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Research Article

Intercomparison of Parameter Estimation Methods of EV1 Distribution for Modelling of Annual 1-Day Maximum Rainfall

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Abstract— Design rainfall depth is one of the important parameters in the hydraulic modelling of urban drainage systems that directly contributes to runoff. Also, analysis of rainfall characteristics is considered as one of the effective techniques for planning of water resources projects. This can be carried out by applying the Extreme Value Type-1 (EV1) distribution to the series of observed annual 1-day maximum rainfall (AMR) data. This paper presented a study on modelling the AMR series of Akkalkuwa, Kamrej, Navapur, Sakri, Shahada and Taloda rain gauge sites located in the surrounding regions of river Tapi. The parameters of EV1 were determined by Method of Moments (MoM), Maximum Likelihood Method (MLM), Method of L-Moments (LMO) and Method of Least Squares (MLS), and further used for rainfall data analysis. Anderson-Darling (A^2) and Kolmogorov-Smirnov (KS) tests were employed for examining the fitting EV1 distribution to the AMR series while the selection of best fit method was made through cross correlation matrix analysis (CCMA) and model performance analysis with various indicators such as correlation coefficient (CC), mean squared error (MSE) and Nash-Sutcliffe model efficiency (NSE). The A^2 test results indicated that all four methods of EV1 are acceptable for modelling the AMR of Akkalkuwa, Kamrej, Sakri, Shahada and Taloda whereas MLM and LMO for Navapur. But, the KS test results supported the use of all four methods of EV1 for modelling the AMR of six sites. The outcomes of CCMA showed that there is a perfect correlation between the observed and estimated rainfalls by four methods of EV1, which is nearer to 1.000. The study showed that the NSE given by four methods of EV1 vary from 92.1% to 98.8%. The MSE computed by LMO is minimum than those values of MoM, MLM and MLS. Based on A^2 and KS tests results, CCMA and model performance analysis, the LMO was identified as better suited amongst four methods for modelling the AMR data of six sites.

Keywords— Anderson-Darling, Extreme Value Type-1, Kolmogorov-Smirnov, L-Moments, Rainfall

1. Introduction

Rainfall is one of the key natural resources for agricultural activities, hydro-power generation, flood control and sustainability of biodiversity. Moreover, knowledge of rainfall characteristics is of utmost importance for planning and management of water resources. Apart from this, for computing the water requirement in a particular area or a region, estimation of rainfall for a desired duration and given return period is needed. Since the distribution of rainfall varies over space and time, it is required to analyze the data covering long periods and recorded at various locations to arrive at a reliable information for decision support [1].

A number of probability distributions include Extreme Value Type-1 (EV1), Extreme Value Type-2, 2-parameter Log Normal, Log Pearson Type-3, Generalized Gamma, Generalized Pareto, etc., are generally applied for modelling the hydrometeorological data viz., rainfall, temperature, wind speed, etc. However, the EV1 (commonly known as Gumbel) is one of the most popularly used distribution for modelling the rainfall data [2] and hence used in this paper. Standard analytical procedures like Method of Moments (MoM), Maximum Likelihood Method (MLM), Method of L-Moments (LMO) and Method of Least Squares (MLS) are generally applied for determination of parameters of EVI [3]. Number of studies on analyzing the characteristics of the parameter estimation methods of EV1 was carried out by different researchers [4-8]. Research reports indicated that MoM is a natural and relatively easy method for determination of parameters the distribution [9]. MLM is considered the most efficient method, since it provides the smallest sampling variance of the estimated estimators and hence of the estimated quantile compared to other methods [10]. But, the MLM has the disadvantage of frequently giving biased estimates and often failed to give the desired accuracy in estimating the extremes from hydrological data. [11]. However, there is no general agreement in applying particular method for a region because of the characteristics of the estimators of EV1. In view of the above, for the present study, the MoM, MLM, LMO and MLS were applied in determining the parameters of EV1 for modelling the AMR. The adequacy of fitting four methods of EV1 to the AMR series was examined through Goodness-of-Fit tests viz., Anderson-Darling (A^2) and Kolmogorov-Smirnov (KS) while the selection of best fit method of EV1 was made through cross correlation matrix analysis (CCMA) and model performance analysis (MPA) with various indicators such as correlation coefficient (CC), mean square error (MSE) and Nash-Sutcliffe model efficiency (NSE). This paper presented a methodology adopted in modelling the AMR using four parameter estimation methods of EV1 with an illustrative example and the results obtained thereon.

Section 1 details the significance of a study on modelling the rainfall data using probability distribution for planning of water resources management projects. Section 2 describes the methodology adopted in determining the parameters of EV1 distribution by MoM, MLM, LMO and MLS, computation of GoF tests statistic, CCMA and MPA. The study area and data used in this paper is detailed in Section 3 whereas the results and discussions are given in Section 4. The conclusion obtained from the study is presented in Section 5 whereas the scope for future work is detailed in Section 6.

