pareto, Generalized Extreme Value, and Weibull distributions and concluded that Generalized Pareto distribution was the most suited distribution for the river. Engeland et al. (2018) applied GEV distributions for historical data (mainly water levels) of Bulken, Lalm, Stranderfjord, and Labru basins in Norway using the Bayesian approach and avoid absurd computation of shape parameters by adding a prior likelihood as suggested by Martin & Stedinger (2000). Jiang and Kang (2019) suggested and applied a time-varying framework based on changing scale, shape, and location of GEV distribution on Yichang station of China on the annual maximum floods. The results of the analysis confirmed a decrease peak for different return periods under non-stationary conditions. Similarly, several others have carried out at-site, regional, and POT flood frequency modeling in different parts of the world (Jaiswal et al. 2004; Bhuyan et al. 2010; Qin and Lu, 2014; Apipattanavis et al. 2010; Dawdy et al. 2012; Ahmed et al. 2015; Romali and Yusop 2017; Ganamala and Sundar Kumar 2017; Shah and Prasad 2017;

Kumar et al. 2018; Wu et al. 2018; Guru and Jha 2015b; Bezak et al. 2014; Alobaidi et al. 2015, Ghadrei et al. 2019, etc.).

1.1 Flood Frequency Analysis in Mahanadi Basin

Guru & Jha (2015a) have carried out at-site flood frequency analysis for 23 stations in the lower Mahanadi basin by testing seven different distributions namely exponential, Gumbel, GEV, logistic and generalized logistic, lognormal, and Pearson type III, and compared with the best assumed partial duration based Generalized Pareto (PDS-GP). The GP distribution was found the most suitable based on precision and stability. Baidya et al. (2020) have carried out flood frequency analysis using 18 sites in the Mahanadi basin for gauged as well as ungauged sites and the main focus was on ungauged catchments where inverse distance, ordinary kriging as at-site, and area-weighted method as regional approach were used for analysis. The results of the analysis suggested that for lower return periods of 2 to 5 years, the flood estimation is better in the flood index method while the direct interpolation gives better results for flood quantiles of higher return periods. The main weakness in this research of ignorance of homogeneity which is very important in flood frequency modeling. Mahanadi basin is one of the worst affected regions due to adverse hydro-meteorological conditions (Swetapadma and Ojha 2018) require systematic study especially in the upper part of the basin where availability of data is poor. The main motivation for the present study is to identify different homogeneous regions in the upper Mahanadi basin lies in Chhattisgarh state and identify suitable distributions for gauged as well as ungagged basins using less bias technique for computation of parameters to minimize the error and uncertainties.

2.0 STUDY AREA

The Mahanadi river basin is the main source of water for irrigation, industries, and drinking water in Chhattisgarh. It is considered as the lifeline for Chhattisgarh state as it drains through more than 60% of the state's geographical area. Many cities like Raipur (capital city of Chhattisgarh), Gariaband, Balodabazar, Balod, Rajnandgaon, Korba, Kanker, Narayanpur, and Surajpur situated on the river Mahanadi or its tributaries. The map of the study area is presented in Fig. 1.

Fig. 1

3.0 DATA USED

The daily discharge data of 15 sites of Central Water Commission, Govt. of India, and 11 sites of Water Resources Department, Govt. of Chhattisgarh on river Mahanadi and its tributaries have been used in the analysis. The daily discharge data of 10 to 42 years with some gaps were used to determine the annual flood series. The drainage and mean annual flood for different sites have been presented in Table 1.

Table 1

4.0 METHODOLOGY

As per the availability of data, the flood frequency modeling can be carried out either at the at-site, at-site regional, or regional only flood frequency method. The at-site analysis uses the flood series of the site of interest (when sufficient data available), the at-site regional analysis uses mean annual flood computed from flood data of site of interest and regional distribution (when limited data is available), while the regional only analysis develops the relationship between mean annual flood and catchment characteristics (i.e. catchment area, slope, length, etc. in case of non-availability of data) to determine to mean annual flood and regional distribution to compute flood quantiles at the site of interest. The prerequisite for carrying out flood frequency modeling is that the series of the annual flood should be random, free from outliers and the region should be homogeneous. The turning point and Grubb's test were used to identify randomness and outliers respectively. The homogeneity of the region was tested with the help of discordancy measures & L-moment based on *X-10* tests. The standardized probability weighted moments and L-moment techniques were used to determine parameters of different distributions to compute flood quantiles. The framework used for regional flood frequency modeling is presented in Fig. 2.

Fig. 2

4.1 Flood Frequency Modeling

If $Q_1, Q_2, Q_3 \ldots\ldots\ldots. Q_N$ is a collection of maximum data of each year where N is the number of years of observed time series. The probability distribution of AM values may be defined by its distribution function as given below:

$$F(q) = PR(Q/q) \quad (1)$$

then the variate value having return period T, namely Q_T is defined implicitly by the

$$1 - F(Q_T) = \frac{1}{T} \quad (2)$$

4.2 Application of PWMs and L-Moments in Flood Frequency Analysis

The method of moment (MOM) is the oldest, easy, simple, and the most widely used technique but less accurate and unable to estimate parameters of complex distributions which are common in FFM. The probability weighted moments (PWM) and L-moments can yield relatively unbiased estimates of the basic moments, parameters, and quantiles compared to the conventional MOM technique. L-moments have higher robustness can provide higher efficiency with small-size samples (Delicado and Goria 2008; Peters et al. 2016) and recognition of homogeneity (Lim and Voeller 2009).

4.3 Distributions and Parameter Estimation Techniques

The various distributions and parameter estimation techniques employed for flood frequency analysis are presented in Table 2. The L-moments can be expressed through linear functions of PWMs (Hosking 1986, 1990) using the given below simple equations.

