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Graphical and Parametrical Analysis of Wind Speed for Gondar City, Amhara Region, Ethiopia

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Abstract— The Gondar city is an anciently established and immerged government in Ethiopia, and this city also has tourist attractions. Currently, the city is increasing through the construction of high-rise buildings. As per the Ethiopian code, there is no specified basic reference wind speed in a Gondar city, so that it needs to develop basic wind speed by comparing parametrical and analytical techniques from wind engineering perspective view. For high-rise building constructions, the analysis of basic wind speed is the priority to design of the wind load. If not, the building may face serious wind load effects in the Gondar city due to geometrical conditions. This research paper focused on the forecast of the basic wind speed of Gondar city by comparing the parametrical and analytical techniques. Extreme Value Analysis is an imperative statistical discipline for basic research. It is appropriate; because it gives the path for evaluating technique models that forecast phenomena at highly with fewer likelihoods. The highest yearly basic wind speed for Gondar City has processed to analyze the extreme value. The highest basic wind speed data in a year denoted in the form of distribution type (EVI). Gumbel distribution via graphical and analytical techniques used for computing the gradient of the regression line and the intercept of the graph. There are different analytical methods; for instance, the moment method and L-moment methods used to calculate the gradient of the regression line and the intercept of the graph—the probable values of the highest basic wind speed calculated at the values of the different recurrence intervals. To forecast the highest basic wind speed, the computed values of the gradient of the regression line, and the intercept of the graph of different approaches used to select the proper technique. Based on the lowest values of the normalized root mean square error, the graphical method is the best proper technique for evaluating the gradient of the regression line and the intercept of the graph. The outcomes indicated that the probable highest basic wind speeds at 5, 10, 15, 20, 25, 30, 50, 100, 200, 500 and 1000 years are 23, 28, 31, 33, 34, 36, 39, 43, 47, 53 and 57 m/sec, respectively. The meanings of the result, for instance, at 50 year return period, the probability of highest basic wind speed may greater than 39m/sec is 2% and equal or less than is 98%.

Index Terms— Analytical Method, Graphical Method, L- Moment Method, Moment Method, Type I distribution, Return Period.

1 INTRODUCTION

High wind speed causes the structure collapsed, especially those at exposed sites—the extreme value analysis used for accurate assessment of the magnitude and frequency of excessive wind speed. The strict value analysis approach has used to forecast extreme wind speed, which expected to affect the area of Gondar under different exceedance probabilities or return periods. "The criticality of the structure to be protected from the effects of extreme wind speed determines the return period for which the extreme wind determined to protect the structure against" [1,2]. Gumbel introduced the Gumbel distribution function, which is known as the extreme value distribution (EV1) [3]. The purpose of this distribution is for modeling the absolute values (maximum or minimum) and also used for frequency analysis. Gumbel distribution is for the study of extreme meteorological values, extreme hydrologic values, flood discharges, intensities of maximum rainfall, the flow of peak discharges, and forecasting the maximum extremely conservative range for the design safety concern [3, 12]. As indicated by Flesch and Wilson and others, the Gumbel distribution is the most suitable probabilistic model for extreme gust wind speed [4]. In this work, the highest yearly wind speed information was gathered and examined for Gondar city. This study devoted to the town of Gondar explores the most top annual wind speed. The estimation strategies divided into two, such as graphical and analytical techniques. Moment Method (MM) and L- Moment Method (LMM) falls under analytical methods. The forecasted values of maximum wind speed computed for different values of the return period(P); A recurrence period (return period) is the mean long-term interval between continuous exceedance of the events [5]. The Normalized Root Mean Square Error (NRMSE) is the prime technique applied for estimating the EVI parameter. "The theoretical return period is the inverse of the probability that the event exceeded in any one year" [6,11]. The Normalized Root Mean Square Error (NRMSE) procedure is applied to choose a proper technique for evaluating the EVI distribution parameters. The author focused on the estimation of EVI parameters such as scale parameters (slope, ß) and location parameter (area parameter, α) for the data acquired on the Ethiopian National Meteorological Agency from 1994 to 2014 [13].

