World Academics Journal of Engineering Sciences
Vol.**11**, Issue.**2**, pp.**07-11**, June **2024**
E-ISSN: 2348-635X
Available online at: www.isroset.org

Research Article

Effect of Data Length on Assessment of Dependable Flow from Flow Duration Curve using Empirical Method

N. Vivekanandan[1]

[1]Central Water and Power Research Station, Pune 411024, Maharashtra, India

**Corresponding Author: vivek.cwprs@gmail.com*

Received: 26/Apr/2024; **Accepted**: 28/May/2024; **Published**: 30/Jun/2024

Abstract— Assessment of dependable flows at different probability of exceedance levels is considered as one of the important parameters for planning, design and management of various water related projects. For this purpose, the Flow Duration Curve (FDC) is considered by analyzing the available stream flow data at the site when adequate length of observed data is not available. This paper presented a study on effect of data length on assessment of dependable flows from FDCs using empirical method wherein the probability of exceedance for each sample is determined by Weibull and Blom plotting position formulae (PPF). The selection of most suitable PPF amongst Weibull and Blom applied in empirical method was made through qualitative assessment by the fitted curves of FDCs and quantitative assessment using model performance indicators viz., correlation coefficient and relative error. The study showed that the relative error obtained from the constructed FDCs by Blom is minimum than those value of Weibull though there is a good correlation between the observed and computed flows by the FDCs of Weibull and Blom. The study suggested that the dependable flows at different probability of exceedance levels given by the FDC with Blom PPF could be used for design purposes and various hydrologic analyses at a site.

Keywords— Blom, Correlation coefficient, Empirical, Flow duration curve, Relative error, Stream flow, Weibull

1. Introduction

Information of several stream flow characteristics viz., catchment yield, peak discharge or design flood, low-flows, etc. is generally required for the design of various water resources projects. Moreover, the temporal variability of these characteristics has to be evaluated for the effective planning, design and management of various water related projects such as hydro power generation, irrigation systems, reservoir sedimentation [1-3]. This can be carried out by constructing a flow duration curve (FDC) that is a graphical representation of the relationship between a stream flow (Q) and its probability of exceedance level [P(Q)].

Section 1 contains the introduction of the research article whereas Section 2 presents the literature review that describes the related work carried out by different researchers. Section 3 details the methodology adopted in constructing the FDCs using empirical method with Weibull and Blom plotting position formulae. Section 4 describes the application of the research work reported in this paper. Section 5 details the results and discussion whereas Section 6 concludes the research work and future scope of the study.

2. Literature Review

A number of studies have been carried out by different researchers for constructing the FDC using empirical method. Smakhtin and Masse [4] developed a method for continuous daily stream flow generation using the 1-day FDC and duration curves of rainfall-related index that reflects the daily fluctuations of wetness of the catchment. Smakhtin [5] derived a FDC to estimate magnitude and frequency of low-flows for the ungauged catchments. Pao-Shan Yu et al. [6] evaluated the stream flow variability of Cho-Shuei Creek in Taiwan using FDCs. Tallaksen and Van Lanen [7] identified the techniques for low-flow estimation in ungauged catchments that include construction of regional FDCs. Patrick et al. [8] developed a method to remove the climate signal from stream flow records to identify the impact of vegetation on flow from the afforested catchments and quantify its impact on the FDC. Attilio Castellarin et al. [9] constructed an annual FDC for unregulated river basins of Italy by applying the empirical and regional index flow methods. Study by Yusuf [10] revealed that the step-wise regression method using dependable flow, land use and climate descriptor data can be applied to construct a FDC for prediction of stream flow for the ungauged catchments in Mid-Atlantic Region, USA.

Baltas [11] expressed that the FDC indicates the water availability at a site and is important for the estimation of the hydropower potential for western and north-western Greece. Hrachowitz et al. [12] developed the innovative models to investigate the space-time variability of hydrological processes. Khopade and Oak [13] estimated the runoff yield for Nira Deoghar catchment through empirical equations. Yongqiang Zhang et al. [14] stated that the FDC approach was the best at predicting medium to low-flows in traditional calibration against the Nash-Sutcliffe efficiency or root mean square error. Muller and Thompson [15] developed the FDCs for stream flow prediction of Nepal region by stochastic (process-based) and statistical methods. Maya Atieh et al. [16] applied the novel model for prediction of FDCs at ungauged basins using artificial neural networks for North America. Ebru Eris et al. [17] identified a best-fit distribution function to estimate the low-flows using the up-to-date data of intermittent and non-intermittent rivers in Turkey. Elena Ridolfi et al. [18] developed the FDCs at partially gauged basins using precipitation data gauged at another basin. This paper presented the procedures applied in constructing the FDC using empirical method with an illustrative example and the results obtained from the study.

