Extreme Value Analysis of Rainfall at Tarapur

9

Comparison of Annual Maximum Series and Annual Exceedance Series

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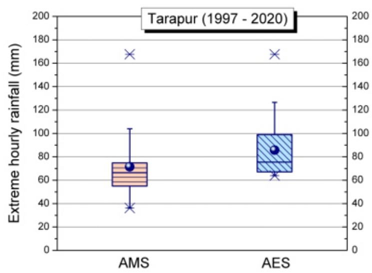

Box and whisker plot of extreme rainfall data by AMS and AES approaches for Tarapur during 1997 – 2020

ABSTRACT

Precipitation is an important consideration for ascertaining the design parameters for nuclear facilities and for flooding studies. Highest rainfall expected to occur at a site for a particular return period is estimated by extreme value analysis (EVA). For sample selection of EVA, two possible approaches are annual maximum series (AMS) and annual exceedance series (AES), each with respective strengths and limitations. In most of the studies on extreme precipitation for nuclear sites in general and Tarapur in particular, the annual maximum series approach had been adopted for discrete rainfall measurement. With continuous high-resolution (hourly) rainfall data now being available for 24 years (1997-2020) for Tarapur, the present article compares EVA of rainfall at Tarapur, conducted using both approaches in order to identify their respective limitations when applied for Indian rainfall conditions.

KEYWORDS: *Extreme Value Analysis; Tarapur; Rainfall; Annual Maximum Series; Annual Exceedance Series*

Introduction

Safety is one of the prime concerns during design of nuclear facilities, and safety against (external) flooding has attained renewed attention after the Fukushima accident in 2011. For the flooding analysis, the extreme rainfall that can be expected at a given site, corresponding to the designated return period for the facility, is generally ascertained by statistical analysis of the extreme rainfall values observed at site, also known as extreme value analysis (EVA). After Fukushima event, the design basis of flood protection measures for nuclear facilities in India, having offsite radiological hazard potential, has been upgraded from a return period of 1 in 1000 years to 1 in 10000 years [1]. AERB also provides the guidelines for extreme value analysis methodology for different meteorological parameters [2]. EVA consists of three steps: selection of a set of extreme values; finding the probability distribution function best suited to represent the selected sample; and finding the extreme value corresponding to the designated return period for the facility. Broadly, there are two different approaches for the first step, i.e. selection of a set of extreme values. These are called block maxima (BM) and peak-over-threshold (POT) approaches.

The BM approach initially specifies a certain block, generally chosen as a year owing to the annual periodicity of the seasons. Annual maximum series (AMS) is one BM approach in which the maximum (say, hourly) rainfall occurring in a year would be one sample; the maximum occurring in the next year would be the second sample, and so on – such that the final sample size would be equal to the number of years of rainfall records. The other approach, POT, first defines a threshold value of rainfall, and then selects all the rainfall values higher than that threshold as the samples for EVA. In the former approach, high (say, hourly) rainfall occurring in two (or more) different instances in the same year would be missed and rainfall values less than these, but highest in other years could be selected – thereby affecting the EVA results. Annual exceedance series (AES) is one type of POT approach, which could be useful to overcome this limitation. However, in POT, the issue of fixing the threshold beforehand could be a serious limitation, as there are varied opinions regarding the selection of threshold across the hydraulic and statistical communities. The debate over the appropriate method for selection of threshold along with the requirement of extensive studies for the identification for a given problem has been discussed in literature [3, 4].

EVA has been reported for Tarapur based on the AMS approach in literature, using long term data spanning over 40 years [5]; 51 years [6]; and 60 years [7]. In this article, we present the results of EVA on Tarapur hourly rainfall data spanning over 24 years, conducted by both AMS and AES approaches.

Data and Methodology

The data for this study was obtained from Environmental Survey Laboratory, EMAD, BARC, Tarapur. This data was recorded by a continuous-recording rain gauge, and hourly rainfall values were aggregated for each hour. For the study, such hourly rainfall records were available for all 24 years, from 1997 to 2020. The quality checks were performed on the data received from this recording station and the results were found to be of very good quality as discussed in literature [8]. There was no gap in the data in any year, and this emphasizes the high quality standards maintained for data and records at ESL, Tarapur.