2. Methodology

The Probability Distribution Function [PDF; f(x, α, β)] and Cumulative Distribution Function [CDF; F(x, α, β)] of EV1 distribution [12] is given by:

$$f(x,\alpha,\beta)=\frac{1}{\beta}\exp\left\{-\left[\frac{x-\alpha}{\beta}\right]-\exp\left[\left(\frac{x-\alpha}{\beta}\right)\right]\right\}, -\infty<x<\infty,\ \beta>0 \quad (1)$$

$$F(x,\alpha,\beta)=\exp\left\{-\exp\left[-\left(\frac{x-\alpha}{\beta}\right)\right]\right\}, -\infty<x<\infty,\ \beta>0 \quad (2)$$

Where, x is the random variable [i.e., AMR], α is the location parameter and β is the scale parameter. The parameters of EV1 are computed by MoM, MLM, LMO and MLS, and also used to estimate the rainfall [x(T)] for a given return period (T) from:

$$x(T) = \alpha + Y(T)\,\beta \quad (3)$$

Where, Y(T) is a reduced variate of a return period (T) and defined by Y(T)=-ln{-ln[1-(1/T)]}. Table 1 presents the equations employed in determining the parameters of EV1 by MoM, MLM, LMO and MLS [13].

2.1. Goodness-of-Fit Tests

Out of number of GoF tests, the Anderson-Darling (A^2) and Kolmogorov-Smirnov (KS) are widely applied for checking the adequacy of fitting EV1 to the series of observed AMR and therefore used in this paper. Theoretical descriptions of GoF tests statistic [14] are given as below:

$$A^2=(-n)-(1/n)\sum_{i=1}^{n}\{(2i-1)\ln[Z(i)]+(2n+1-2i)\ln[1-Z(i)]\} \quad (4)$$

$$KS=\underset{i=1}{\overset{n}{Max}}\{F_e[x(i)]-F_D[x(i)]\} \quad (5)$$

The computed CDF of x(i) for i^{th} sample is defined by $Z(i)=F_D[x(i)]=\exp\{-\exp[-(x(i)-\alpha)/\beta]\}$ for i=1,2,3,…,n and x(1)<x(2)<….<x(n) wherein x(1) and x(n) indicates the lowest and highest values in the series of observed data. Likewise, the empirical CDF of x(i) for i^{th} sample is defined by $F_e[x(i)]=[(i-0.44)/(n+0.12)]$. If the computed values of GoF tests statistic are not greater than its theoretical values at the desired significance level (either 5% or 1%) then the method is considered as adequate for modelling the AMR.

Table 1. Determination of the parameters of EV1 distribution

Method	Location parameter (α)	Scale Parameter (β)
MoM	$\mu(x)-(0.5772157)\beta$	$\frac{\sqrt{6}}{3.14286}\left[\frac{1}{n-1}\sum_{i=1}^{n}[x(i)-\mu(x)]^2\right]^{0.5}$
MLM	$-\beta\ln\left\{\frac{\sum_{i=1}^{n}\exp\left[\frac{-x(i)}{\beta}\right]}{n}\right\}$	$\mu(x)-\frac{\sum_{i=1}^{n}x(i)\exp\left[\frac{-x(i)}{\beta}\right]}{\sum_{i=1}^{n}\exp\left[\frac{-x(i)}{\beta}\right]}$
LMO	$\lambda(1)-(0.5772157)\beta$ wherein $\lambda(1)=\mu(x)=\frac{\sum_{i=1}^{n}x(i)}{n}$	$\lambda(2)/\ln(2)$ wherein $\lambda(2)=b(0)-2b(1)=\lambda(1)-2\left\{\frac{\sum_{i=1}^{n}x(i)(i-1)}{n(n-1)}\right\}$
MLS	$\mu(x)+\frac{\sum_{i=1}^{n}\ln\left\{-\ln\left[\frac{(i-0.44)}{(n+0.12)}\right]\right\}\beta}{n}$	$\frac{\left[\left(\sum_{i=1}^{n}x(i)\right)^2-\left(n\sum_{i=1}^{n}x(i)^2\right)\right]}{\left\{n\sum_{i=1}^{n}x(i)\left\{\ln\left[-\ln\left(\frac{i-0.44}{n+0.12}\right)\right]\right\}\right\}-\left\{\left[\sum_{i=1}^{n}x(i)\right]\left[\sum_{i=1}^{n}\ln\left[-\ln\left(\frac{i-0.44}{n+0.12}\right)\right]\right]\right\}}$

In Table 1, the x(i) is the observed value of i^{th} sample, y(i) is the estimated value of i^{th} sample, μ(x) is the average of the observed values, μ(y) is the average of the estimated values, λ(1) and λ(2) are the first and second LMO, and n is the sample size.

2.2. Model Performance Analysis

The theoretical descriptions of model performance indicators (viz., CC, MSE and NSE) [15] applied in selecting the best fit method of EV1 for modelling the AMR is given as below:

$$CC=\frac{\sum_{i=1}^{n}[x(i)-\mu(x)][(y(i)-\mu(y)]}{\sqrt{\left(\sum_{i=1}^{n}[x(i)-\mu(x)]^2\right)\left(\sum_{i=1}^{n}[(y(i)-\mu(y)]^2\right)}} \quad (6)$$

$$MSE=\left(\frac{1}{n}\sum_{i=1}^{n}[(x(i)-y(i)]^2\right) \quad (7)$$

$$NSE\,(\%)=\left(1-\frac{\sum_{i=1}^{n}[x(i)-y(i)]^2}{\sum_{i=1}^{n}[x(i)-\mu(x)]^2}\right)*100 \quad (8)$$

The parameter estimation method with high CC, less MSE and better NSE is considered as better suited for modelling the AMR.

