Comparison of Probability Distributions for Extreme Value Analysis of Wind Speed Data

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Abstract

Estimation of the occurrence of Extreme Wind Speed (EWS) for a particular return period is carried out by fitting of Probability Distribution (PD) to the observed wind speed data to arrive at a design value for designing of civil and hydraulic structures. This paper illustrates the adoption of five PDs such as Exponential, Extreme Value Type-1, Extreme Value Type-2, Generalized Extreme Value (GEV) and Generalized Pareto for Extreme Value Analysis (EVA) of wind speed for Delhi and Kanyakumari. Parameter estimation procedures such as method of moments, maximum likelihood method and L-Moments (LMO) are used for determination of parameters of the distributions. The adequacy of fitting of PDs is evaluated by non-parametric Goodness-of-Fit test using Kolmogorov-Smirnov test and diagnostic test using D-index. The GoF and diagnostic tests results indicate the GEV (using LMO) is better suited PD for estimation of EWS. The estimated EWS obtained from GEV (using LMO) distribution is compared with the EWS values of IS 875 procedure to select an appropriate design wind speed for the regions under study. Based on the analysis of EVA results obtained from five PDs (using MoM, MLM and LMO) and IS 875 procedure, the suggestions are made thereof and presented in the paper.

Keywords - *D-index, Extreme Value Analysis, Generalized Extreme Value, IS 875 Procedure, Kolmogorov-Smirnov, L-Moments, Wind Speed*

I. INTRODUCTION

The design of vital engineering structures requires an understanding of extreme weather conditions that may occur at the site of interest. It is very much essential that the structures can be designed to withstand extreme wind loads over the entire intended economic lifetime. In this context, an estimation of the occurrence of Extreme Wind Speed (EWS) for a particular return period is carried out by fitting of Probability Distribution (PD) to the observed wind speed data to arrive at a design value for designing of civil and hydraulic structures [1]. This can be achieved through Extreme Value Analysis (EVA) by fitting of PDs to the observed wind speed data. In the absence of hourly wind speed data, IS 875 procedure is considered as an alternative approach to estimate the design wind speed [2].

Research reports iterated that the PDs of Exponential (EXP), Extreme Value Type-1 (EV1), Extreme Value Type-2 (EV2), Generalized Extreme Value (GEV) and Generalized Pareto (GP) are commonly used for EVA of wind speed. Based on the applicability, standard parameter estimation procedures viz., Method of Moments (MoM), Maximum Likelihood Method (MLM) and L-Moments (LMO) are used for determination of parameters of the PDs [3]. Since MoM estimates are usually inferior in quality especially for distributions with three or more number of parameters because higher order moments are more likely to be highly biased in relative small samples. Under these circumstances, MLM is considered to be more efficient method for determining the parameters of the PDs [4]. The studies carried by various researchers indicated that the estimated parameters of distributions fitted by the MoM are often less accurate than those obtained by MLM and LMO. In view of the above, MoM, MLM and LMO are applied for determination of parameters of the PDs. In the recent past, number of studies has been carried out by researchers adopting PDs for EVA of wind speed. Kunz et al. [5] compared the Gamma and GP distributions for estimation of EWS and concluded that the GP provides better estimates than Gamma. Morgan et al. [6] applied Extreme Value, Gamma and Normal family of PDs for estimation of EWS using the 10-minute wind speed observations recorded at various stations around North America. They have found that the 2-parameter Log Normal (LN2) distribution yielded the best estimate of EWS, but still exhibited large errors. El-Shanshoury and Ramadan [7] applied EV1 distribution to estimate EWS for Dabaa area in the north-western coast of Egypt. Lee et al. [8] applied Gumbel (EV1) and 2-parameter Weibull (WB2) distributions for estimation of EWS using the Korea wind map. They have observed that the EV1 distribution gives better results than WB2. Daneshfaraz et al. [9] carried out the wind speed frequency analysis adopting LN2, truncated extreme value, truncated logistic and WB2 distributions and found that the truncated extreme value is the most appropriate distribution for Iran.