2. DESCRIPTION OF THE STUDY AREA

The study area located in the Amhara regional state of North Gondar, North Ethiopia, and roughly about 738 Km away from capital city Addis Ababa and located explicitly, as shown in Fig. (1). The collected wind speed data was 10min hourly.

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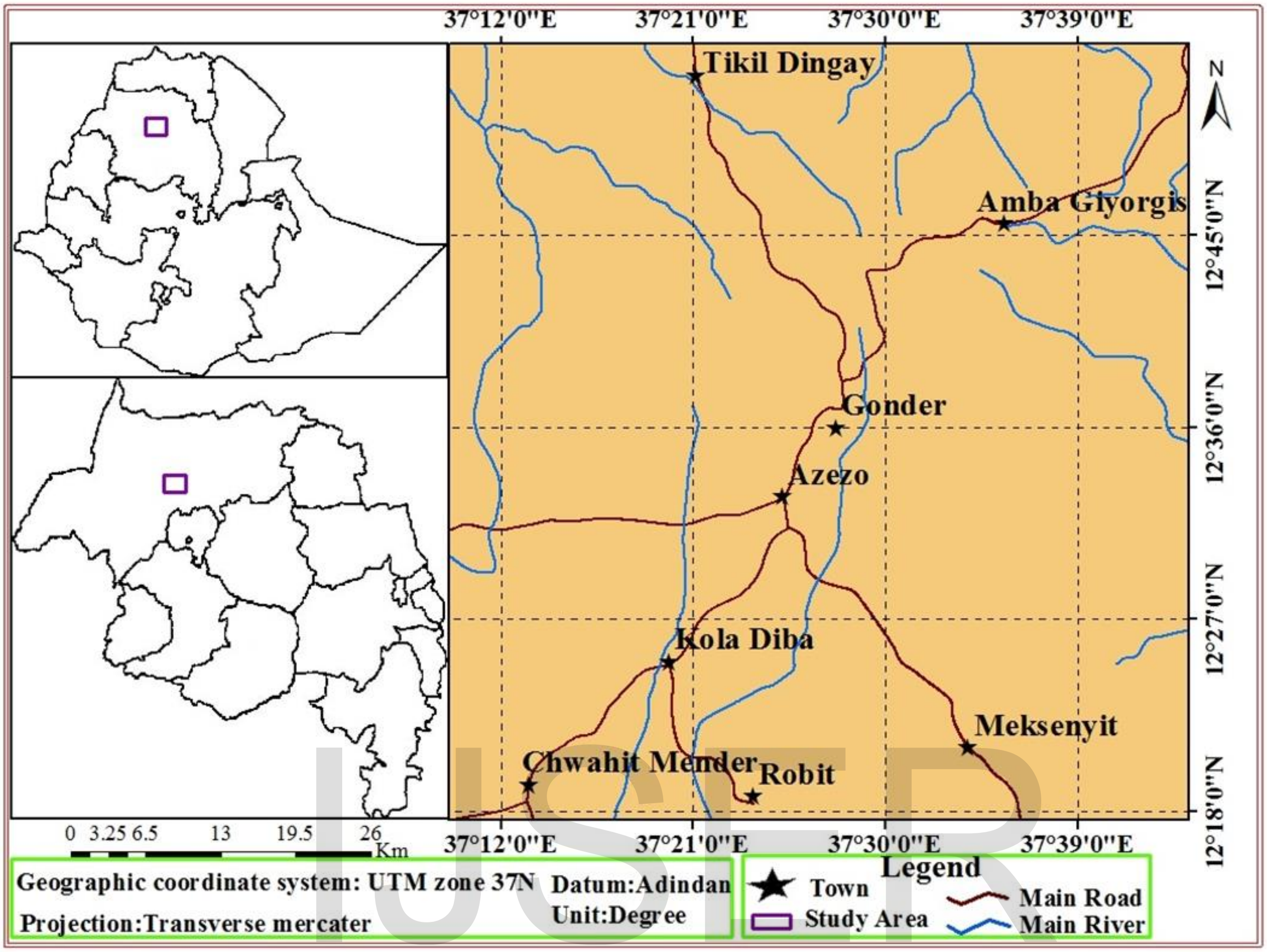