2.3. Cross Correlation Matrix Analysis

The cross-correlation matrix (CCM) of two random vectors is a matrix that contains the cross-correlation of all pairs of elements of the random vectors. The CCM analysis (CCMA) is used in checking the appropriateness of correlation between the observed and estimated rainfall using four parameter estimation methods of EV1.

3. Study Area and Data Used

In this paper, a study on modelling the AMR data observed at six rain gauge sites located in the surrounding regions of river Tapi using four parameter estimation methods of EV1 was carried out.

The Tapi river basin extends over states of Madhya Pradesh, Maharashtra and Gujarat having total catchment area of about 65145 km^2. It lies between longitudes 72° 33′ to 78° 17′ E and latitudes 20° 9′ to 21° 50′ N. The river basin is situated in the Deccan plateau, which is bounded by the Satpura range on the north, the Mahadev hills on the east, the Ajanta range and the Satmala hills on the south, and Arabian Sea on the west. The total length of the river from origin to the outfall into the Arabian Sea is 724 km and its important tributaries are Suki, Gomai, Arunavati and Aner that joins it from right whereas the tributaries namely, Vaghur, Amravati, Buray, Panjhra, Bori, Girna, Purna, Mona and Sipna are joining from left. For the present study, the AMR series was extracted from the daily rainfall data observed at Akkalkuwa, Kamraj, Navapur, Sakari, Shahada and Taloda sites during the period 1960 to 2022 and used in rainfall data analysis by employing four parameter estimation methods (viz., MoM, MLM, LMO and MLS) of EV1. Figure 1 shows the index map of the study area with locations of six rain gauge sites whereas the descriptive statistics of the AMR series of six sites are presented in Table 2.

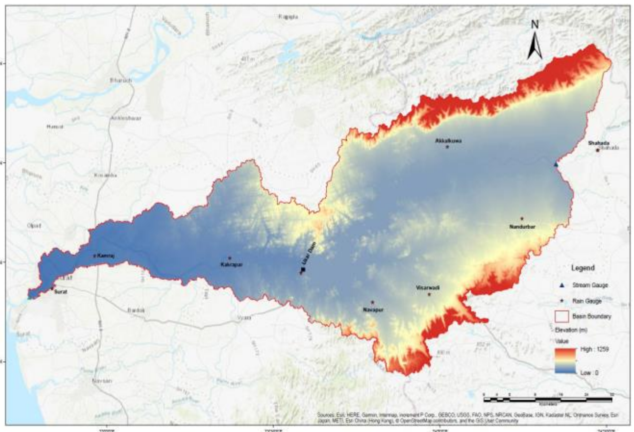


Figure 1. Index map of the study area with locations of rain gauge sites

Table 2. Descriptive statistics of the AMR series of six sites

Site	Descriptive statistics				
	Average (mm)	SD (mm)	CV (%)	C_s	C_k
Akkalkuwa	119.4	53.9	45.1	0.649	-0.675
Kamrej	172.5	74.7	43.3	1.110	1.823
Navapur	137.3	70.2	51.1	1.455	1.621
Sakri	73.7	28.7	39.0	1.827	4.898
Shahada	82.6	33.6	40.7	0.744	0.292
Taloda	93.0	43.2	46.5	1.672	4.044

SD: Standard Deviation; CV: Coefficient of Variation; C_s: Coefficient of skewness; C_k: Coefficient of kurtosis

From Table 2, it is noted that the average and SD of AMR pertaining to Kamrej is higher than those values of other five sites considered in the study. The percentage of CV [i.e., (Average/SD)*100] of AMR of six sites vary between 39.0% and 51.1%. Also, from Table 2, it can be found that the higher order moments (C_s and C_k) of six sites have different behaviour to each other.

4. Results and Discussion

By applying the parameter estimation procedures of EV1 distribution, as described above, the modelling of AMR of six sites was carried out by applying four methods of EV1 and the results are presented in the ensuing sections.

4.1. Modelling of AMR Using EV1

The AMR series of six sites was applied in determining the parameters of EV1 by MoM, MLM, LMO and MLS and also used for estimation of extreme (i.e., annual 1-day maximum) rainfall. Figure 2 shows the plots of the estimated rainfall with observed AMR of six sites. From Figure 2, it is noted that the estimated rainfall using MLS is higher than those values of MoM, MLM and LMO for all sites other than Shahada. For Shahada, it is found that the variation between the estimated rainfall by LMO and MLS for a return period from 5-year to 100-year are minimum. The fitted trend lines by four methods of EV1 showed that a perfect linear relationship exists between the return period and estimated rainfall.

4.2. Analysis of Results Based on GoF Tests

The adequacy of fitting four methods of EV1 to the AMR series of six sites was evaluated through GoF tests. The parameters of EV1 obtained from MoM, MLM, LMO and MLS were used to compute the GoF tests statistic and the results are presented in Table 3. From A^2 test results, it is noted that all four methods of EV1 are acceptable for modelling the AMR of Akkalkuwa, Kamrej, Sakri, Shahada and Taloda whereas MLM and LMO for Navapur. The computed values of KS statistic by four methods of EV1 are not greater than its theoretical value of 0.171 at 5% significance level, and at this level, all four methods are acceptable for modelling the AMR of six sites.