Table 2

$$\lambda_1 = M_{100} \quad (1)$$

$$\lambda_2 = 2M_{110} - M_{100} \quad (2)$$

$$\lambda_3 = 6M_{120} - 6M_{110} + M_{100} \quad (3)$$

$$\lambda_4 = 20M_{130} - 30M_{120} + 12M_{110} - M_{100} \quad (4)$$

Where,

$$M_{i,j,k} = \int_0^1 x^i(F)\, F^j\, (1-F)^k\, dF \quad (5)$$

The scale and shape of a probability distribution can be appropriately expressed through L-moments. The L-moment ratios of x are defined to be

$$\tau_r = \frac{\lambda_r}{\lambda_2}, \qquad r = 3,4\Lambda \quad (6)$$

The L_{cv} (τ_2), L_{cs} (τ_3), and L_{ck} (τ_4) reflects variation, symmetry, and peakedness respectively, and are useful to identify the best-fit distribution and can be expressed as,

$$L_{CV} = \tau_2 = \frac{\lambda_2}{\lambda_1} \quad (7)$$

$$L_{CS} = \tau_3 = \frac{\lambda_3}{\lambda_2} \quad (8)$$

$$L_{CK} = \tau_4 = \frac{\lambda_4}{\lambda_2} \quad (9)$$

L-moments can be used to estimate parameter when fitting a distribution to a sample by equating the first p-sample L-moments to corresponding population L-moments. Parameter estimation with L-moments is more accurate than even the maximum likelihood estimate; in case of small sample (Hosking, 1990).

4.4 Regional Flood Frequency Modeling (RFFM)

The regional flood frequency modeling is an alternative and only solution for the areas where limited or no data available (Alobaidi et al. 2015).

4.5 Relationship between mean annual flood and catchment characteristics

For ungauged basins of a hydrologically homogeneous basin, the mean annual flood is required. For a homogeneous region, the relationship can be developed between mean annual flood and any one or more of the basin characteristics including size and shape (Area), soil index/geology, catchment storage, overland, and channel slope, density and distribution of streams, rainfall, etc. (Mimikou and Gordios 1989; Griffiths and McKerchar 2008; Smith et al. 2015; Kumar et al. 2003; Dubey et al. 2019) In the present study only catchment area has been considered because of non-availability of other data related to catchment characteristics. The relationship between mean annual flood and catchment area is of the following form:

$$\overline{Q} = mA^d \tag{10}$$

4.6 Methods based on standardized PWM's and L-moments

In the study, the method based on standardized PWM's has been used for the computation of regional parameters of various distributions. Following sequential steps have been carried out for at site regional and regional flood frequency analysis:

- Determine at site values of probability-weighted moments for each site.
- Standardize the at-site values of PWM's by dividing them by at-site mean.

- Compute standardized L-moments for each site using standardized PWMs.
- Compute the regional values of standardized PWMs and L-moments averaged across all sites in the region in the ratio of record length.
- Estimate regional parameters of different distributions.
- Flood quantile for any site (Q_{Ti}) can be determined using the following equation.

$$Q_{Ti} = Q_r * \overline{Q} \tag{11}$$

Where Q_{Ti} = flood of T year return period for any site i, Q_r = flood quantile calculated from regional parameters, and $\overline{Q}$ = Mean annual flood of that site.

4.7 Selection of Best-fit distribution for the regional approach

Various goodness of fit tests such as L-moment ratio diagram, simulation experiments (L-Kurtosis), D-index, and efficiencies was applied to identify the best distribution.

4.7.1 L-Moment ratio diagram

The L-moment diagram was proposed by Hosking (1990) for the selection of a suitable probability distribution constructed by plotting the theoretical L-skewness and L-kurtosis for a different distribution. The L-moment ratio diagram has the advantage of its simplicity by comparing several distributions through a simple graphical instrument.

4.7.2 Measure based on L-Kurtosis

The goodness of fit based on the L-moment ratio diagram is subjective to some extent. Hosking and Wallis (1993) proposed a criterion for the selection of suitable distribution based on L-kurtosis. The quality of fit is judged by the difference between the L-kurtosis of fitted distribution and the average L-kurtosis of the region. To assess the significance of this difference we compare it with the sampling variability of τ_4.

Let σ_4 denote the standard deviation of τ_4, the goodness of fit measure is

$$Z^{GEV} = (\tau_4 - \tau_4^{GEV})/\sigma_4 \tag{12}$$

σ_4 can be obtained by repeated simulation of a homogeneous region with GEV distribution. For other distributions simulation can be done with the parameter of that distribution and τ_4^{GEV} will be replaced by the τ_4 of that distribution. The theoretical values of different distributions as proposed by Hosking and Wallis (1993) are:

$$\tau_4^{GEV} = (1.0 - 6*2^{k} + 10*3^{-k} - 5*4^{-k})/(1-2^{-k}) \tag{13}$$

$$\tau_4^{EV\text{-}I} = 0.1504 \tag{14}$$

$$\tau_4^{LOG} = 1/6 \tag{15}$$

$$\tau_4^{GLOG} = (1+5k^2)/6.0 \tag{16}$$

$$\tau_4^{GPD} = (1-k)(2-k)/((3+k)(4+k)) \tag{17}$$

$$\tau_4^{NOR} = 0.1226 \tag{18}$$

4.7.3 Descriptive measure

The measures like D-index and Nash-Sutcliff efficiency were used to assess how a proposed distribution fitted with the observed data.

5.0 ANALYSIS AND RESULTS

The present study has been taken up to develop the regional flood frequency formulae/curves for the Mahanadi river system in Chhattisgarh state.

5.1 Homogeneity Testing

For the determination of regional parameters for the Mahanadi basin, approaches of standardized PWM's and L-moments were applied. Initially, the mean annual flood series of all the sites were determined and Grubb's outlier test has been applied to remove outlier values from each series. The turning point has been used to ascertain the randomness of the series. From the analysis, it has been observed that all the series were random at 90% significance level. The homogeneity of the region was tested using discordancy measures and the L-moment based *X-10* test and found that the region was not homogeneous. Therefore, the sites in the region were divided into two groups based on the k-means clustering technique and divided into two groups as Region-1 and Region-2. The different sites in both regions are given in Table 3. Region-1 consists of the upper Mahanadi and Seonath basin while Region-2 has the Lower Mahanadi basin, Hasdeo, and Kelo basins.