Lawan et al. [10] evaluated the suitability of five PDs through GoF tests and found that the Gamma and LN2 distributions are better suited for modelling wind speed data of Miri, Malaysia. Generally, when different PDs are used for EVA, a common problem that arises is how to determine which model fits best for a given set of data. This can be evaluated by quantitative assessment using non-parametric Goodness-of-Fit (GoF) and diagnostic tests and qualitative assessment using plots of estimated values of EWS obtained from PDs. A non-parametric GoF test, say Kolmogorov-Smirnov test is applied for checking the adequacy of fitting of PDs to the recorded wind speed data [11]. A diagnostic test of D-index is used for the selection of a suitable PD with parameter estimation method for estimation of EWS. In addition, the design wind speed values are computed by using IS 875 procedure and the results are compared with the EWS values obtained from PDs to select an appropriate design wind speed for design purposes.

This paper illustrates the procedures involved in selection of suitable PD for estimation of EWS though GoF and diagnostic tests, estimation of EWS using IS 875 procedure and suggested values of design wind speed for designing of hydraulic structures with illustrative example.

II. METHODOLOGY

The procedures involved in EVA of wind speed of Delhi and Kanyakumari are: (i) prepare the Annual Hourly Maximum Wind Speed (AHMWS) data series from hourly wind speed data; (ii) determination of parameters of five PDs viz., EXP, EV1, EV2, GEV and GP using MoM, MLM and LMO; (iii) check the adequacy of fitting of PDs using GoF and diagnostic tests to identify the suitable PD; (iv) estimate the EWS using PDs (using MoM, MLM and LMO); (v) estimate the EWS using IS 875 procedure and compare with the EWS values obtained from PDs; and (vi) analyse the results and suggestions made thereof. Table 1 presents the Cumulative Distribution Function (CDF) and quantile estimator (W_T) of PDs considered in the study. In Table 1, F(w) is the CDF of variable w (i.e., wind speed), α is the location parameter, β is the scale parameter, γ is the shape parameter and T is the return period. For EV1 and EV2 distributions, the reduced variate (Y_T) corresponding to T is defined by $Y_T=-\ln(-\ln(1-(1/T)))$ [12-13]. The parameters of the distributions are determined by MoM, MLM and LMO, and used to estimate the EWS by the quantile functions of the PDs, as given in Table 1. Theoretical descriptions of the determination of parameters of PDs by MoM, MLM and LMO are available in the text book titled ‘Flood Frequency Analysis’ published by Rao and Hameed [14].

Table 1: CDF and Quantile Estimator of Five PDs

Distribution	CDF	Quantile estimator (W_T)
EXP	$F(w;\beta,\gamma)=(1-\exp(-\beta w))^{\gamma}$, w>0, β>0	$W_T=\frac{1}{\beta}\left[-\ln\left(1-\left(1-\left(\frac{1}{T}\right)\right)\right)^{(1/\gamma)}\right]$
EV1	$F(w;\alpha,\beta)=\exp\left(-\exp\left(-\frac{(w-\alpha)}{\beta}\right)\right)$, w>0, β>0	$W_T=\alpha+Y_T\beta$
EV2	$F(w;\beta,\gamma)=\exp\left(-\left(\frac{w}{\beta}\right)^{-\gamma}\right)$, w>0, β>0	$W_T=\beta\exp\left(\frac{Y_T}{\gamma}\right)$
GEV	$F(w;\alpha,\beta,\gamma)=\exp\left\{-\left[1-\gamma\left(\frac{w-\alpha}{\beta}\right)\right]^{(1/\gamma)}\right\}$, w>0, β>0, γ≠0	$W_T=\alpha+\left(\frac{\beta}{\gamma}\right)\left[1-\left(-\ln\left(1-\left(\frac{1}{T}\right)\right)\right)^{\gamma}\right]$
GP	$F(w;\beta,\gamma)=1-\left(1-\frac{\gamma w}{\beta}\right)^{(1/\gamma)}$, w>0, β>0, γ≠0	$W_T=\left(\frac{\beta}{\gamma}\right)\left[1-\left(\frac{1}{T}\right)^{\gamma}\right]$