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The earlier studies on extreme rainfall at Tarapur considered monthly [5], daily [5 – 7], and hourly [5] rainfall values of rainfall for EVA. Comparing the extreme daily rainfall value (539.9 mm for 50-years, and 657.1 mm for 100-years) estimated by Patel et al. [5] and those estimated by the recent study [7] as 629.88 mm for 50-years and 792.68 mm for 100-years, it can be observed that the inclusion of rainfall observations from the recent years have enhanced the probable maximum daily precipitation at the site. Compared to the extreme hourly rainfall values reported in literature [5] for Tarapur, as 107.1 mm for 50-year and 117.9 mm for 100-year return periods, the observed maximum rainfall at the site is higher (167.5 mm). The possible reasons for this phenomenon could be the enhanced precipitation in the recent years due to climate change effects, and the method of distribution fitting (graphical or least square technique) that was adopted for the study [5]. The aforementioned observations exemplify that EVA should be updated with new observed data and more advanced techniques. Updating the EVA for nuclear sites with latest data, and revisiting the hydrologic design in light of the same has been advised in the AERB standard as well [2]. In view of above, an attempt of examining the applicability of AES approach in estimate of extreme hourly rainfall for Tarapur has been made in this study.

For the comparison of the two approaches (AMS and AES), hourly rainfall values have been selected. The annual maximum values of hourly rainfall were taken from the data, and these 24 values formed the sample for EVA by a BM approach, known as AMS [9]. For AES approach, the threshold is selected such that the number of samples becomes equal to the number of years of record, making the sample size of AES same as that obtained in AMS approach [9]. The rainfall values higher than the threshold so selected were extracted from the 24-year records and this formed the sample for EVA by AES approach.

For maintaining uniformity, generalized extreme value distribution (GEV) is chosen for examining the suitability, as this was reported to fit the extreme rainfall values at this site [7]. The method of maximum likelihood estimation (MLE) is employed for estimation of the parameters of GEV distribution. MLE has been advocated by Srivastava et al. [7] for better estimates compared to the graphical [5] or Lieblein technique [6] for Tarapur, and the same has been adopted for this study as well.

Therefore, for each sample chosen by AMS and AES approaches, GEV distribution parameters were evaluated by MLE, as was mentioned earlier. After fitting a probability distribution to a sample, the goodness-of-fit (GOF) needs to be examined before subsequent analysis. Compared to the GOF tests such as Chi-squared or Kolmogorov-Smirnov (K-S) tests, it is generally recommended to use Anderson-Darling (A-D) test in EVA, for proper evaluation of the fitted distribution towards the tails that are the zones of interest. The distribution functions, methods of parameter estimation, and GOF test are explained in textbooks [9 – 11]. After confirming from A-D test that the fitted distribution was acceptable for the data, the extreme rainfall values for various return periods pertinent for the nuclear facilities were estimated from the distributions obtained in the two approaches and the results are compared.

Table 1: Descriptive statistics of extreme hourly rainfall data at Tarapur during 1997–2020.

Statistics	AMS approach	AES approach
Count (nos.)	24	24
Maximum (mm)	167.50	167.50
Minimum (mm)	36.50	64.00
Range (mm)	131.00	103.50
Mean (mm)	71.46	85.68
Median (mm)	66.50	76.00
Standard deviation (mm)	29.34	24.96
Coefficient of variation (COV)	0.41	0.29
Skewness	1.82	1.86
Kurtosis	4.28	3.98

Results & Discussions

The descriptive statistics of the extreme hourly rainfall data obtained by adopting AMS and AES approaches are compared in Table 1 below, and the same is presented pictorially in Fig.1 as box and whisker plot.

From the data distribution presented in Fig.1, compared to the AMS approach, an upward shift of the extreme rainfall data can be discerned in the AES approach. One may also observe the descriptive statistics in Table 1, and note this as follows. The range of extreme rainfall reduced from 131.00 mm in AMS, to 103.50 mm in AES, whereas the maximum value remained the same for both. This shift of data was further reflected in a higher mean value as well as higher median value of rainfall for AES, when compared to AMS. Consequently the standard deviation as well as the COV has reduced for AES. The most note-worthy fact is that the non-zero skewness that indicates asymmetry of both the distributions, and the higher positive value for the AES series meaning that the variable (in AES) is more widely spread towards the upper extreme [11]. This property would result in higher values of extreme rainfall for lower probabilities of exceedance (higher return periods).

The empirical and fitted distributions are plotted in Fig.2(a) for AMS and Fig.2(b) for AES. From the figures, it is noted that both the distributions represent good fit to the data, which has been further corroborated by the A-D statistics as well. However, towards the upper end (cumulative probability closer to unity), whereas the fitted distribution lies above the empirical one (higher value) for AMS, it lies below (lower value) for the AES. This results in higher extreme rainfall values for low probability of exceedance in AES approach when compared to AMS.