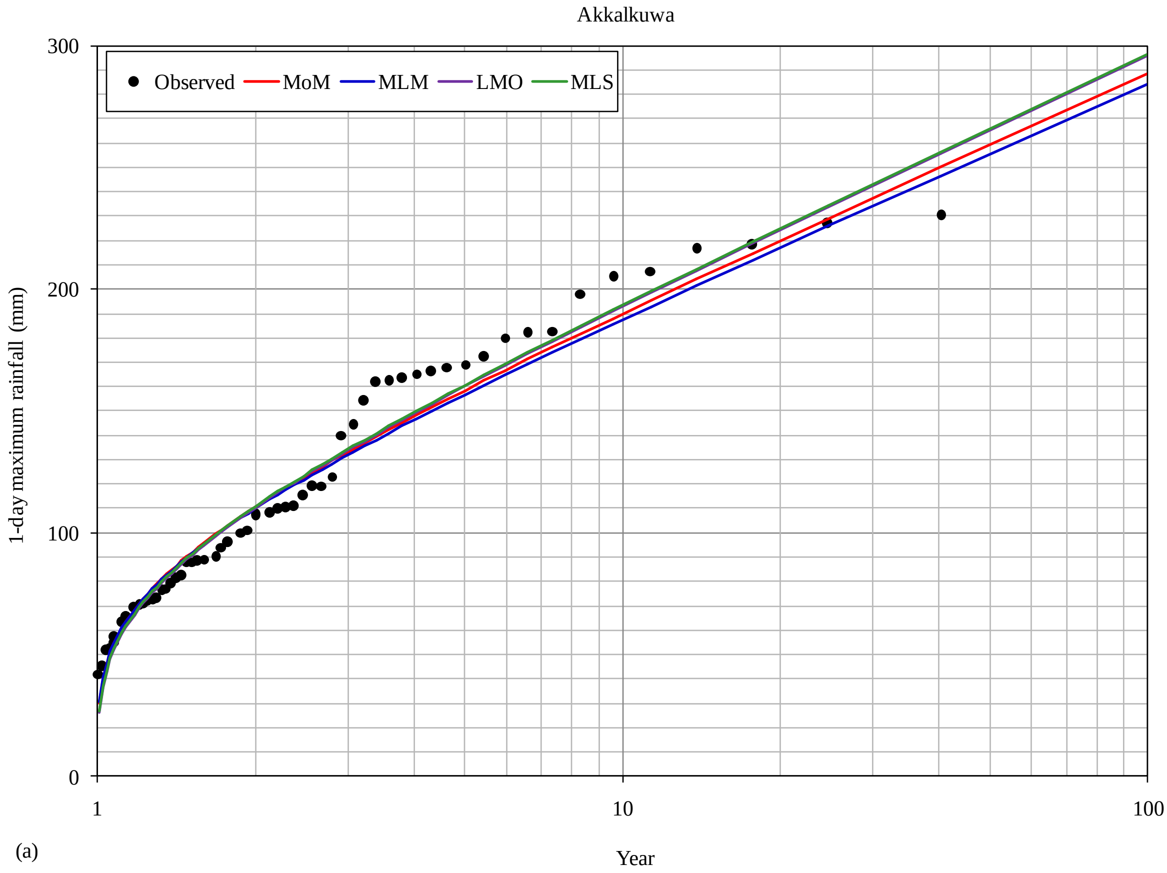
Table 3. Computed values of GoF tests statistic by four methods of EV1

Site	A^2				KS			
	MoM	MLM	LMO	MLS	MoM	MLM	LMO	MLS
Akkalkuwa	0.870	0.903	0.739	0.707	0.109	0.116	0.102	0.089
Kamrej	0.302	0.372	0.289	0.337	0.044	0.048	0.047	0.063
Navapur	1.071	0.948	0.997	1.500	0.082	0.062	0.070	0.111
Sakri	0.507	0.175	0.266	1.034	0.068	0.045	0.052	0.078
Shahada	0.276	0.245	0.185	0.151	0.069	0.069	0.063	0.050
Taloda	0.542	0.372	0.430	0.970	0.071	0.053	0.060	0.083