A. *Goodness-of-Fit Test*

Generally, A^2 test statistic is applied for checking the adequacy of fitting of EV1 and EV2 distributions. The procedures involved in application of A^2 test statistic for EXP, GEV and GP are more complex though the utility of the test statistic is extended for checking the quantitative assessment. In view of the above, KS test is widely applied for the purpose of quantitative assessment. Theoretical description of KS test statistic is as follows:

$$KS=\underset{i=1}{\overset{N}{\mathrm{Max}}}\left(F_e(w_i)-F_D(w_i)\right) \quad \ldots (1)$$

where, $F_e(w_i)$=M/N+1 is the empirical CDF of w_i and $F_D(w_i)$ is the derived CDF of w_i by PDs. Here, M is the rank assigned to each of the observations (w_i) and N is the number of observations. The theoretical value KS statistic for different sample size (N) at 5% significance level is available in the technical note on ‘Goodness-of-Fit Tests for Statistical Distributions’ by Charles Annis [15]. If the computed value of KS test statistic given by the distribution or method is less than that of theoretical value at the desired significance level (either at 5% or 1%), the PD with parameter estimation method would be taken as acceptable for EVA of wind speed at that level.

B. Diagnostic Test

Sometimes the GoF test results would not offer a conclusive inference thus posing a problem for the user in selecting a suitable PD or method for their application. In such cases, a diagnostic test in adoption to GoF is applied for making inference. The selection of a suitable PD for estimation of EWS is performed through D-index test [16], which is defined as below:

$$\text{D-index} = \left(1/\overline{w}\right)\sum_{i=1}^{6}\left|w_i - w_i^*\right| \qquad \ldots (2)$$

Here, $\overline{w}$ is the average value of the observed data whereas w_i (i= 1 to 6) and w_i^* are the six highest observed and corresponding estimated values by different PDs. The PD with parameter estimation method having the least D-index is considered as better suited for EVA.

III. APPLICATION

EVA of wind speed data was carried out to estimate the EWS for different return periods adopting five PDs viz., EXP, EV1, EV2, GEV and GP for Delhi and Kanyakumari. Standard parameter estimation procedures such as MoM, MLM and LMO were applied for determination of parameters of the PDs. The hourly wind speed observed at Delhi for the period 1969 to 2013 and Kanyakumari for the period 1970 to 2014 was used. The AHMWS data series was extracted from the hourly data series and used for EVA. From the scrutiny of the wind speed data of Delhi, it was observed that the data for the period of twelve years (1974, 1979 to 1981, 1983 to 1988, 1990 and 2004) are missing, which were imputed by the series maximum value of 85 km/hr so as to arrive at conservative estimates [17]. For Kanyakumari, it was observed that there are no missing data in AHMWS data series. After imputing the missing values for Delhi, the AHMWS data series of Delhi and Kanyakumari was used for EVA. Table 2 gives the descriptive statistics of the AHMWS data.

Table 2: Descriptive Statistics of AHMWS Data

Site	Statistical parameters			
	Average (km/hr)	SD (km/hr)	CS	CK
Delhi	66.6	15.4	-0.007	-1.584
Kanyakumari	42.2	9.7	2.546	10.557
SD: Standard Deviation; CS: Coefficient of Skewness; CK: Coefficient of Kurtosis				

IV. RESULTS AND DISCUSSIONS

Based on the parameter estimation procedures of EXP, EV1, EV2, GEV and GP probability distributions, parameters were determined by using MoM, MLM and LMO with the aid of statistical software viz., Hydrognomon and VTFIT, and used for EVA of wind speed data. The estimated EWS for Delhi and Kanyakumari given by five PDs (using MoM, MLM and LMO) are presented in Tables 3 and 4 respectively. Figures 1 and 2 present the plots of observed and estimated EWS obtained from five PDs (using MoM, MLM and LMO) for Delhi and Kanyakumari respectively. From Table 3, it is noted that the estimated EWS obtained from EV2 (using MLM) is comparatively higher than the corresponding values of other PDs (or methods) for return periods from 10-year to 1000-year for Delhi. Similarly, from Table 4, it is noted that the estimated EWS obtained from GP (using MLM) is higher than the values of other PDs (or methods) for return periods from 10-year to 1000-year for Kanyakumari. From Figures 1 and 2, it can be seen that the fitted lines of the estimated EWS by EV2 (using MLM) for Delhi and GP (using MLM) for Kanyakumari are in the form of exponential curve.

A. Analysis Based on GoF Test

By using the parameters of PDs (using MoM, MLM and PWM), KS test statistic values were computed by using Eq. (1) and GoF test results are presented in Table 5. From KS test results, it is noted that the computed values by EXP, EV1, EV2, GEV and GP distributions (using MoM, MLM and LMO) are less than the theoretical value of 0.203 at 5% significance level, and at this level, all five PDs are found to be acceptable for EVA of wind speed for Delhi. From Table 5, it is also noted that the computed values of KS test statistic by EXP, EV1, EV2 and GEV (using MoM, MLM and LMO) are less than its theoretical values at 5% significance level, and at this level, the four distributions are found to be acceptable for EVA of wind speed for Kanyakumari.