Table 3

5.2 Relationship Between Mean Annual Floods and Catchment Areas

For estimation of mean annual flood at any ungauged site in the Mahanadi basin, relationships have been developed between the mean annual flood and catchment area for both regions. The following equations may be used to compute the mean annual flow ($\overline{Q}$) in m^3/sec and catchment area (A) in km^2.

For Region-1

$$\overline{Q} = 0.1149A^{1.0787} \tag{19}$$

For Region-2

$$\overline{Q} = 0.9372A^{0.8725} \tag{20}$$

5.3 L-moment Ratio Diagram

The regional L-skewness and L-kurtosis for both the regions were plotted on L-moment ratio diagrams (Fig. 3 (a) & 3 (b)). The L-moment ratio diagram is a diagram that consists of a graphical representation of standard L-skewness and L-kurtosis of different distributions on the same graph. In the L-moment ratio diagram, the regional L-skewness and L-kurtosis have been plotted along with the standard graph of different distributions to determine the best-fit distribution for a region. The L-skewness and L-kurtosis for both regions were computed and given in Table 4

Fig. 3a, 3b and Table 4

F[illegible]e L-moment ratio diagram, it was found that the Generalized Extreme Value distribution may be the best fit for Region-1, while Generalized Pareto may give the best results for Region-2.

5.4 Goodness of Fit Measure Based on L-kurtosis

In the case of the goodness of fit measure based on L-kurtosis, *Z*-values for different distributions used in the regional flood frequency modeling have been computed using repeated simulation. The values of *Z* for different distributions are given in Table 5. Out of all the distributions used in the simulation, the Generalized Extreme Value (GEV) distribution for Region-1 and Generalized Pareto for Region-2 has given a minimum value of *Z* and hence can be considered the best-fit distributions for the respective regions.

Table 5

Both the test and other descriptive measures have suggested that GEV and Generalized Pareto may be considered the best fit distributions for Region-1 and Region-2 respectively. After finalizing the best-fit distribution, flood quantiles for different return periods were computed for both regions.

5.5 Regional Flood frequency Equations

5.5.1 Regional flood frequency equation for region-1

The homogeneity tests confirmed that gauging sites of the Upper Mahanadi and Seonath basin can be considered as a homogeneous region (Region-1). All the results for the selection of best-fit distribution based on L-moments and other tests show that the Generalized Extreme Value

(GEV) distribution may be the best-fit distribution for computation of probable flow at any site in Region-1. The following may be the regional parameters of Generalized Extreme Value (GEV) distribution for Region-1.

u= 0.754, α = 0.391 and k = -0.051 (22)

The following regional equation may be used for any gauged/partially gauged and ungauged sites in the region.

For gauged/partially gauged site in Region-1

$$Q_T = \left[0.754 - 7.747\left\{1 - \left[-ln\left(1 - \frac{1}{T}\right)\right]^{-0.051}\right\}\right]\bar{Q} \tag{23}$$

For ungauged site in Region-1

$$Q_T = \left[0.087 - 0.89\left\{1 - \left[-\ln\left(1 - \frac{1}{T}\right)\right]^{-0.051}\right\}\right]A^{1.0787} \tag{24}$$

Where, Q_T, $\overline{Q}$ and A is the flood quantile in m^3/sec of T year return period, mean annual flood in m^3/sec, and catchment area in km^2 respectively. It is recommended that flood quantiles in any partial or gauged site should be estimated using equation 23 in which mean annual flood should be obtained from observed records can be used. In the case of an ungauged basin equation (24) can be used to compute flood of any return period, where the catchment area of the site of interest is used.

the flood quantiles for different sites in Region-1 of Mahanadi basin of Chhattisgarh using at-site regional flood frequency modeling for 3, 7, and 10 years return periods were computed and presented in Table 6.

Table 6

5.5.2 Regional flood frequency equation for region-2

The Generalized Pareto distribution was found the best-fit regional distribution for Region-2 and regional parameters of this distribution are as follows

$u = 0.426$, $\alpha = 0.643$ and $k = 0.1196$ (25)

The following regional equation may be used for any gauged/partially gauged and ungauged sites in the region.

For gauged/partially gauged site in Region-2

$$Q_T = \left[0.426 + 5.376\left\{1 - \left(\frac{1}{T}\right)^{0.1196}\right\}\right]\overline{Q} \quad (26)$$

For un-gauged site in Region-2

$$Q_T = \left[0.339 + 5.039\left\{1 - \left(\frac{1}{T}\right)^{0.1196}\right\}\right]A^{0.8725} \quad (27)$$

The flood quantiles for different year return periods for different sites using at-site regional modeling are given in Table 7. Generally, field practitioners require flood at different return periods but compel to use Dicken's or Ryve's formula in the form of $Q=CA^n$ (C is the constant and A is the catchment area in sq km. and *n* is the constant) does not have any consideration of return period. In the study, an attempt has been made to provide to compute C by replacing with C_t having two different relationships for region-1 & 2 with the coefficient of determination more than 0.99 presented in Fig. 6a and 6b and following equations.

For Region-1

$$Q_T = C_T\, A^{0.8725} \quad (28)$$

$$C_T = 0.0644 + 0.0569 Ln(T) \quad (29)$$

For Region-2

$$Q_T = C_T\, A^{1.0878} \tag{30}$$

$$C_T = 0.6237 + 0.3774 Ln(T) \tag{31}$$

6.0 CONCLUSIONS

Flood frequency modeling is one of the simplest and widely used applications of statistics in the field of hydrology. In the present study, an attempt has been made to develop regional relationships for the computation of flood quantiles in the Mahanadi basin of Chhattisgarh state. The PWM and L-moments have been applied for the estimation of parameters and D-index, efficiency, L-moment diagram, and L-kurtosis have been used for the selection of best-fit distribution. The regional formulae developed in the study can be used for the computation of flood quantiles at any ungauged or gauged sites with limited data in the region. The annual flood series of different sites in Mahanadi basins are random in nature and do not indicate any trend. Hence, this series can be used for probabilistic analysis.