3. Methodology

The empirical and class-interval methods are widely adopted for the construction of FDC using the stream flow data. However, in this paper, the empirical method using Weibull and Blom plotting position formulae (PPF) was applied.

3.1. Construction of FDCs using Empirical Method

The construction of the FDCs using the annual maximum series (AMS) of stream flow (Q) data with different data length can be performed through empirical method [19], which is given as below:

i) Formulate the set of ordered sample [Q(1)>Q(2)>Q(3)>…..Q(N)] using the observed stream flow data [Q(i), i=1,2,.....,N] wherein Q(i) is the observed data of i^{th} sample, Q(1) and Q(N) are the largest and the smallest values in the data series respectively.

ii) Construct the FDCs by plotting the ordered observation of each sample [Q(i)] against its probability of exceedance [P(Q(i))], which is generally dimensionless. The probability of exceedance (P) of flow data (Q) for i^{th} sample [P(Q(i)] is computed by:
P[Q(i)]=m/(N+1) (for Weibull)
P[Q(i)]= (m-0.375)/(N+0.250) (for Blom)
Where, 'm' is the rank assigned to the each sample (i) arranged in the descending order and N is the number of samples. For example, the rank 1 is assigned to the first largest value, rank 2 for the second largest and so on.

iii) Fit a curve for the constructed FDCs in the form of $Q=Ae^{BP(Q)}$ wherein the constants (A and B) can be determined by the method of least square.

3.2. Model Performance Analysis

The performance of the Weibull and Blom PPF used in constructing the FDCs was quantitatively assessed by model performance indicators [viz., correlation coefficient (CC) and relative error (RE)] and qualitatively assessed through fitted curves of the estimated flows. Theoretical descriptions of CC and RE [20] are given as below:

$$CC = \frac{\sum_{i=1}^{N}\left[Q(i)-\mu(Q)\right]\left[Z(i)-\mu(Z)\right]}{\sqrt{\sum_{i=1}^{N}\left[Q(i)-\mu(Q)\right]^2 \sum_{i=1}^{N}\left[Z(i)-\mu(Z)\right]^2}} \quad (1)$$

$$RE = \frac{1}{N}\sum_{i=1}^{N}\left[\frac{Q(i)-Z(i)}{Q(i)}\right] \quad (2)$$

Where, Q(i) is the observed AMD of i^{th} sample, μ(Q) is the average of observed AMDs, Z(i) is the computed AMD of i^{th} sample and μ(Z) is the average of the computed AMDs. The PPF with good correlation (say, CC>0.9) and minimum RE was adjudged as better suited for the construction of FDCs that can be used for computation of dependable flows at different probability of exceedance levels at a site.

4. Application

In this paper, a study on effect of data length on assessment of dependable flow from FDC using empirical method was carried out. For this purpose, the AMS of stream flow data with different data length (D in years) viz., D50 (1941 to 1990), D60 (1941 to 2000), D70 (1941 to 2010) and D80 (1941 to 2020) was derived from the daily stream flow data (1941 to 2020) of Sarangkheda site and used in developing the FDCs with Weibull and Blom PPF. Table 1 presents the descriptive statistics [viz., Average, Standard Deviation (SD), Coefficient of Variation (CV), Coefficient of Skewness (C_s), Coefficient of Kurtosis (C_s)] of AMS of stream flow data applied in FDCs.

Table 1. Descriptive statistics of AMS of flow data with different data length applied in FDCs

Data series	Average (cumecs)	SD (cumecs)	CV (%)	C_s	C_k
D50	12875.5	9494.9	73.7	1.315	1.606
D60	12776.9	9284.2	72.7	1.304	1.466
D70	12352.9	9247.1	74.9	1.397	1.571
D80	12358.4	9026.3	73.0	1.335	1.453

From Table 1, it was found that (i) the average of the observed AMDs of D50 series is comparatively higher than those values of D60, D70 and D80; (ii) the standard deviation of the observed AMDs pertaining to the series D50, D60, D70 and D80 are in decreasing order; and (iii) the coefficient of variation of the AMS of stream flow data with different data length vary from 72.7% to 74.9 %.