B. Analysis Based on Diagnostic Test

As GoF test results confirmed the applicability of MoM, MLM and LMO methods of four PDs, viz., EXP, EV1, EV2 and GEV adopted for estimation of EWS for both Delhi and Kanyakumari, the selection of an appropriate PD with parameter estimation method for EVA of wind speed was carried out by diagnostic test using D-index. The diagnostic tests results together with rank assigned to each PD with parameter estimation method based on D-index values are presented in Table 6. From diagnostic test results, it is noted that the D-index values of GEV (using LMO) distribution for Delhi and Kanyakumari are found to be minimum when compared with the corresponding values of other PDs and methods.

Table 3: Estimated EWS for Different Return Periods by Five PDs (using MoM, MLM and LMO) for Delhi

Return period (year)	Extreme Wind Speed (km/hr)														
	MoM					MLM					LMO				
	EXP	EV1	EV2	GEV	GP	EXP	EV1	EV2	GEV	GP	EXP	EV1	EV2	GEV	GP
2	61.9	64.0	62.9	66.5	66.5	61.5	64.0	62.2	67.3	70.1	61.2	64.0	62.2	66.9	67.3
5	75.9	77.7	75.2	79.9	82.7	80.9	79.1	80.2	80.6	86.3	77.3	78.1	76.3	80.2	82.4
10	86.7	86.7	84.5	86.7	87.8	88.1	89.2	95.0	86.7	91.4	89.6	87.8	87.1	86.7	87.1
20	97.1	95.3	94.6	92.1	90.3	99.3	98.9	111.2	90.6	94.2	101.4	96.8	99.3	91.4	89.2
50	111.5	106.5	109.4	97.5	92.1	115.1	111.5	137.1	93.9	95.7	117.6	108.6	116.9	96.0	90.3
100	121.9	114.7	121.9	100.7	92.4	120.1	120.9	160.1	95.3	96.0	129.9	117.6	132.7	98.6	90.6
200	132.7	123.0	136.0	103.6	92.8	132.7	130.2	186.7	96.0	96.4	142.1	126.3	150.0	100.7	90.6
500	146.8	134.2	156.8	106.5	92.8	141.0	142.8	229.1	96.0	96.4	157.9	137.8	177.0	102.9	90.6
1000	157.6	142.4	174.5	107.9	92.8	152.9	151.8	267.3	95.7	96.8	170.1	146.8	200.4	104.0	90.6

Table 4: Estimated EWS for Different Return Periods by Five PDs (using MoM, MLM and LMO) for Kanyakumari

Return period (year)	Extreme Wind Speed (km/hr)														
	MoM					MLM					LMO				
	EXP	EV1	EV2	GEV	GP	EXP	EV1	EV2	GEV	GP	EXP	EV1	EV2	GEV	GP
2	39.2	40.6	39.9	39.9	39.2	44.6	40.6	39.9	40.3	42.8	39.2	40.6	39.9	39.9	39.9
5	48.2	49.3	47.5	47.8	47.5	50.7	47.8	48.2	47.8	50.7	47.8	48.6	47.5	47.5	48.9
10	54.7	54.7	53.6	53.6	54.0	55.4	52.5	54.3	53.2	57.6	54.3	53.6	53.2	53.2	54.7
20	61.5	60.4	59.7	59.7	61.2	60.1	57.2	60.8	59.0	64.7	60.8	58.3	59.4	59.4	60.1
50	70.5	67.3	69.1	69.1	70.9	66.2	62.9	70.5	66.5	74.8	69.4	64.7	68.3	68.0	65.8
100	77.0	72.7	77.0	77.0	78.8	70.5	67.6	79.1	73.0	82.7	75.9	69.4	76.3	75.5	69.8
200	83.8	77.7	85.6	85.6	87.1	75.2	71.9	88.1	79.5	91.4	82.4	74.1	84.5	83.5	73.4
500	92.8	84.9	98.9	98.6	98.6	81.3	77.7	102.2	88.8	103.2	91.0	80.2	97.1	95.3	77.3
1000	99.3	89.9	110.1	109.7	107.9	86.0	82.0	114.4	96.8	116.5	97.5	84.9	108.3	105.0	80.2