Fig. (1): Study Area

3. METHODS

3.1 Graphical Methods

The graphical approach in a simple least square regression analysis applied, the ranked wind speed, and the Gumbel reduce variate considered as the dependent and independent variables, respectively. For the sake of simplicity and speediness, most of the time graphical method is more appropriate. However, this method gives a substantial probability error [7]. The type 'EVI' distribution, Cumulative Distribution Function (CDF) is provided by [8,9,11]:

$$F(w) = \exp\left[-exp\left(-\frac{w-\alpha}{\beta}\right)\right] \quad (1)$$

Where: 'β' is the scale parameter,' α' is the location parameter, and 'w' is the rate of highest yearly wind speed. Applying twice the natural logarithm equation (1) gives:

$$-\ln\left(-\ln(F(w))\right) = \frac{w-\alpha}{\beta} \quad (2)$$

$$Fi = \frac{m}{N+1} \quad (3)$$

Where: 'N' is the number of highest yearly wind speed, 'm' is the series in increasing order, and 'Fi' is the probability of non-exceedance.

Change 'Fi' into Gumbel reduce variate, which can be defined by [11]:

$$yi = -\ln\left(-(\ln(Fi))\right)$$

Plot W_i versus Y_i and draw continuous lines to connect the points. The next equations will yield:

$$w = \alpha + \beta * y \quad (4)$$

Or

$$w = \alpha + \beta[-\ln(-ln(Fi)] \quad (5)$$

The recurrence interval 'P' is a statistical perception to estimate the probability of an event. It is an average every 'P' time in which the basic wind speed exceeded. The likelihood that 'w_i' exceeded is $E_i = 1-F_i$. The recurrence interval 'P' defined by the inverse of E_i [11]. Therefore;

$$P = 1/(1-Fi) \quad (6)$$

Then;

$$Fi = 1 - \frac{1}{P} \quad (7)$$

The parameters of Gumbel distribution and the highest wind speed of any stated recurrence interval evaluated from equations (5) and (7). The expected possible model is [11]:

$$WME = \alpha + \beta[-ln(-ln(1-1/P))] \quad (8)$$

3.2 Analytical Methods

Due to the sensitivity of error in using the graphical method, checking the analytical method also is preferred. In estimating type EVI parameters, some of the analytical approaches discussed.

3.2.1 Moment Method (MM)

It is an estimation parameter technique regarding coordinating the sample moments with relating distribution moments. This method is the most widely and oldest method in observed data in frequency distribution fitting. Since the representative data $w_1, w_2, w_3, \ldots, w_n$ is an arbitrary sample from a distribution $F(w_i)$.

Where: α and ß are unfamiliar values; Those parameter values α and ß can be found using the moment estimators [8,11].

The moment method estimators for the EVI distribution can be found from the next equations [11]:

$$\beta = (\sigma * \sqrt{6})/(Pi) \quad (9)$$

$$\alpha = \overline{w} - g*b \quad (10)$$

Where: $\overline{w}$ is the mean yearly maximum wind speed, σ is the standard deviation, and g≅0.577216 is Euler's constant.