5. Results and Discussion

By applying the procedures of empirical method, as described above, the FDCs using D50, D60, D70 and D80 series were constructed and are presented in Figure 1 (a-d). The fitted equations of the FDCs by Weibull and Blom PPF are in the form of exponential curve [$Q=Ae^{-0.02P(Q)}$ wherein Q is the dependable flow (in cumecs) and P(Q) is the probability of exceedance of flow (in percentage)] that are presented in Table 2. By using the fitted curves of the FDCs, the dependable flows at different probability of exceedance levels (viz., 50%, 75%, 90% and 95%) were computed and are presented in Table 3(a-b). From Figure 1(a-d), it was witnessed that the estimated flows by Blom PPF is closer to the observed flows while applying the D50, D60, D70 and D80 series in constructing the FDCs. The MPIs values of the constructed FDCs using empirical method with Weibull and Blom PPF are presented in Table 4.

Table 2. Fitted equations of the FDCs by empirical method

Data series	Value of A in $Q=Ae^{-0.02P(Q)}$ of the constructed FDCs	
	Weibull	Blom
D50	38244	37484
D60	36595	36007
D70	34456	33990
D80	34031	33634

Table 3(a). Observed and computed flows at different probability of exceedance levels using D50 and D60 series

P(Q) (%)	Q (cumecs)					
	D50			D60		
	Observed	Weibull	Blom	Observed	Weibull	Blom
50	9160.4	14071.9	13792.3	9415.24	13464.4	13248.1
75	18936.7	23199.5	22736.3	18448.3	22198.2	21842.3
90	25060.1	31313.7	30695.1	25142.2	29962.9	29483.9
95	37233.5	34611.2	33919.6	36838.5	33113.4	32584.7

Table 3(b). Observed and computed flows at different probability of exceedance levels using D70 and D80 series

P(Q) (%)	Q (cumecs)					
	D70			D80		
	Observed	Weibull	Blom	Observed	Weibull	Blom
50	8877.2	12676.9	12505.5	8877.2	12520.3	12374.2
75	16558.1	20900.2	20616.5	17400.5	20642.0	20401.6
90	25142.2	28211.2	27831.4	25108.3	27863.0	27539.2
95	35494.8	31180.1	30756.7	33879.3	30793.0	30435.5

Table 4. MPIs values computed by the fitted curves of the constructed FDCs using Weibull and Blom PPF

Data series	MPIs computed from the fitted curves of the FDCs			
	Weibull		Blom	
	CC	RE	CC	RE
D50	0.960	0.543	0.960	0.510
D60	0.962	0.455	0.962	0.430
D70	0.967	0.407	0.967	0.387
D80	0.970	0.369	0.970	0.352

From Table 4, it was found that (i) the correlation between the observed and computed flows using the D50, D60, D70 and D80 series vary between 0.960 and 0.970; (ii) the relative error between the observed and computed flows through the constructed FDCs are in decreasing order when data length increases; and (iii) the relative error computed by Blom PPF is minimum than those values of Weibull for the data series with different data length applied in constructing the FDCs.