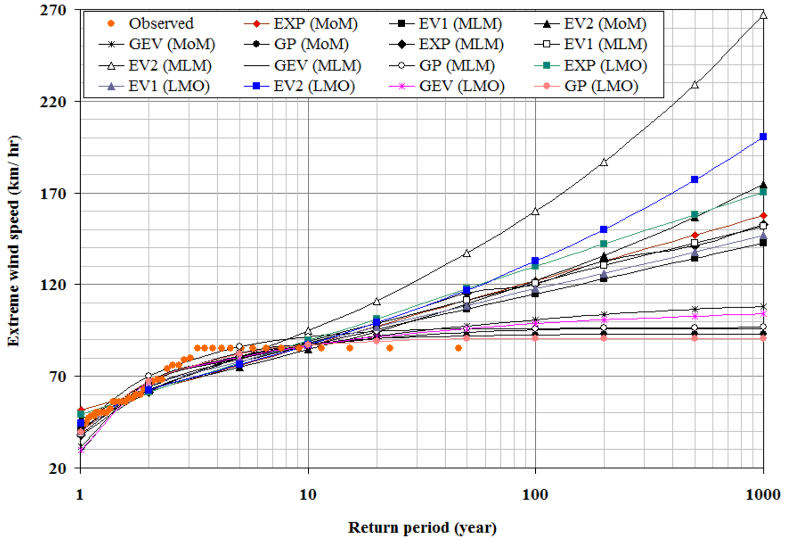

Figure 1: Plots of Observed and Estimated EWS by EXP, EV1, EV2, GEV and GP distributions (using MOM, MLM and LMO) for Different Return Periods for Delhi

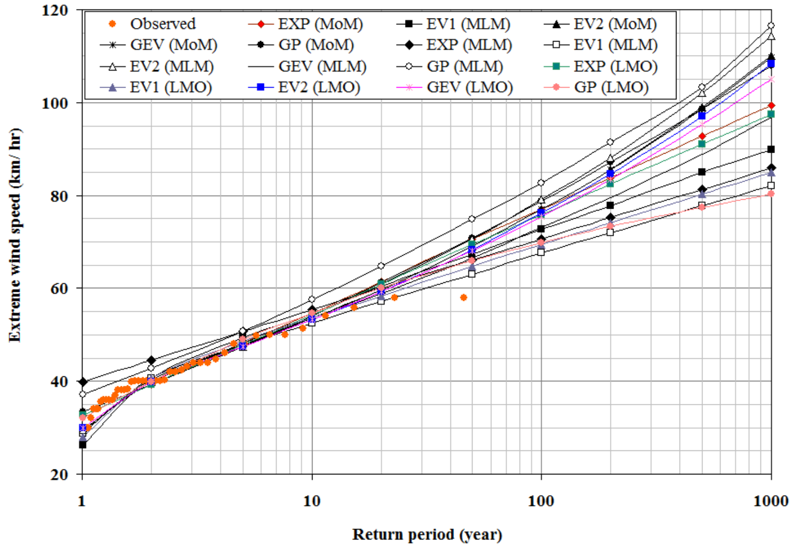

Figure 2: Plots of Observed and Estimated EWS by EXP, EV1, EV2, GEV and GP distributions (using MOM, MLM and LMO) for Different Return Periods for Kanyakumari

Table 5: Computed Values of KS Test Statistic by Five PDs (using MOM, MLM and LMO)

Parameter estimation method	Probability distribution	Computed values of KS test statistic for	
		Delhi	Kanyakumari
MoM	EXP	0.198	0.144
	EV1	0.190	0.089
	EV2	0.197	0.107
	GEV	0.181	0.106
	GP	0.149	0.284
MLM	EXP	0.161	0.159
	EV1	0.198	0.104
	EV2	0.190	0.120
	GEV	0.184	0.092
	GP	0.158	0.239
LMO	EXP	0.185	0.141
	EV1	0.181	0.090
	EV2	0.189	0.103
	GEV	0.182	0.099
	GP	0.157	0.259

Table 6: D-Index Values with Rank Assigned to Each Probability Distribution/ Method