The Mahanadi basin in the Chhattisgarh region can be grouped into two regions based on the homogeneity tests. Region-1 consists of G/D sites of Upper Mahanadi and Seonath basin, while Region-2 has G/D sites of Lower Mahanadi and Hasdeo basin. For both regions, separate equations have been developed to compute the mean annual flood for an ungauged basin using catchment area as input. From the analysis, Generalized Extreme Value (GEV) with its parameters as u= 0.754, α = 0.391 and k = -0.051 for Region-1 and Generalized Pareto distribution with its parameters with its parameters as u= 0.426, α = 0.643 and k = 0.1196 and L-moments as parameter estimation technique has been found the best-fit regional distributions. The present study provided the return period-based Dicken's or Ryve's formulae for both regions in the

Mahanadi basin of Chhattisgarh state for field engineers and practitioners to determine a return period flood at any ungauged basins for the design of small structures and cross drainage works.

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8.0 CONFLICT OF INTEREST

There is no known conflict of interest.

9.0 FUNDING

No funding was available for this study.

10.0 ETHICAL DECLARATION

The manuscript is not submitted to any other journal. Work done is original and all authors have contributed to the study. No known plagiarism.

11.0 COMPETING INTEREST

There is no competing interest

12.0 DATA AVAILABILITY

Data and programs are available. The program can be given on request.

12.0 AUTHORS CONTRIBUTION

Dr. R.K. Jaiswal- Planning, programming, writing

Dr. T. R. Nayak- Planning, data collection, and analysis

Dr. A. K. Lohani- Programming, manuscript preparation

Sri R. V. Galkate- Analysis, manuscript

13.0 REFERENCES

- Ahmed I, Fawad M, Mahmood I (2015) At-site flood frequency analysis of annual maximum stream flows in Pakistan using robust estimation methods. Pol J Environ Stud 24(6):2345-2353

- Alobaidi MH, Marpu PR, Ouarda TBMJ, Chebana F (2015) Regional frequency analysis at ungauged sites using a two-stage resampling generalized ensemble framework. Adv Water Resour 84. https://doi.org/10.1016/j.advwatres.2015.07.019
- Apipattanavis S, Rajagopalan B, Lall U (2010) Local polynomial based flood frequency estimator for mixed population. J Hydrol Eng. https://doi.org/10.1061/ASCEHE.1943-5584.0000242
- Asad MA, Ahmeduzamman M, Kar S, Khan MA, Rahman MN, Islam S (2013) Flood frequency modelling using Gumbel's nad Powell's method for Dhudhkumar river. J Water Resour Ocean Sci 2(2):25-28. https://doi.org/10.11648/j.wros.20130202.13
- Baidya S, Singh A, Panda SN (2020) Flood frequency analysis. Nat Hazards 100:1137-1158
- Bezak N, Brilly M, Šraj M (2014) Comparison between the peaks-over-threshold method and the annual maximum method for flood frequency analysis. Hydrol Sci J 59 (5):959–977
- Bhuyan A, Borah M, Kumar R (2010) Regional flood frequency analysis of north-bank of the river Brahmaputra using L-moments. Water Resour Manag 24:1779–1790
- Castellarin A, Vogel R, Matalas N (2005) Probabilistic behaviour of a regional envelope curve. Water Resour Res. https://doi.org/W06018, 10.1029/2004WR003042
- Dawdy D R, Griffis VW, Gupta VK (2012) Regional flood frequency analysis: how we got here and where we are going. J Hydrol Eng 17(9). https://doi.org/10.1061/(ASCE)HE.1943-5584.0000584
- Delicado P, Goria MN (2008) A small sample comparison of maximum likelihood, moments and L-moments methods for the asymmetric exponential power distribution. Comput Stat Data Anal 52(3):1661-1673
- Dubey A (2019) Development of regional flood frequency relationship for Narmada basin using index flood procedure. Int J Inno Technol Exploring Eng 8(12):2744-2752
- Engeland K, Wilson D, Borsányi P, Roald L, Holmqvist E (2018) Use of historical data in flood frequency analysis: a case study for four catchments in Norway. Hydrol Res 49(2):466–486
- Fang B, Guo S, Wang S, Liu P, Xiao Y (2007) Non-identical models for seasonal flood frequency analysis. Hydrol Sci J 52:5:974-991. https://doi.org/10.1623/hysj.52.5.974
- Ganamala K, Sundar Kumar P (2017) A case study of flood frequency analysis. Int J Civil Eng Technol 8(4):1762-1767

- Ghaderi K, Motamedvaziri B, Vafakhah M, Dehgani AA (2019) Regional flood frequency modeling: a comparative study among several data-driven models. Arab J Geosci 12:588. https://doi.org/10.1007/s12517-019-4756-7
- Griffiths GA, McKerchar AI (2008) Dependence of flood peak magnitude on catchment area. J Hydrol (New Zealand) 47(2):123-131
- Guru N, Jha R (2015a) Flood estimation in Mahanadi river system, India using partial duration series. J Georisk: Assess Manage Risk Eng Sys Geohazards. https://doi.org/10.1080/17499518.2015.1116013
- Guru N, Jha R (2015b) Flood frequency analysis of Tel basin of Mahanadi river system, India using annual maximum and pot flood data. Aquatica Proc 4:427-434
- Hailegeorgis TT, Alfredsen K (2017) Regional flood frequency analysis and prediction in ungauged basins including estimation of major uncertainties for mid-Norway. J Hydrol: Reg Studies 9:104-126
- Hallegatte S, Green C, Nicholls RJ, Corfee-Morlot J (2013) Future flood losses in major coastal cities. Nat Clim Chang 3:802–806
- Hosking JRM (1986) The theory of probability weighted moments, IBM Math Res Rep RC 12210, New York
- Hosking JRM (1990) L-Moments: Analysis and estimation of distribution using linear combination of order statistics. J Royal Stat Soc B 52:105-124
- Hosking JRM, Wallis JR (1993) Some statistics useful in regional frequency analysis. Water Resour Res 29(2):271-281
- Jaiswal RK, Goel NK, Singh P, Thomas T (2004) L-moment based flood frequency modeling, J Inst Eng India (Civil Eng Div) 84:6-10
- Jiang S, Kang L (2019) Flood frequency analysis for annual maximum streamflow using a non-stationary GEV model, E3S Web of Conferences 79, 03022.https://doi.org/10.1051/e3sconf/20197903022
- Kidson R, Richards KS (2005) Flood frequency analysis: assumptions and alternatives. Progr Phy Geog 29(3):392–410
- Kumar R, Chatterjee C, Kumar S, Lohani AK, Singh RD (2003) Development of regional flood frequency relationships using L-moments for middle Ganga plains subzone 1(f) of India. Water Resour Manag 17:243-257
- Kumar M, Sharif M, Ahmed S (2018) Flood estimation at Hathnikund barrage, river Yamuna, India using the peak-over-threshold method. ISH J Hyraul Eng. https://doi.org/10.1080/09715010.2018.1485119