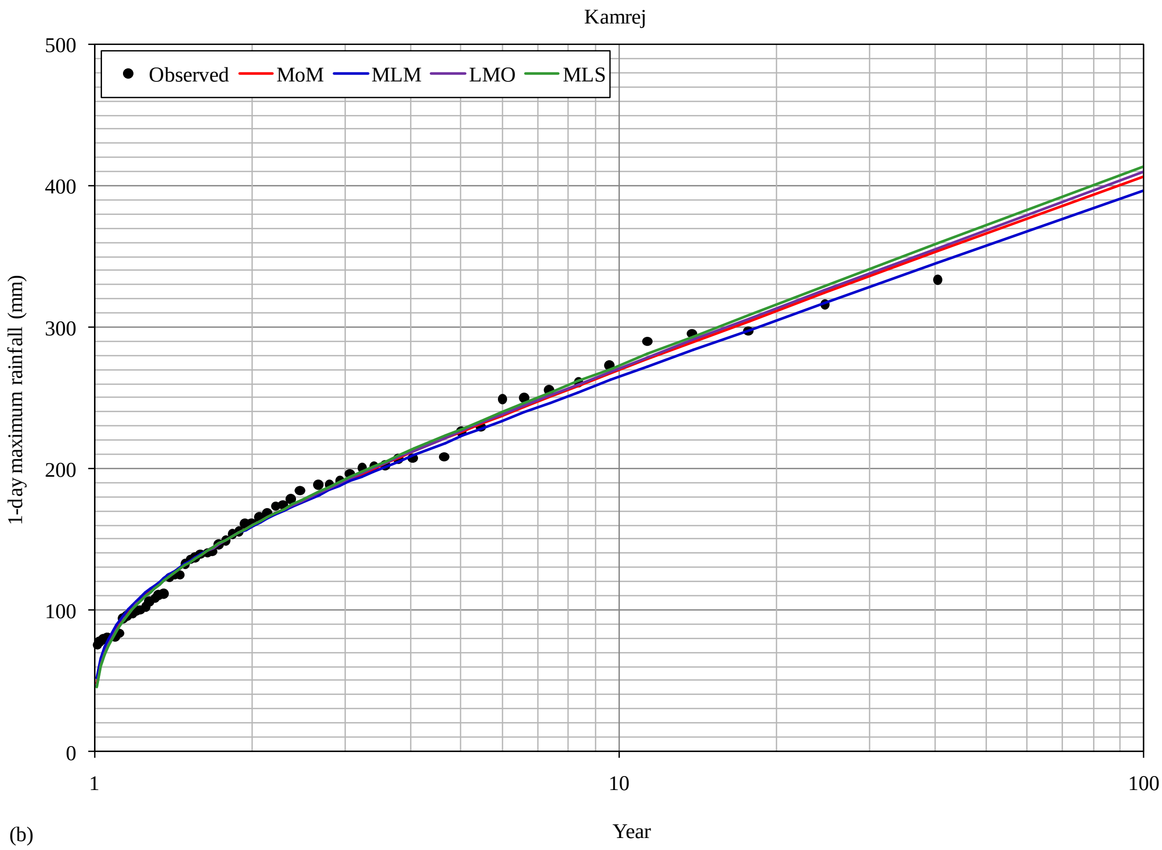
Theoretical value of A^2 statistic at 1% and 5% levels are 1.038 and 0.757

4.3. Model Performance Analysis

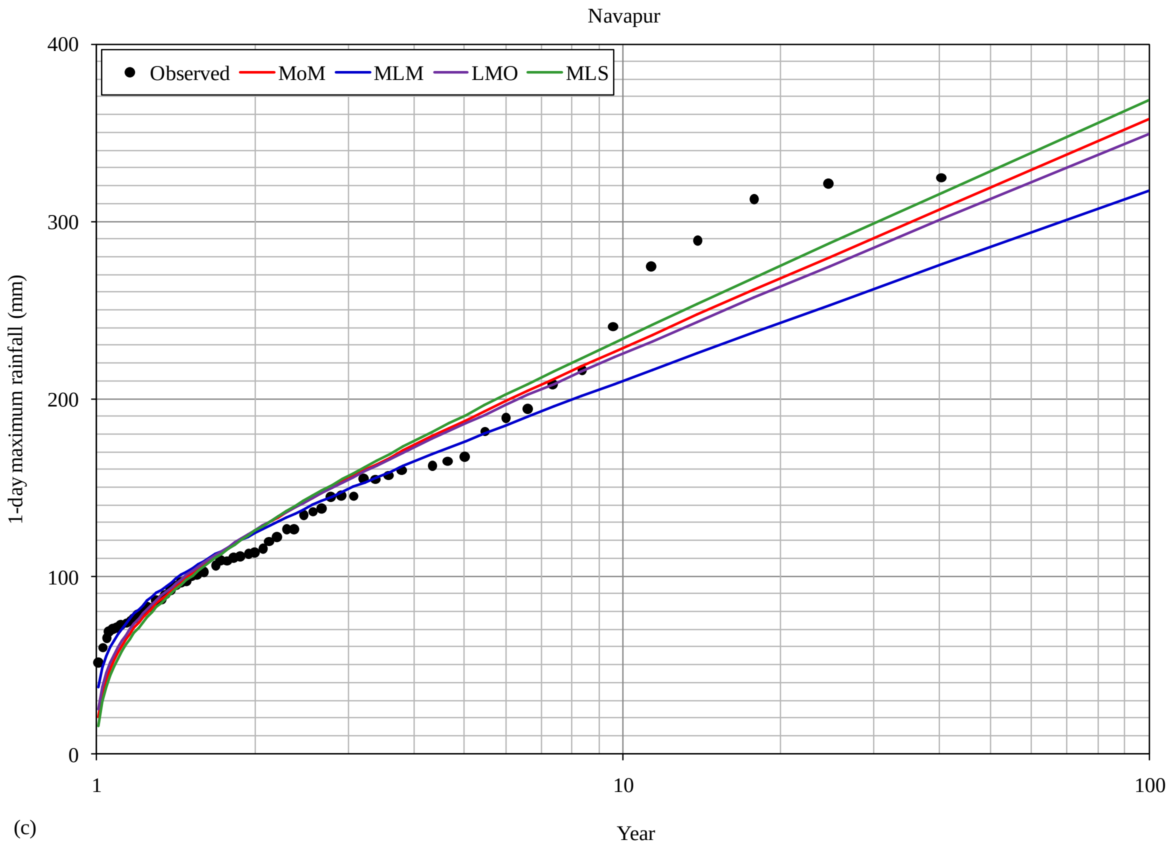
The model performance indicators viz., CC, MSE and NSE were computed by four methods of EV1 and are presented in Table 4. These indicators were further used in selecting the best fit method of EV1 for modelling the AMR of six sites. From Table 4, it is found that the MSE computed by LMO is minimum than those values of MoM, MLM and MLS. For all six sites, it can be found that the model efficiency obtained from four methods of EV1 vary from 92.1% to 98.8%. The CC computed by four methods of EV1 varies between 0.975 and 0.994. The results of model performance analysis indicated that the LMO is better suited method for modelling the AMR.