3.2.2 L-Moment Method (LMM)

It is less sensitive and very robust to outliers of the database for lesser samples; The ranked observations are usually linear combinations of the sample estimators of LMOM. Sample estimators of LMOM are subject to less bias than a method of moments [3,13]. For the Gumbel type(I) distribution the LMM estimators are given by:

$$\beta = L2/\log e2 \quad (11)$$

$$\alpha = Xo - g\beta \quad (12)$$

$$A = 2X1 - Xo \quad (13)$$

Where:

$$X1 = \frac{1}{n}\sum_{m}^{n}\frac{m-1}{n-1}; \quad Xo = \frac{1}{n}\sum_{m=1}^{n}Wm$$

$g \cong 0.577216$ *is Euler's constant;* n *is a sample size*

4 RESULTS AND DISCUSSION

4.1 Analysis of Extreme Value

In the field of engineering, extreme value theory has several advantages and well-established applications. Evaluating excessive wind speed provides the construction standard author and the building designer have useful information on the severe winds that may affect the structure through its lifetime [12]. The annual extremes (maximum or minimum) modeled; It is the only required for analyzing the extreme value.

The highest yearly wind speed of Gondar city from the year 1994 to 2014 obtained from the National Meteorological Agency of Ethiopia [13]. The maximum values of annual wind speeds documented in Gondar shown in Figure (2).

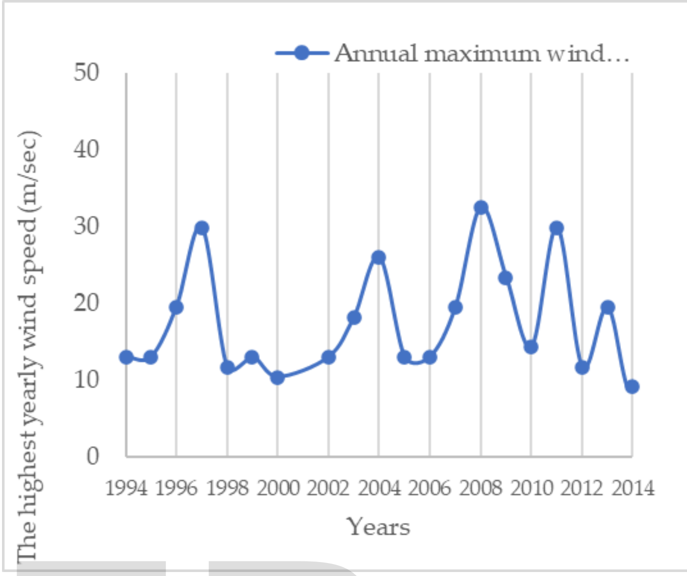

Fig. (2): The highest yearly wind speed in Gondar City, m/sec

Figure (2) indicates that yearly maximum wind speed is fluctuating between increasing and decreasing values from 1998 to 2001. The wind speed reached a maximum value of 32.5 m/sec in the year 2008. The minimum amount recorded at 9.1 m/sec in the year 2014. The bell-shape of yearly maximum wind speed between years 1995&1998, 2002&2005, 2006& 2009, 2010&2012 and 2012&2014 represented by Gaussian distribution. The fluctuations of maximum wind speed appear every two years successively.

4.2 Curve Fitting Methods for Graphical Analysis

The yearly extreme wind speed placed by increasing order to compute the likelihood of exceedance Ei, return period (Pi) and cumulative likelihood Fi for each essential wind speed happening.

Gumbel reduces variates that determined by using the highest yearly critical wind speed in equation (2). In the table (1) below, the results have shown clearly.

Table (1): Gumbel Reduce Variates, Return Recurrence Interval, and Series Wind Speeds for all Highest Yearly Wind Speed for Gondar City from 1994-2014.