- Lattenmaier DP, Potter KW (1985) Testing flood frequency estimation methods using a regional flood generation model. Water Resour Res 23(2):313-323
- Lim YH, Voeller DL (2009) Regional flood estimations in Red river using l-moment-based index-flood and bulletin 17B procedures. J Hyraul Eng 14(9). https://doi.org/10.1061/(ASCE)HE.1943-5584.0000102
- Martins ES, Stedinger JR (2001) Historical information in a generalized maximum likelihood framework with partial duration and annual maximum series. Water Resour Res 37:(10)2559–2567. https://doi.org/10.1029/2000WR000009
- Mimikou M, Gordios J (1989) Predicting the mean annual flood and flood quantiles for ungauged catchments in Greece. Hydrol Sci J 34(2):169-184. https://doi.org/10.1080/02626668909491322
- Mishra BK, Takara K, Yamashiki Y, Tachikawa Y (2009) Selection of regional frequency distribution using simulated flood data. Annuals of Disas Prev Res Inst, Kyoto
- Odry J, Arnaud P (2017) Comparison of flood frequency analysis methods for ungauged catchments in France. Geosci 7(88). https://doi.org/10.3390/geosciences7030088
- Peters GW, Chen WY, Gerlach RH (2016) Estimating quantile families of loss distributions for non-life insurance modeling via L-Moments. Risks 4(14). https://doi.org/10.3390/risks4020014
- Qin XS, Lu Y (2014) Study of climate change impact on flood frequencies: A combined weather generator and hydrological modeling approach. J Hydrometeorol 15(3):1205-1219
- Romali NS, Yusop Z (2017) Frequency analysis of annual maximum flood for Segamat river. MATEC Web of Conferences 103, 04003. https://doi.org/10.1051/matecconf/20171030 ISCEE 2016 4003
- Shah S, Prasad J (2017) Flood frequency analysis of Kumaon region rivers Uttarakhand, India. Int J Eng Res Manage Studies 4(2):1-11
- Smith A, Sampson C, Bates P (2015) Regional flood frequency analysis at the global scale. Water Resour Res 51: 539-553. https://doi.org/10.1002/2014WR015814
- Swetapadma S, Ojha CSP (2018) Assessment of Flood Frequency Models using Annual Peak Flows for Mahanadi River Basin in India, Conference of AGU Fall Meeting 2018. https://ui.adsabs.harvard.edu/abs/2018AGUFM.H41M2287S

- Wu Y, Lall U, Lima CHR, Zhong P (2018) Local and regional flood frequency analysis based on hierarchical Bayesian model: application to annual maximum streamflow for the Huaihe river basin. Hydrol Earth Syst Sci Discuss. https://doi.org/10.5194/hess-2018-22
- Yen B (2002) System and component uncertainties in water resources: In Bogardi JJ, Kundzewicz ZW (eds) Risk, reliability, uncertainty and robustness of water resources systems, Cambridge: Cambridge University Press, 133–42.

Table 1: Drainage area and mean annual flood at different sites in Mahanadi basin

S.N.	Name of G/D site	Stream	Tributary/ River	Maintained by	Drainage area (Sq km.)	Latitude, Longitude	Mean annual flood (m^3/sec)
1.	Andiarkhor	Hamp	Seonath	CWC	2210	21.83, 81.60	328.97
2.	Ghatora	Kharang	Seonath	CWC	3035	22.05, 82.22	627.29
3.	Jandhora	Seonath	Mahanadi	CWC	29645	21.71, 82.33	5320.87
4.	Kotni	Seonath	Seonath	CWC	6990	21.24, 81.25	2252.60
5.	Pathardih	Kharun	Seonath	CWC	2511	21.34, 81.60	1158.96
6.	Rampur	Jonk	Mahanadi	CWC	2920	21.64, 82.52	2399.12
7.	Seorinarayan	Mahanadi	Mahanadi	CWC	48050	21.72, 82.60	11435.27
8.	Simga	Seonath	Seonath	CWC	30761	21.63, 81.68	5016.93
9.	Agar	Agar	Seonath	WRD CG	875	22.10, 81.67	139.89
10.	Arpa	Arpa	Seonath	WRD CG	1700	22.30, 82.10	341.24
11.	Hamp	Hamp	Seonath	WRD CG	550	22.21, 81.40	120.43
12.	Maniyari	Maniyari	Seonath	WRD CG	1250	21.92, 82.00	97.85
13.	Rajim	Mahanadi	Mahanadi	CWC	8760	20.97, 81.88	4453.45
14.	Bamnidhi	Hasdeo	Hasdeo	CWC	9730	21.91, 82.71	3115.36
15.	Baronda	Pairy	Mahanadi	CWC	3225	20.91, 81.89	2386.94
16.	Kelo	Kelo	Mahanadi	CWC	950	21.89, 83.40	775.90
17.	Manendragarh	Bango	Mahanadi	CWC	1120	23.20, 82.22	335.11
18.	Narayan	Ib	Ib	WRD CG	624	22.84, 83.91	196.28
19.	Tapkara	Ib	Ib	WRD CG	3334	22.48, 83.93	850.80
20.	Kelo Raigarh	Kelo	Mahanadi	WRD CG	1175	21.94, 83.38	352.25
21.	Lath Madhopali	Lath	Mahanadi	WRD CG	984	21.58, 83.16	445.911
22.	Maini	Maini	Ib	WRD CG	764	22.63, 83.68	74.06
23.	Mand	Mand	Mahanadi	WRD CG	3930	22.31, 83.08	589.63
24.	Basantpur	Mahanadi	Mahanadi	CWC	57780	21.74, 82.79	13913.09
25.	Khoring	Khoring	Ib	WRD CG	475	22.37. 83.93	86.15
26.	Lawa	Lawa	Sankh	WRD CG	650	22.97, 84.12	96.79