Parameter estimation method	Probability distribution	D-index values with rank assigned to each probability distribution/ method			
		Delhi		Kanyakumari	
		D-index	Rank	D-index	Rank
MoM	EXP	0.813	10	0.799	11
	EV1	0.678	6	0.823	12
	EV2	0.712	8	0.667	5
	GEV	0.451	5	0.671	6
	GP	0.366	3	0.711	8
MLM	EXP	1.884	15	0.877	14
	EV1	0.924	11	0.643	2
	EV2	1.863	14	0.728	9
	GEV	0.349	2	0.657	4
	GP	0.694	7	0.893	15
LMO	EXP	1.082	13	0.763	10
	EV1	0.774	9	0.705	7
	EV2	0.958	12	0.649	3
	GEV	0.266	1	0.618	1
	GP	0.397	4	0.824	13

C. Selection of PD for EVA of Wind Speed

On the basis of GoF and diagnostic test results, the study suggested that the GEV (using LMO) is an appropriate PD for EVA of wind speed for both Delhi and Kanyakumari. The estimated EWS of both Delhi and Kanyakumari obtained from GEV (using LMO) are compared with the results of IS 875 procedure for arriving at a final decision regarding selection of design wind speed for design purposes.

D. Estimation of Design Wind Speed using IS 875 Procedure

Following IS 875(Part 3) [18], Figure 3 gives the basic wind speed (m/s) based on 50-year return period for India. From Figure 3, for Delhi and Kanyakumari regions, the basic wind speed W_b is obtained; and subsequently modified to account for different effects and get design wind speed W_z (m/s) at height z (m) for the chosen class of structure. The relationship can be expressed as:

$$W_z=W_bK_1K_2K_3 \qquad \dots (3)$$

where, W_z is the design wind speed at any height z (m/s), W_b is the regional basic wind speed (m/s), K_1 is the probability factor/ risk-coefficient, K_2 is the terrain and height factor and K_3 is the topography factor. Value of K_1 for different classes and mean probable design life of structures can be computed from Eq. (4) and given by:

$$K_1 = \frac{A - B\left[\ln\left\{-\frac{1}{N}\ln(1-P_N)\right\}\right]}{A+4B} \qquad \dots (4)$$

Here, N is the mean probable design life (year) of the structure, P_N the risk level in N consecutive years, A and B appropriate coefficients for the basic wind speed zone (IS 875). The 3-sec averaged EWS ($W_{3\text{-sec}}$) can also be computed from hourly wind speed data by using the Eq. (5) and given by:

$$W_{3\text{-sec}}(\text{m/s})=1.52 \text{ x } W_{1\text{-hr}}(\text{km/hr}) \text{ x } 0.278 \qquad \dots (5)$$

For Delhi, the coefficients of A and B, corresponding to the basic wind speed of 47 m/s, are 88.0 and 20.5 respectively. Similarly, for Kanyakumari, the coefficients of A and B, corresponding to the basic wind speed of 39 m/s, are 84.0 and 14.0 respectively.

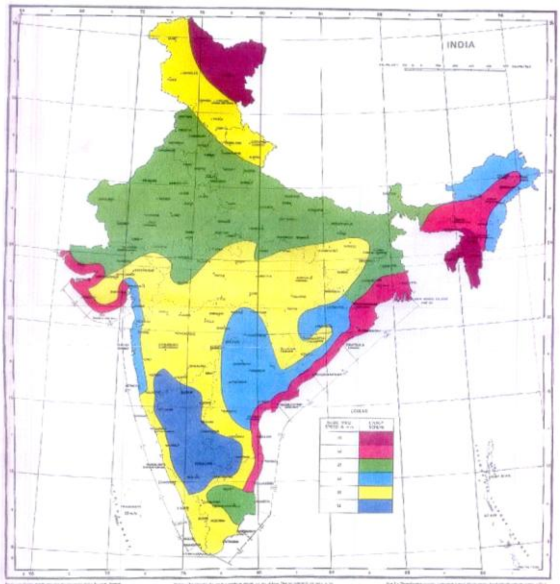

Figure 3: Basic Wind Speed (m/s) Based on 50-year Return Period (IS 875)

By using the values of W_b, K_1, K_2 and K_3, the design wind speed at a standard height of 10m was computed by using the Eqs. (3 and 4), and the results are presented in Table 7. The results of 3-sec averaged EWS obtained from GEV (using LMO) distribution for both Delhi and Kanyakumari are also presented in Table 7.