Akkalkuwa
Observed
MoM
MLM
LMO
MLS
1-day maximum rainfall (mm)
300
200
100
0
1
10
100
Year

(a)

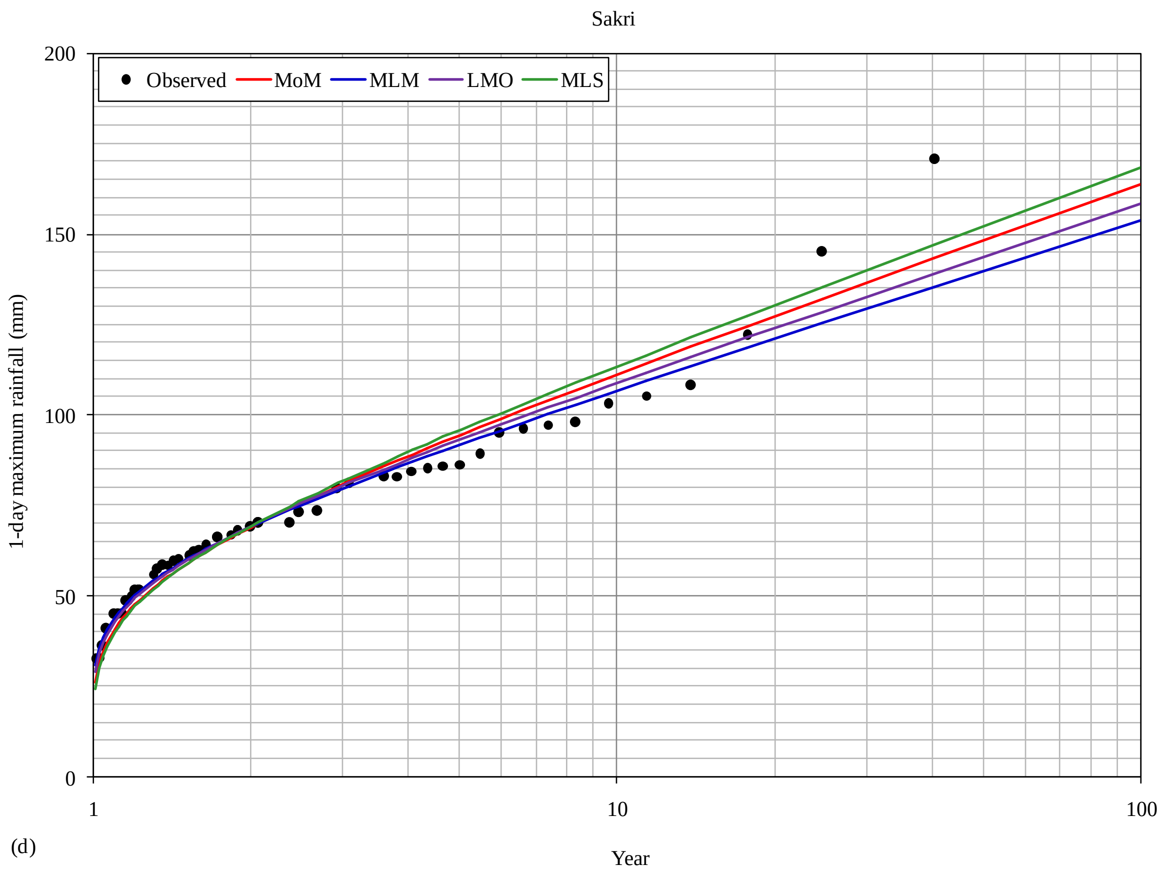

Kamrej
Observed
MoM
MLM
LMO
MLS
1-day maximum rainfall (mm)
500
400
300
200
100
0
1
10
100
Year

(b)