Table 2: Parameter estimation techniques used

S.N.	Parameter estimation technique	Distributions applied
1.	Probability weighted moments (PWMs)	Wakeby-4, Wakeby-5, EV I, GEV distribution
2.	L-moments	EV I, GEV, Logistic, Generalised logistic, Generalised Pareto, Normal, Log Normal distribution

Table 4: Regional L-skewness and L-kurtosis for both regions

S.N.	Region	L-skewness	L-kurtosis
1.	Region-1	0.199	0.16
2.	Region-2	0.299	0.136

Table 5: Results of the goodness of fit tests based on L-kurtosis

S.N.	DISTRIBUTIONS	*Z*	
		Region-1	Region-2
1.	EV-I	0.26	0.44
2.	GEV	**0.13**	1.78
3.	Logistic	0.26	0.14
4.	Generalized Logistic	1.33	2.75
5.	Generalized Pareto	2.66	**0.07**
6.	Normal	1.16	1.43
7.	Log Normal	-	-

Table 6a Flood quantiles for different return periods in Region-1

S.N.	Name of G/D site	Mean annual flood (m^3/sec)	3-Years	7-Years	10-Years
1.	Andiarkhor	328.97	366.8	500.3	554.6
2.	Ghatora	627.29	699.4	954.0	1057.6
3.	Jandhora	5320.87	5932.9	8092.1	8971.1
4.	Kotni	2252.60	2511.7	3425.8	3797.9
5.	Pathardih	1158.96	1292.3	1762.6	1954.0
6.	Rampur	2399.12	2675.1	3648.6	4045.0
7.	Seorinarayan	11435.27	12750.5	17391.0	19280.1
8.	Simga	5016.93	5594.0	7629.9	8458.6
9.	Agar	139.89	156.0	212.7	235.9
10.	Arpa	341.24	380.5	519.0	575.3
11.	Hamp	120.43	134.3	183.2	203.0
12.	Maniyari	97.85	109.1	148.8	165.0
13.	Rajim	4453.45	4965.7	6772.9	7508.6
14.	Bamnidhi	3115.36	3473.7	4737.9	5252.5
15.	Baronda	2386.94	2661.5	3630.1	4024.4

Table 6b Flood quantiles for different return periods in Region-2

S.N.	Name of G/D site	Mean annual flood (m^3/sec)	3-Years	7-Years	10-Years
1.	Kelo	775.9	843.9	1196.4	1334.5
2.	Manendragarh	335.11	327.0	503.7	567.8
3.	Narayan	196.28	191.6	295.0	332.6
4.	Tapkara	850.8	830.3	1278.8	1441.5
5.	Kelo Raigarh	352.25	343.8	529.4	596.8
6.	Lath Madhopali	445.911	435.2	670.2	755.5
7.	Maini	74.06	72.3	111.3	125.5
8.	Mand	589.63	575.4	886.2	999.0
9.	Basantpur	13913.09	13578.0	20912.0	23573.2
10.	Khoring	86.15	84.1	129.5	146.0
11.	Lawa	96.79	94.5	145.5	164.0