Wind speed (m/s)	Rank	Non-exceedance (F_i)	Exceedance (E_i)	Return period (P_i)	Gumbel reduce variate
9.1	1	0.04545	0.95455	1.04762	-1.1
10.4	2	0.09091	0.90909	1.10000	-0.9
11.7	3	0.13636	0.86364	1.15789	-0.7
11.7	4	0.18182	0.81818	1.22222	-0.5
13	5	0.22727	0.77273	1.29412	-0.4
13	6	0.27273	0.72727	1.37500	-0.3
13	7	0.31818	0.68182	1.46667	-0.1
13	8	0.36364	0.63636	1.57143	0.0
13	9	0.40909	0.59091	1.69231	0.1
13	10	0.45455	0.54545	1.83333	0.2
14.3	11	0.50000	0.50000	2.00000	0.4
18.2	12	0.54545	0.45455	2.20000	0.5
19.5	13	0.59091	0.40909	2.44444	0.6
19.5	14	0.63636	0.36364	2.75000	0.8
19.5	15	0.68182	0.31818	3.14286	1.0
19.5	16	0.72727	0.27273	3.66667	1.1
23.4	17	0.77273	0.22727	4.40000	1.4
26	18	0.81818	0.18182	5.50000	1.6
29.9	19	0.86364	0.13636	7.33333	1.9
29.9	20	0.90909	0.09091	11.0000	2.4
32.5	21	0.95455	0.04545	22.0000	3.1

Least square regression analysis is a mathematical regression which is considered the series wind speed as the dependent variable, and Gumbel reduced variates as the independent variable [3]. These regression analysis results are indicated graphically in figure (2). Where: the gradient of the regression line (β = 6.1493) and the intercept of the graph (α = 14.513). The independent of Gumbel reduced variate, and the dependent of the highest yearly wind speed has processed for the derivation of the equation and manipulation of the coefficient of determination, as shown in Fig. (3)

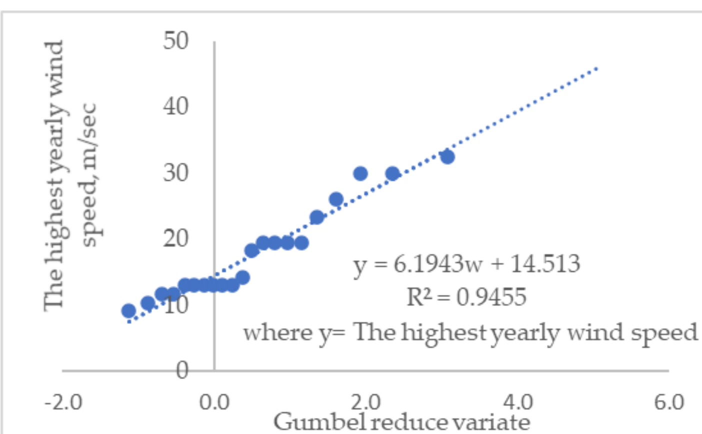

Fig. (3): Gumbel reduce variate against highest yearly essential wind speed

4.3 Comparing, Analytic Evaluation, and Graphical Techniques

Two analytical estimation techniques and graphical techniques compared for estimating the reference critical wind speed for Gondar city. These analytic strategies are MM and LMM. The MM and LMM approaches computed with equations 9-12, respectively. Forecasting equation parameter values for each method, such as the Graphical Method, Moment Method (MM), and L-Moment Method (LMM) and the gradient regression line and the intercept of the graph of all studied techniques indicated in the table (2).

Table (2): The gradient of the regression line and the intercept of the chart using different evaluation techniques

Parameters	Graphical Method	Moment Method (MM)	L-Moment Method (LMM)
α	14.513	14.70075073	17.18945067
β	6.1943	5.311557431	4.461532735

With different values of the recurrence interval, the probable of the highest essential wind speed computed in equation (8). For any stated recurrence interval, the likelihood of the most top critical wind speed indicated in the table (3).

Table (3): Probable values of highest necessary wind speed at d/t values of recurrence interval using d/t estimation approaches.