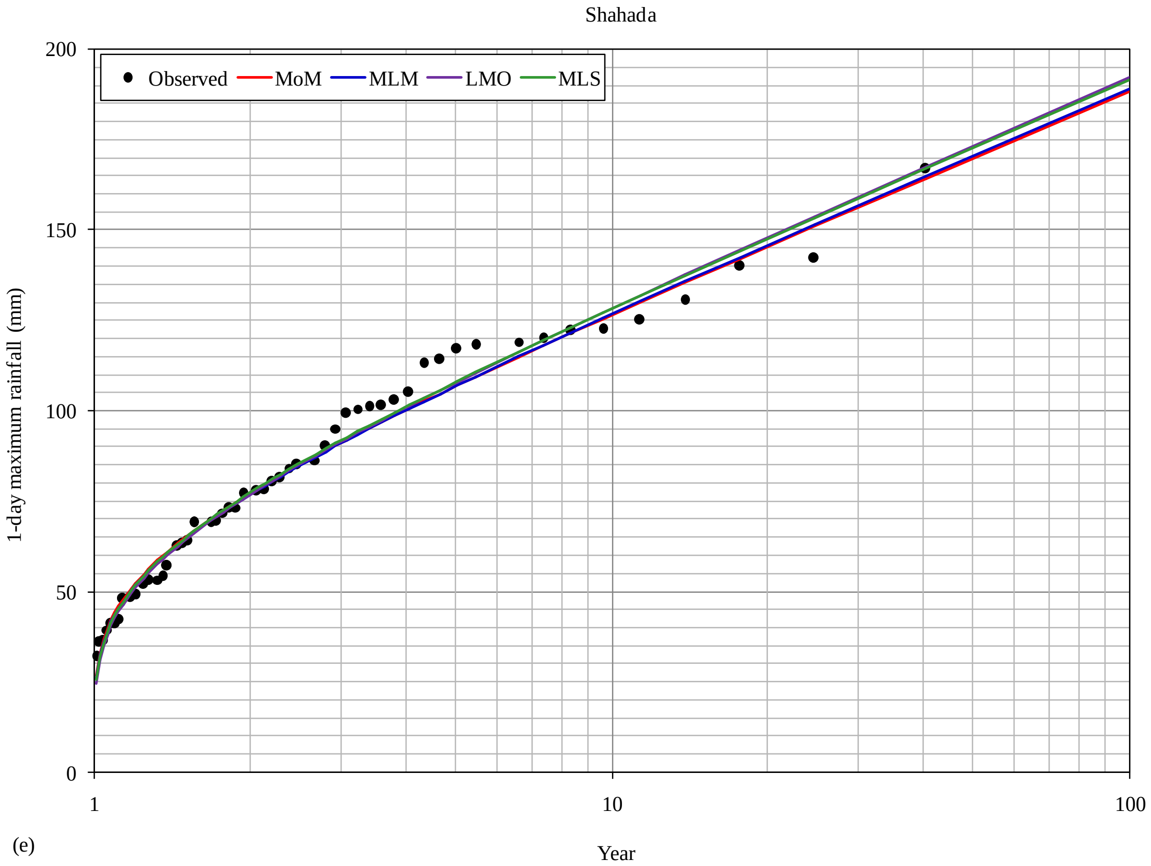
Navapur
Observed
MoM
MLM
LMO
MLS
1-day maximum rainfall (mm)
0
100
200
300
400
1
10
100
Year

(c)

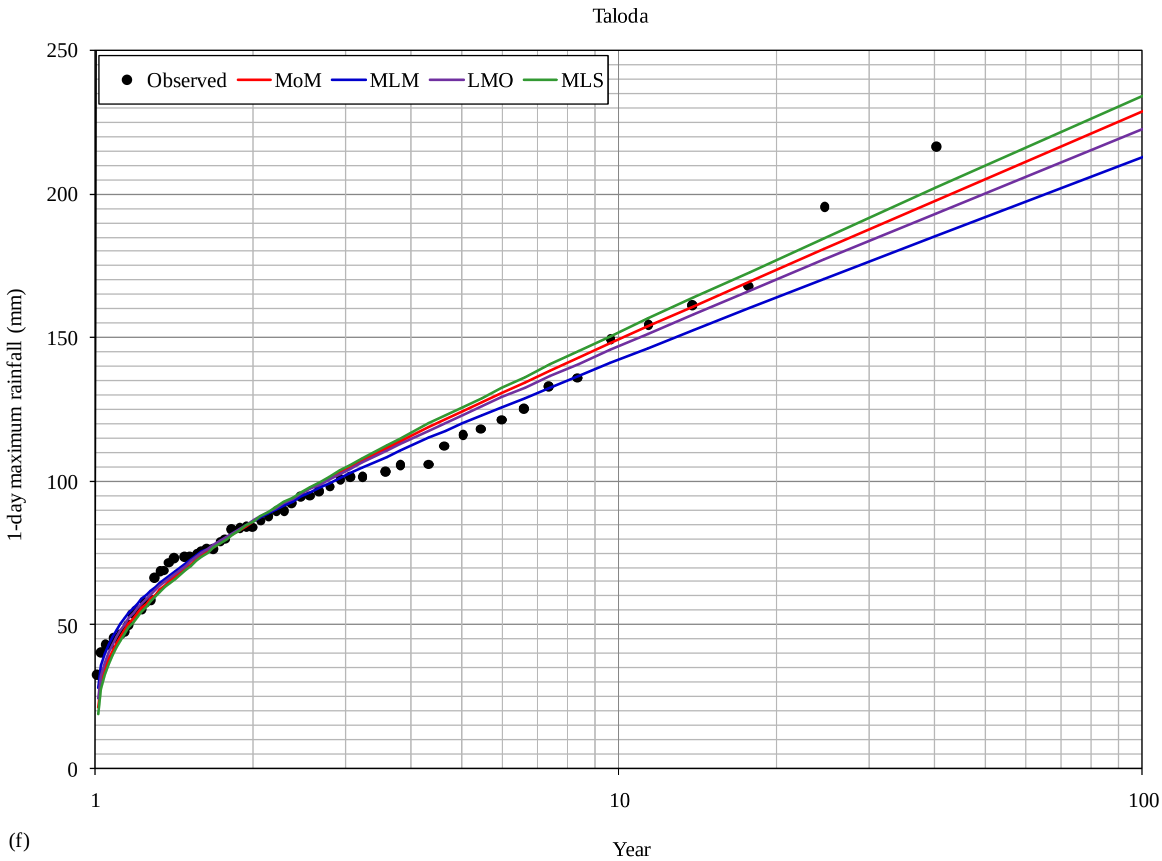


Sakri
Observed
MoM
MLM
LMO
MLS
1-day maximum rainfall (mm)
0
50
100
150
200
1
10
100
Year