Regional Flood Frequency Modeling for a Large Basin in India

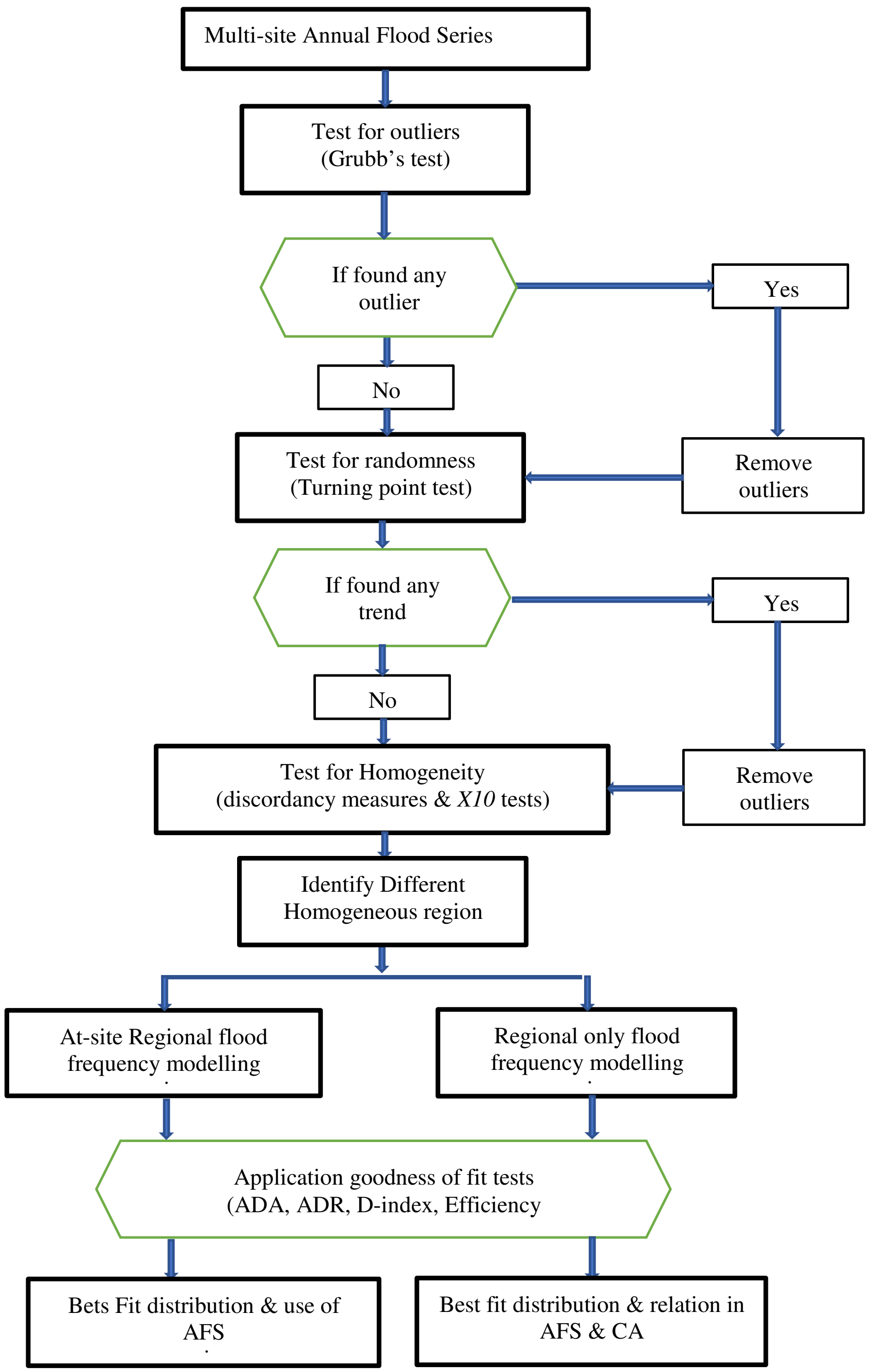

Fig. 1 Framework for at-site and regional only flood frequency modeling

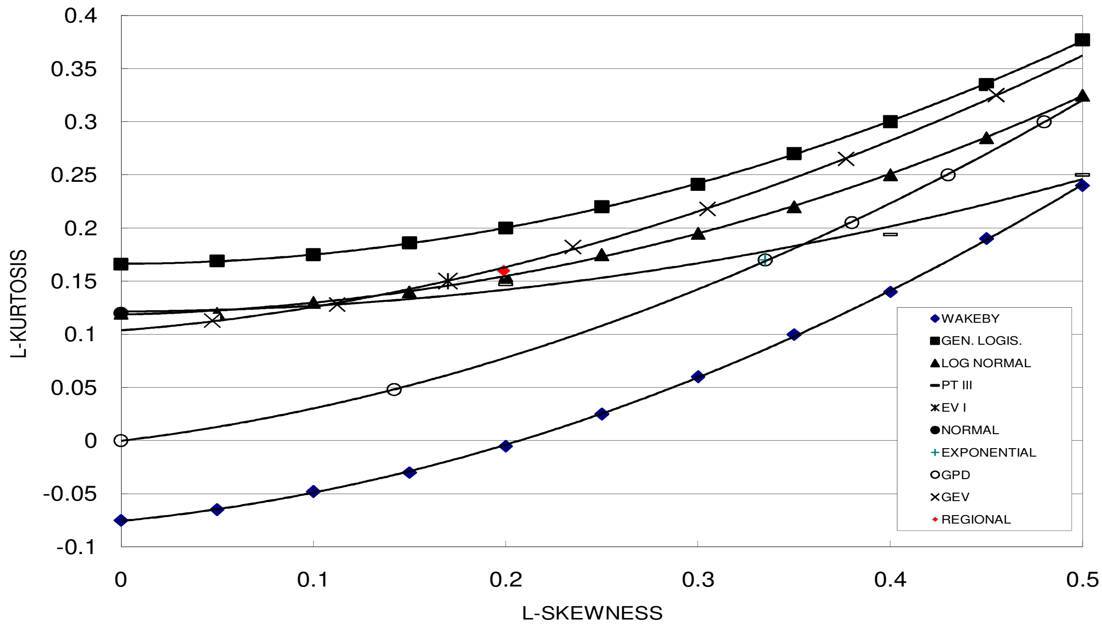

Fig. 2 (a): L-moment Ration diagram for Region-1