P	Fi= 1-1/p	-ln (-ln (Fi))	Wind speed (Graphical)	Wind speed (MM)	Wind speed (LMM)
5	0.800	1.500	23.804	22.668	23.881
10	0.900	2.250	28.452	26.654	27.230
15	0.933	2.669	31.043	28.875	29.095
20	0.950	2.970	32.911	30.477	30.441
25	0.960	3.199	34.326	31.690	31.460
30	0.967	3.395	35.540	32.731	32.334
50	0.980	3.902	38.683	35.426	34.598
100	0.990	4.600	43.008	39.135	37.713
200	0.995	5.296	47.317	42.830	40.817
500	0.998	6.214	53.002	47.705	44.912
1000	0.999	6.907	57.299	51.389	48.006

Where: The recurrence interval (arrival time frame) is to be in years, and the highest necessary wind speed is in m/sec. The probable highest essential wind speed and estimate the arrival time frame simplified via drawing. Likewise, at different values of the most top critical wind speed, the recurrence interval for the highest first wind could be estimated by substituting equation (1) in equation (6). Table (4) displays estimate values of the recurrence interval for any stated highest necessary wind speed.

Table (4): The forecasted values of recurrence interval at d/t values of the highest essential wind speed using d/t estimation approaches

W_i (Extreme Wind Speed)	P (Graphical Method)	P (Moment Method (MM))	P (L-Moment Method (LMM))
9.10	1.10	1.06	1.00
10.40	1.17	1.12	1.01
11.70	1.26	1.21	1.03
11.70	1.26	1.21	1.03
13.00	1.39	1.34	1.08
13.00	1.39	1.34	1.08
13.00	1.39	1.34	1.08
13.00	1.39	1.34	1.08
13.00	1.39	1.34	1.08
13.00	1.39	1.34	1.08
14.30	1.55	1.52	1.17
18.20	2.36	2.48	1.82
19.50	2.77	3.00	2.23
19.50	2.77	3.00	2.23
19.50	2.77	3.00	2.23
19.50	2.77	3.00	2.23
23.40	4.72	5.66	4.54
26.00	6.90	8.90	7.72
29.90	12.50	17.99	17.77
29.90	12.50	17.99	17.77
32.50	18.75	29.04	31.43

The values of probable highest essential wind speed versus recurrence interval and the importance of the recurrence interval versus the most top critical wind speed indicated in Fig. (4) and (5), respectively. At different estimation methods such as graphical method, moment method, and L-moment methods, the coefficient of determination is constant in the case of return period is independent, and probable highest basic wind speed is dependent indicated in Fig. (4) as shown below, and the coefficient of determination is varying where the return period is dependent on the highest basic wind speed indicated in Fig. (5) shown below.

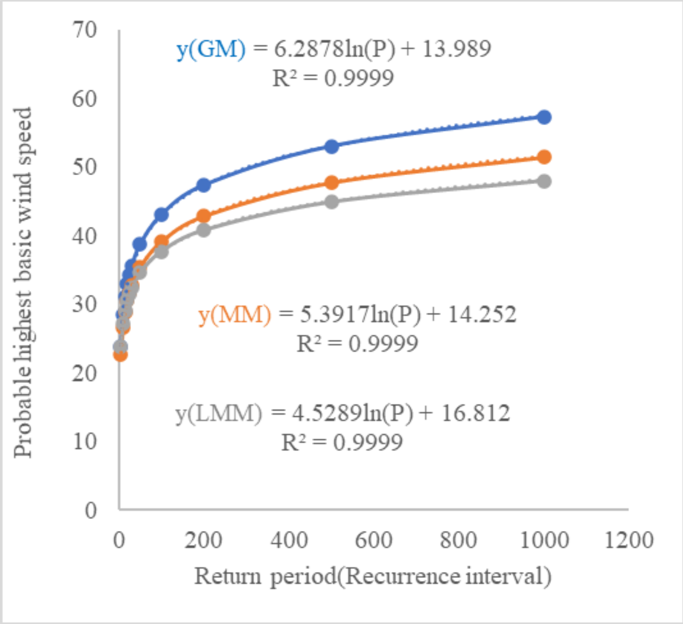

Fig. (4): Probable highest essential wind speed on the recurrence interval of different estimation approaches