The comparison of the extreme rainfall values obtained from the fitted distributions for various return periods are presented in Table 2, where it can be seen that the AES approach has

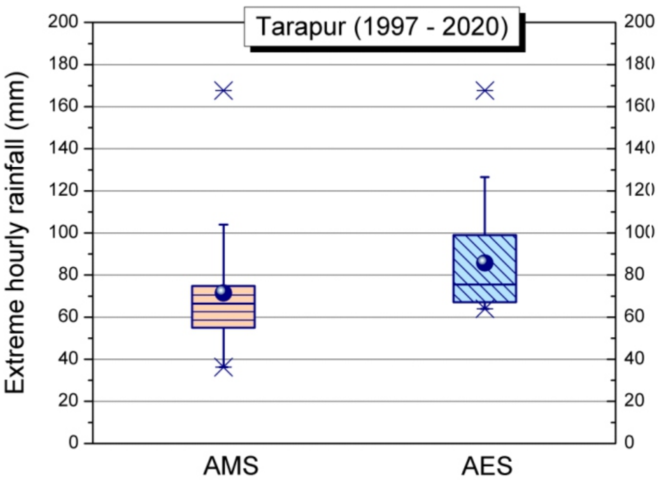

Fig.1: Box and whisker plot of extreme rainfall data by AMS and AES approaches for Tarapur during 1997 – 2020.

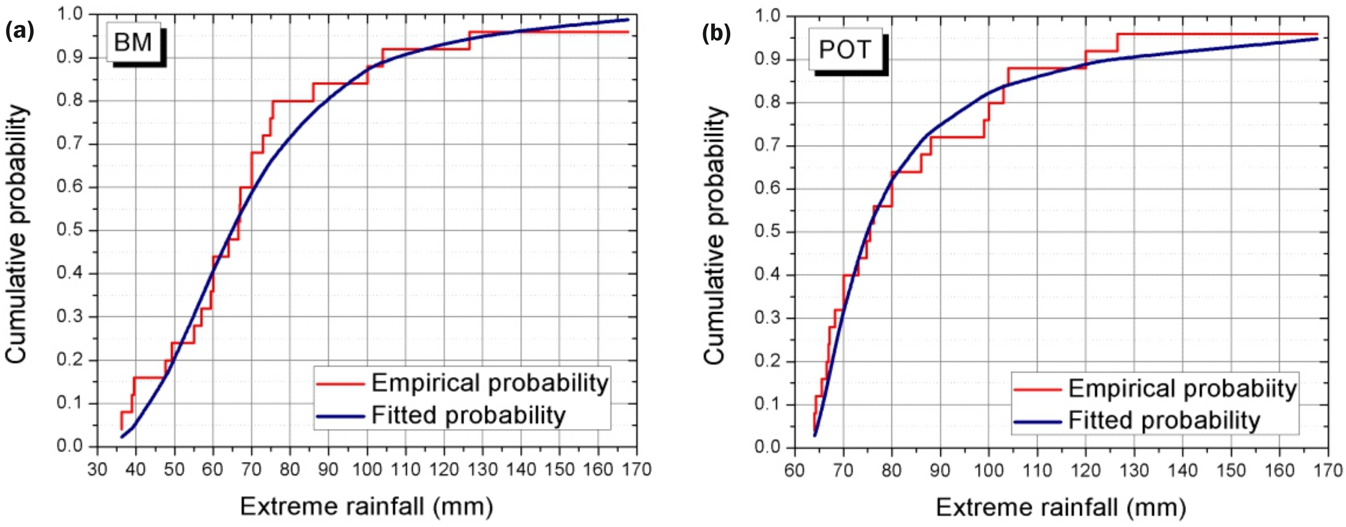

Fig.2: Empirical and fitted distributions, (b) AMS approach; (b) AES approach.

resulted in higher extreme rainfall compared to the AMS approach in each case considered. Additionally, the extreme hourly rainfalls for 50-year and 100-year return periods estimated (AMS as well as AES) from the recent 24-year data are substantially higher than those reported in literature [5] for Tarapur. A possible reason for this occurrence would be the inclusion of recent records in the present analysis, which were higher than those used by Patel et al. [5]. That the maximum hourly rainfall (167.5 mm) observed during the study period of 24 years is higher than the extreme rainfall at 50-year return period estimated in AMS approach indicates a limitation of that approach. In AES approach, this is overcome as the 50-year return period value is higher than the highest observed for the 24-year period. However, for larger return periods, it is observed that AES approach may lead to physically improbable values. In the present case, the extreme 1000-year hourly rainfall estimated in AES approach became comparable to the average annual rainfall for the site and much higher for higher return periods. This observation highlights that there is limitation in adopting AES approach as well. In literature, a similar observation was made for extreme 10000-year daily rainfall estimated using AMS approach for this site [7].