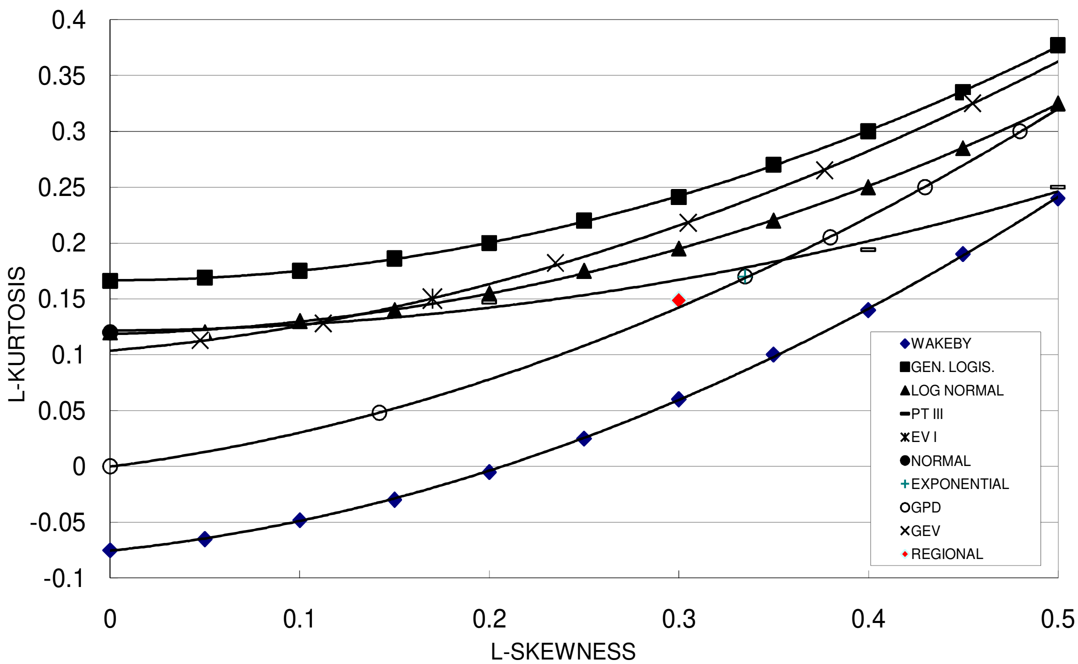

Fig. 2(b) L-moment Ration diagram for Region-2

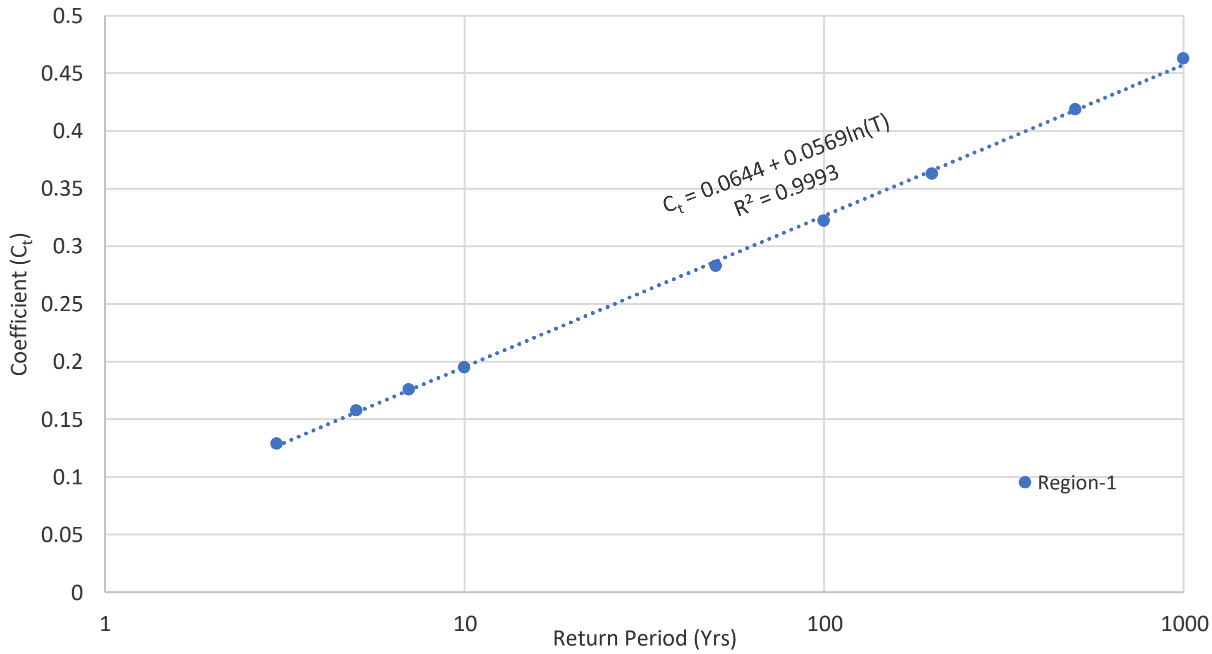

Fig. 6a Graph for computation of Coefficient (Ct) for Region-1

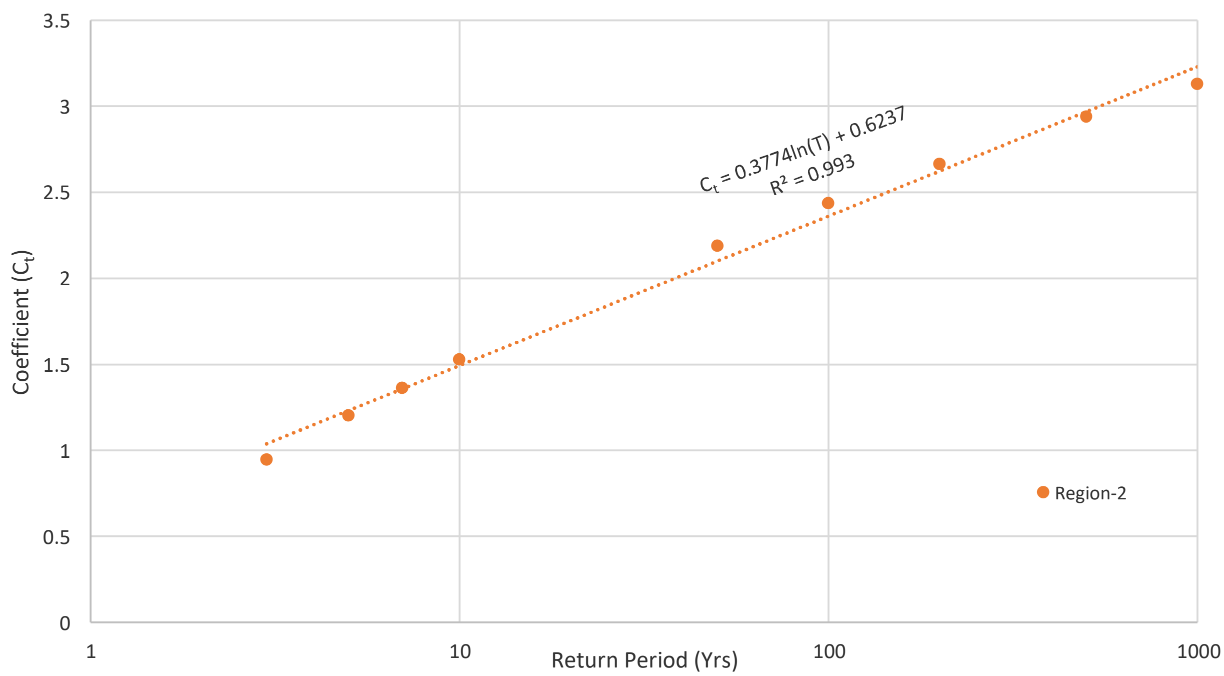

Fig. 6b Graph for computation of Coefficient (Ct) for Region-2