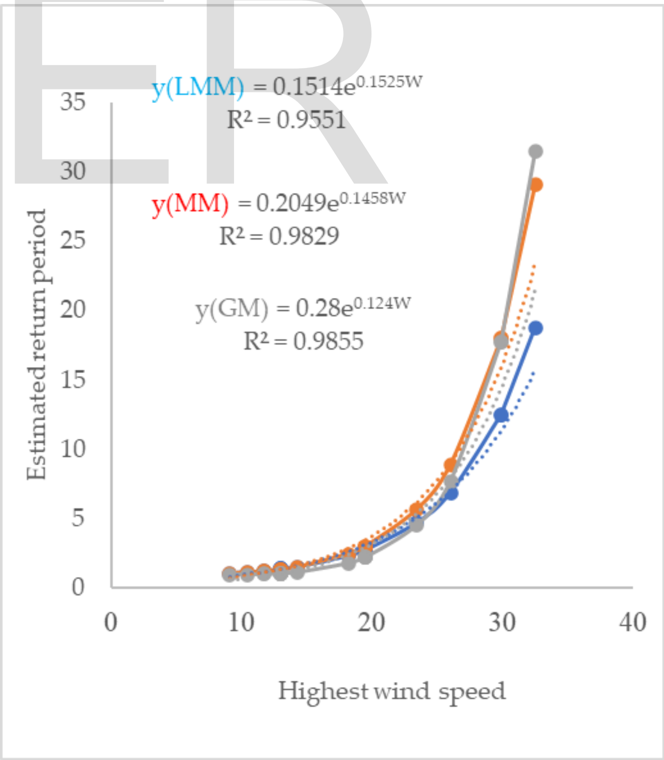

Fig. (5): The probable recurrence interval on the highest essential wind speed of different estimation approaches

Figure (3) shows the conditions relating to the Expected Extreme Wind Speed to different periods at various estimation techniques with a correlation constant of $R^2 = 0.9999$, and the final equations forecasting the highest necessary wind speeds are as per the following:

$$y(Graphical\ Method) = 6.2878\ln(P) + 13.989;\quad R^2 = 0.9999$$

$$y(Moment\ Method) = 5.3917\ln(P) + 14.252;\ R^2 = 0.9999$$

$$y(LMoment\ Method) = 4.5289\ln(P) + 16.812;\ R^2 = 0.9999$$

Figure (4) indicates that the equations express the different recurrence interval to the highest basic wind speed at various estimation methods with correlation constant (R^2) ranging from 0.9551 to 0.9855, and the simplified equations for estimate different recurrence intervals are as follows:

$$y(LMoment\ Method) = 0.1514e^{0.1525w};\ R^2 = 0.951$$

$$y(Moment\ Method) = 0.2049e^{0.1458w};\ R^2 = 0.9829$$

$$y(Graphical\ Method) = 0.28e^{0.124w};\ R^2 = 0.9855$$

Where: w is the Highest Basic Wind Speed (HBWS).
It distinguished from Fig. (3 & 4) that the coefficient of correlation for logarithmic and exponential functions are ranging from 0.951 to 0.98529 and 0.9999, respectively. The two analytical and graphical methods made to compare to select the best appropriate technique for probable highest basic wind speed based on Normalized Root Mean Square Error [14]. The method which has the lowest value of the NRMSE is the best estimator technique to forecast it [10, 11, 14].