Summary and Future Scope

As reported in literature during last decade [6, 7], the extreme rainfall at Tarapur is observed to increase in recent years, possibly due to the climate change effects. This EVA study was conducted for hourly rainfall for Tarapur, with latest data (up to 2020) and comparison was made between such estimations performed in two approaches of EVA, namely, AMS and AES. The conclusions of the study are:

Table 2: Extreme hourly rainfall values for Tarapur from analysis of data during 1997-2020.

Return period (years)	Extreme rainfall value (mm)		
	AMS approach Patel et al. [5]	AMS approach (this study)	AES approach (this study)
50	107.1	153	289
100	117.9	176	451
1000	Not Reported	272	2351
2500	Not Reported	320	4685
10000	Not Reported	406	13443

- The extreme hourly rainfall for Tarapur has increased in recent years over those reported in literature two decades earlier [5].
- AES approach is successful in including more number of higher rainfall values in the sample when compared to AMS. This results in an upwards shift of the AES sample when compared to the AMS sample distribution with higher mean and median. The spread of the data reduces in AES compared to AMS, as was indicated by the lower standard deviation and COV. This would also lead to a more conservative design.
- The AMS approach conducted over 24-years data resulted in an estimate of extreme 50- year hourly rainfall value that was lower than the maximum observed value in the dataset used for the estimation. This indicated a shortcoming of the AMS approach, which was overcome in AES approach reported in this study.
- For return period of 1000 years or more, the AES approach yields hourly rainfall values that are physically impossible. These values are higher than the annual rainfall recorded till date at the site. This is indicated as a shortcoming of the AES approach that needs more investigation.

The results of this short comparison, using one approach of threshold selection, highlight the necessity of a comprehensive analysis of the meteorological parameters for Tarapur using different approaches, in order to arrive at updated design parameters applicable for the safety of infrastructure at this important industrial and nuclear site. Similar studies for other nuclear sites, having different meteorological and terrain conditions, with varying database, would provide deeper insights for optimal and safe designs, especially in context of extreme climatic behavior being witnessed.

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References

[1] Atomic Energy Regulatory Board (AERB) (2014) Site evaluation of Nuclear Facilities, AERB Guide No. AERB/NF/SC/S (Rev.1). Atomic Energy Regulatory Board, Mumbai, India.

[2] Atomic Energy Regulatory Board (AERB) (2008) Extreme Value

of Meteorological Parameters, AERB Guide No. AERB/NF/SG/S-3. Atomic Energy Regulatory Board, Mumbai, India.

[3] Bezak N, Brilly M, Sraj Mojca (2014) Comparison between the peaks-over-threshold method and the annual maximum method for flood frequency analysis, Hydrological Sciences Journal, Volume 59, issue 5, 959-977,https://doi.org/10.1080/02626667.2013.831174

[4] Tabari H (2021) Extreme value analysis dilemma for climate change impact assessment on global flood and extreme precipitation, Journal of Hydrology, Volume 593, 125932. https://doi.org/10.1016/j.jhydrol.2020.125932

[5] Patel PV, Patil SS, Kulkarni MR, Hegde AG, Gurg RP (2001) Extreme value analysis of meteorological parameters observed during period 1961 – 2000 at Tarapur. BARC Report No. BARC/2001/E/025. Bhabha Atomic Research Centre, Mumbai, India.

[6] Gupta A, Dauji S, Srivastava PK, Bhargava K (2018) Extreme Value Analysis by Graphical and Lieblein Techniques for Rainfall on Western Coast of India, IWRA (India) Journal, Volume 7, No. 2, July 2018, 38-45.

[7] Srivastava PK, Dauji S, Bharagava K (2023) Site- specific rainfall analysis to generate design parameters: A case study. AIP Conference Proceedings, 2721, 040001. https://doi.org/10.1063/5.0153909

[8] Harshanth R, Dauji S, Srivastava PK (2021) Quality Checks on Continuous Rainfall Records: A Case Study, In: Jha R., Singh V.P., Singh V., Roy L.B., Thendiyath R. (eds.) Climate Change Impacts on Water Resources. Water Science and Technology Library, vol. 98. Springer, Cham. https://doi.org/10.1007/978-3-030-64202-0_20

[9] Chow VT, Maidment DR, Mays LW (1998) Applied Hydrology, McGraw-Hill, Inc., USA.

[10] Coles S (2001) An Introduction to Statistical Modeling of Extreme Values, Springer – Verlag London Limited, Great Britain.

[11] Ang AHS, Tang WH (2007) Probability Concepts in Engineering, Emphasis on Applications in Civil and Environmental Engineering, John Wiley and Sons, New York.