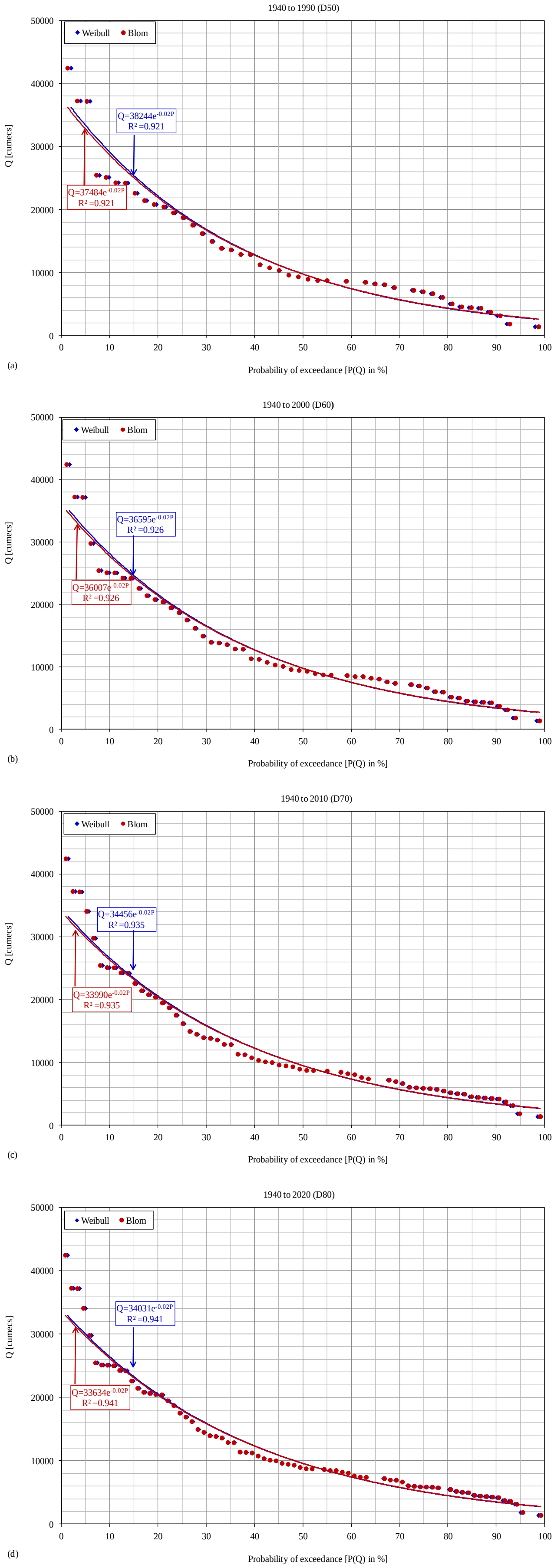

Figure 1(a-d): FDCs for the series of AMD data with different data length using empirical method

6. Conclusion and Future Scope

The paper presented a study on effect of data length on assessment of dependable flows from the FDCs using empirical method with Weibull and Blom PPF. For this purpose, the AMS of stream flow data with different data length (say, D50, D60, D70 and D80) was generated from the AMD data of Sarangkheda site and used in data analysis. The performance of Weibull and Blom PPF applied in constructing the FDCs was evaluated through model performance indicators [viz., correlation coefficient and relative error] and fitted curves of the FDCs. On the basis of the results of data analysis, the conclusions drawn from the study were summarized and are presented below:

- The computed stream flows from the constructed FDCs with Blom PPF are closer to the observed stream flows.
- There is a good correlation between the observed and computed flows using the D50, D60, D70 and D80 series applied in constructing the FDCs, and these values vary between 0.960 and 0.970.
- Relative error obtained from the fitted curves of FDCs with Blom PPF is minimum than those values of Weibull for the D50, D60, D70 and D80 series applied in estimation of dependable flows at different probability of exceedance levels.
- Relative errors between the observed and computed flows using the constructed FDCs are in decreasing order when data length increases.

The study showed that the dependable flows obtained from the constructed FDCs at different probability of exceedance levels [viz., 50%, 75%, 90% and 95%] could be used for design purposes and various hydrologic analyses at a site. The study suggested that the techniques presented in the paper would be beneficial to the stakeholders while looking for the availability of much needed detailed information on characteristics of stream flow data of river Tapi at Sarangkheda site for their future work whenever needed.

Declarations

Data Availability
None

Conflict of Interest
The author declares that he has no competing interest.

Funding Source
None.

Author’s Contribution
The author has defined the methodology, analysed the results and prepared the manuscript.

Acknowledgments
The author is thankful to the Director, Central Water and Power Research Station, Pune, for providing the research facilities to carry out the study. The author is also thankful to M/s Unique Construction, Surat, for making available the stream flow data of Sarangkheda site.

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AUTHOR'S PROFILE

N. Vivekanandan has post graduated in mathematics from Madurai Kamaraj University. He also received M.Phil. (Mathematics), M.E. (Hydrology), M.B.A. (Human Resources), M.A. (Sociology). and M.A. (Public Administration). He is presently working as a Scientist of Central Water and Power Research Station, Pune. He has published more than 250 research papers in national/international journals and conferences. He is a member of Editorial Board of 15 national and international journals. His research interests include applied statistics, applied hydrology, irrigation planning, soft computing, climate change, etc.