From Table 7, it may be noted that the 3-sec averaged EWSs for different return periods from 5-year to 1000-year given by IS 875 procedure are higher than the corresponding design values obtained from GEV (using LMO) distribution for both Delhi and Kanyakumari.

Table 7: Comparison of Design Wind Speed Values Given by GEV (using LMO) Distribution and IS 875 Procedure for Delhi and Kanyakumari

Return period (year)	Design wind speed							
	Delhi				Kanyakumari			
	GEV (using LMO)		IS 875 procedure		GEV (using LMO)		IS 875 procedure	
	3-sec averaged EWS (m/s)	Hourly EWS (km/hr)	3-sec averaged EWS (m/s)	Hourly EWS (km/hr)	3-sec averaged EWS (m/s)	Hourly EWS (km/hr)	3-sec averaged EWS (m/s)	Hourly EWS (km/hr)
2	28.3	66.9	27.6	65.4	16.9	39.9	26.2	62.0
5	33.9	80.2	34.5	81.8	20.1	47.5	30.7	72.7
10	36.6	86.7	39.0	92.3	22.5	53.2	34.0	80.4
20	38.6	91.4	43.4	102.8	25.1	59.4	36.9	87.2
50	40.6	96.0	48.9	115.6	28.7	68.0	40.5	95.9
100	41.7	98.6	52.8	125.0	31.9	75.5	43.4	102.7
200	42.6	100.7	57.2	135.5	35.3	83.5	46.3	109.5
500	43.5	102.9	62.7	148.3	40.3	95.3	50.0	118.2
1000	43.9	104.0	66.6	157.7	44.4	105.0	52.8	125.0

V. CONCLUSIONS

The paper presents briefly the study carried out for EVA of wind speed for Delhi and Kanyakumari by adopting two different approaches i.e., one is based on PDs and other one is based IS 875 procedure. In the first approach, the parameters of five PDs viz., EXP, EV1, EV2, GEV and GP were determined by MoM, MLM and LMO, and used for estimation of EWS. In the second approach, the IS 875 procedure was adopted for estimation of 3-sec averaged EWS. The intercomparison of the results was performed and the following conclusions were drawn from the study:

i) For the return period of 10-year and above, it was found that the estimated EWS by EV2 (using MLM) is comparatively higher than the corresponding values of other PDs (or methods) for Delhi.

ii) For Kanyakumari, it was found that the estimated EWS by GP (using MLM) is higher than the values of other PDs (or methods) for the return period from 10-year to 1000-year.

iii) Qualitative assessment through plots indicated that the fitted lines of the estimated EWS by EV2 (using MLM) for Delhi and GP (using MLM) for Kanyakumari are in the form of exponential curve.

iv) The KS test results confirmed the applicability of EXP, EV1, EV2, GEV and GP distributions (using MoM, MLM and LMO) for EVA of wind speed for Delhi.

v) The KS test results didn't confirm the suitability of GP (using MoM, MLM and LMO) distribution for EVA of wind speed for Kanyakumari.

vi) For Delhi, the percentages of variation on the estimated 3-sec averaged EWS obtained from GEV (using LMO) and IS 875 procedure, with reference to 50-year return period basic design wind speed of 47 m/s, are computed as about 14 % and 4 % respectively.

vii) For Kanyakumari, the percentages of variation on the estimated 3-sec averaged EWS obtained from GEV (using LMO) and IS 875 procedure, with reference to 50-year return period basic design wind speed of 39 m/s, are computed as about 26 % and 4 % respectively.

viii) On the basis of quantitative assessment using GoF and diagnostic tests and qualitative assessment using fitted curves, the study suggested that the 1000-year return period EWS values i.e., 104 km/hr for Delhi and 105 km/hr for Kanyakumari obtained from GEV (using LMO) distribution could be used as a design value while designing of hydraulic structures having a design life of 1000-year.

ix) In absence of hourly wind speed data, the study suggested that the 1000-year return period 3-sec averaged EWS i.e., 66.6 m/s for Delhi and 52.8 m/s for Kanyakumari obtained from IS 875 procedure could be used as design value for designing of hydraulic structures having a design life of 1000-year. However, it is suggested that by considering the design life of the proposed structure, the stakeholders may adopt the appropriate estimated EWS values for design purposes.

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