NRMSE = {sqrt(sum(Oi-Pi)^2)/n}/(Omax-Omin) (14)

Where: Oi is the observed sample or population value; Pi is the predicted value; NRMSE is the Normalized Root Mean Square Error

and $Pi = \alpha + \beta w$;

$for\ graphical\ Pi = 14.513 + 6.194w$;

$for\ MM\ Pi = 14.7 + 5.32w$;

$for\ LMM\ Pi = 17.189 + 4.462w$

Table (5): Different estimation approaches based on Mean Square Deviation (Mean Square Error)

Estimation Method	Graphical Method	L-Moment Method (LMM)	Moment Method (MM)
NRMSE	0.068605589	0.079483026	0.128602831

The Normalized Root Mean Square Error of Graphical, LMM, and MM are 6.86%, 7.948%, and 12.86%, respectively. Since the graphical method has the lowest NRMSE value (6.86%). From here, the gradient of the regression line β= 6.1943 and the intercept of the graph α= 14.513 are the best estimators for probable highest essential wind speed. The result of the cumulative distribution function of graphical and moment method shows overlying values that support both methods are imperative for the prediction of the highest basic wind speed and the correlation of different Cumulative Distribution Functions of varying estimation strategies indicated in Fig. (6)

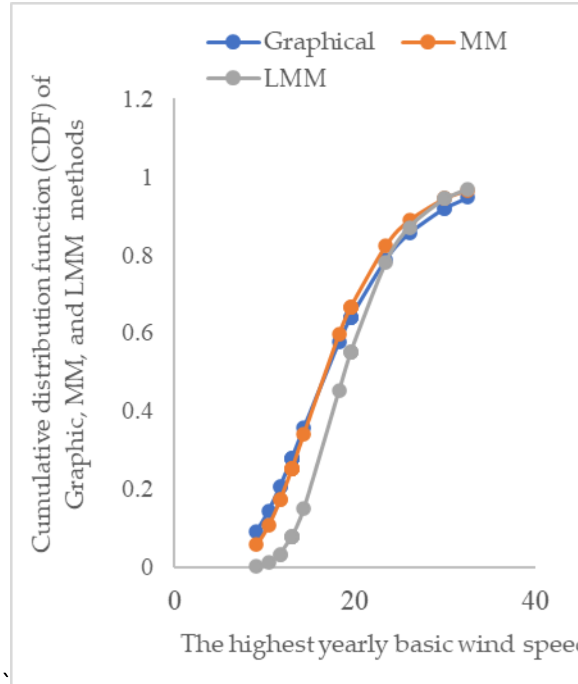

Fig. (6): The relation between the cumulative distribution function of different approaches and the highest yearly basic wind speed.

5 CONCLUSIONS

The outcome of computing extreme basic reference wind speed is an input for the building designer and code writer with information on the extreme winds at the design stage. The Gumbel extreme value distribution type (EVI) used to model the basic wind speed data for Gondar station. The highest yearly basic wind speed data has processed for extreme value analysis. Gumbel reduced variate with simple least square regression is implemented to estimate the intercept of the graph and the gradient of the regression line of graphical method type (EVI) distribution. Two analytical methods (MM and LMM) and their intercept of the graph and the gradient of the regression line of Type (EVI) distribution are estimated. The gradient of the regression line (β) and intercept of the graph (α) parameters found depending on the type of critical method used in their design. At different values of the recurrence interval (P), the probable values of the highest basic wind speed computed using analytical and graphical approaches. At different values of the highest basic wind speed, the values of the recurrence interval (P) calculated. The estimation of the recurrence interval (P) and the technique for the prediction of the highest wind speed disclosed graphically. The probable highest basic wind speed on the recurrence interval (P)at different estimation approaches originated to follow the logarithmic function. For approximating the type (EVI) distribution parameters, The Normalized Root Mean Square Error (NRMSE) scheme devoted to select the proper technique. According to the lowermost value of the Normalized Root Mean Square Error, computational results have shown that the graphical method best followed by the moment's method. The best approaches to forecast the highest basic wind speed and calculation of the recurrence interval are graphical and MM methods. The probable highest basic wind speeds at 5, 10, 15, 20, 25, 30, 50, 100, 200, 500 and 1000 years are 23, 28, 31, 33, 34, 36, 39, 43, 47, 53 and 57 m/sec, respectively.

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