(d)



(e)



(f)

Figure 2. Estimated 1-day maximum rainfall using four methods of EV1 distribution and observed AMR

Table 4. MPIs computed by four methods of EV1 for six rain gauge sites

	MoM	MLM	LMO	MLS
Akkalkuwa				
CC	0.978	0.978	0.978	0.978
MSE (mm)	8.54	8.60	8.36	8.39
NSE (%)	95.6	95.5	95.4	95.4
Kamrej				
CC	0.994	0.994	0.994	0.994
MSE (mm)	5.61	6.19	5.49	5.39
NSE (%)	98.7	98.4	98.8	98.7
Navapur				
CC	0.975	0.975	0.975	0.975
MSE (mm)	11.49	11.03	11.00	12.50
NSE (%)	95.0	92.1	94.9	94.7
Sakri				
CC	0.977	0.977	0.977	0.977
MSE (mm)	4.17	3.08	3.05	4.75
NSE (%)	95.3	94.2	95.0	95.1
Shahada				
CC	0.992	0.992	0.992	0.992
MSE (mm)	3.25	3.20	3.17	3.19
NSE (%)	98.4	98.4	98.3	98.4
Taloda				
CC	0.986	0.986	0.986	0.986
MSE (mm)	4.78	4.48	4.45	5.41
NSE (%)	97.1	95.7	96.9	97.0

4.4. Cross Correlation Matrix Analysis

The CCMA was made to examine the correlation between the observed and estimated values using the parameters of EV1 given by four methods and the results are given in Table 5.

Table 5. Cross correlation matrix of the observed and estimated AMR

Site/ Method	Observed	MoM	MLM	LMO	MLS
Akkalkuwa					
Observed	1.000				
MoM	0.978	1.000			
MLM	0.978	0.996	1.000		
LMO	0.978	0.996	0.996	1.000	
MLS	0.978	0.996	0.996	0.996	1.000
Kamrej					
Observed	1.000				
MoM	0.994	1.000			
MLM	0.994	0.998	1.000		
LMO	0.994	0.998	0.998	1.000	
MLS	0.994	0.998	0.998	0.998	1.000
Navapur					
Observed	1.000				
MoM	0.975	1.000			
MLM	0.975	0.996	1.000		
LMO	0.975	0.996	0.996	1.000	
MLS	0.975	0.996	0.996	0.996	1.000
Sakri					
Observed	1.000				
MoM	0.977	1.000			
MLM	0.977	0.997	1.000		
LMO	0.977	0.997	0.997	1.000	
MLS	0.977	0.997	0.997	0.997	1.000
Shahada					
Observed	1.000				
MoM	0.992	1.000			
MLM	0.992	0.999	1.000		
LMO	0.992	0.999	0.999	1.000	
MLS	0.992	0.999	0.999	0.999	1.000
Taloda					
Observed	1.000				
MoM	0.986	1.000			
MLM	0.986	0.998	1.000		
LMO	0.986	0.998	0.998	1.000	
MLS	0.986	0.998	0.998	0.998	1.000

The outcomes of CCMA indicated that the CC values vary between 0.975 and 0.994. The CCMA showed that there is a perfect correlation between the estimated rainfall by MoM, MLM, LMO and MLS.

5. Conclusion

This paper presented a study on modelling the AMR using four methods of EV1 distribution for Akkalkuwa, Kamrej, Navapur, Sakri, Shahada and Taloda rain gauge sites located in the surrounding regions of river Tapi. The performance of the parameter estimation methods (viz., MoM, MLM, LMO and MLS) of EV1 applied in rainfall estimation was evaluated by GoF (i.e., Anderson-Darling and Kolmogorov-Smirnov) tests, cross correlation matrix analysis (CCMA) and model performance analysis (MPA) using various indicators such as CC, MSE and NSE. Based on the GoF tests results, MPA and CCMA, the conclusions drawn from the study are presented as given below:

- A^2 test results confirmed the applicability of all four methods of EV1 for modelling the AMR of Akkalkuwa, Kamrej, Sakri, Shahada and Taloda whereas MLM and LMO for Navapur.
- KS tests results supported the use of all four methods for estimation of rainfall.
- CCMA showed that there is a perfect correlation between the observed and estimated rainfall by the parameters of EV1 obtained from four methods, which is nearer to 1.
- MSE computed by LMO estimators is minimum than those values of MoM, MLM and MLS.
- NSE given by four methods of EV1 applied in rainfall estimation varies from 92.1% to 98.8%.
- LMO was identified as better suited amongst four methods employed for modelling the AMR of six rain gauge sites.

The results presented in this paper could be helpful to the stake holders for arriving at a design rainfall depth for a given return period as also for planning of water resources management activities in six rain gauge sites of river Tapi.

6. Scope for Future Work

This paper focused a study on modelling the AMR using four parameter estimation methods of EV1 distribution for six sites of river Tapi. It is suggested that the study can be extended by applying other probability distributions like log-normal, Frechet, generalized extreme value, etc to the AMR series with more sample values while modelling the rainfall data of other meteorological sites.

Declarations

Conflict of Interest

The author declares that he has no competing interest.

Funding Source

None.

Author Contribution

The author has contributed in defining the methodology, analyzing the results and preparation of the manuscript.

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