Weibull Distribution Function for Wind Energy Estimation of Gharo (Sindh)

Muhammad Shoaib[1,*], Imran Siddiqui[2], Firoz Ahmed[2], Saif ur Rehman[1], Muhammad Rashid Tanveer[1] and Saif Uddin Jilani[2]

[1]*Department of Physics, Federal Urdu University of Arts, Sciences and Technology, Block 9 Gulshan-e-Iqbal, Karachi – 75300, Pakistan*

[2]*Department of Physics, University of Karachi, Main University Road, Karachi – 75270, Pakistan*

Abstract: Weibull distribution function is fitted to a measured wind speed data set at mast height of 30 m and Gharo-Sindh (Pakistan) is selected as a case site under study. Wind speed data recorded in one minute interval for the year 2004 is used to estimate Weibull parameters (*k* and *c*). Weibull parameters are calculated using Modified Maximum Likelihood Method (MMLM), Maximum likelihood Method (MLM) and Method of Moment (MoM) and the results obtained are compared. Kolomogorov-Smirnov test, Root Mean Square Error (RMSE) and R^2 tests are performed to test the goodness-of-fit of the Weibull distribution function. The analysis is based on recorded monthly and yearly wind speed data. Goodness-of-fit tests indicate a better performance of MMLM and MLM as compared to MoM. Wind power density is estimated for the site under study using MMLM and Weibull function estimator. A lowest Weibull mean wind speed of 3.73 m/s in the month of October and highest value of 7.90 m/s for August are observed and correspondingly power densities of 80.95 W/m^2 and 425.87 W/m^2 are obtained. Descriptive statistics for the measured wind speed data is also evaluated.

Keywords: Weibull function, Shape and Scale Parameters, Gharo-Sindh Pakistan, FUUAST.

1. INTRODUCTION

The use of conventional energy resources such as coal, oil and natural gas for energy production has two-fold impact. The ever increasing energy demand for industrial and economic growth has resulted in the rapid depletion of conventional energy resources and adverse effects on the environment [1,2]. In the absence of proper energy policy, the under developed countries are most affected. As a result the interest in renewable energy resources for energy production has increased considerably. Wind is not only plentiful but is also environmentally friendly and furthermore the cost of clean energy production is less as compared to conventional energy resources.

Higher wind velocities and higher acceptable power densities in various parts of Pakistan such as coastal areas of Sindh and Balochistan, desert areas of Punjab and some Northern areas, present amicable opportunity to setup wind farms. Pakistan Meteorological Department (PMD) and Alternate Energy Development Board (AEDB) conducted a number of studies [3-7] to assess wind energy potential for these areas.

In order to have a reliable assessment of wind power density for a specific region, an extensive investigation of recorded wind speed data and relevant weather parameters are required. A number of research groups [8-29] are involved in the assessment of wind power density for various parts of the world. This would then lead to a better practical understanding in those regions for setting up of wind farms and installation of wind machines for energy production.

2. THEORY

Wind power density for a specific site is calculated by first fitting a theoretical distribution function to the recorded wind speed data points. In order to model the recorded wind speed data, a two parameter Weibull function is commonly used. The two parameters are termed as shape (*k*) and scale (*c*) parameters [25]. Weibull probability density function *f(v)* and cumulative distribution function *F(v)* are expressed as:

$$f(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} \exp\left[-\left(\frac{v}{c}\right)^{k}\right] \quad (1)$$

$$F(v) = 1 - \exp\left[-\left(\frac{v}{c}\right)^{k}\right] \quad (2)$$

where *v* is the wind speed, *k* is a dimensionless parameter and *c* has the dimensions of speed. Equations 3 and 4 determine wind power density, P_v and wind energy density, E_d, using recorded wind speeds, whereas equations 5 and 6 determine Weibull

*Address correspondence to this author at the Department of Physics, Federal Urdu University of Arts, Sciences and Technology, Block 9 Gulshan-e-Iqbal, Karachi – 75300, Pakistan; Tel: (0092-91)99244141-9;
Fax: (0092)021-99244272; E-mail: profmshoaib@fuuast.edu.pk

PACS: 88.50.-k; 88.50.gg.

ISSN: 1814-8085 / E-ISSN: 1927-5129/15

mean wind speed V_m and Weibull energy density E_W, [26-29].

$$P_v = \frac{1}{2}\rho_a v^3 \quad (3)$$

$$E_d = \frac{1}{2}\rho \overline{v^3} \quad (4)$$

$$V_m = c\Gamma\left(1+\frac{1}{k}\right) \quad (5)$$

$$E_W = \frac{\rho_a c}{2}\Gamma\left(1+\frac{3}{k}\right) \quad (6)$$

where $\Gamma()$ is a gamma function given by

$$\Gamma(x) = \int_0^\infty t^{x-1}\exp(-t)dt \quad (7)$$

where ρ_a denotes air density (1.225 kg/m^3). Weibull parameters are estimated by the methods given in the following section.

3. WEIBULL PARAMETERS ESTIMATION METHODS

In this submission Weibull parameters are estimated by using Modified Maximum Likelihood Method (MMLM) (equations 8 and 9), Maximum Likelihood Method (MLM) (equations 10 and 11) and Method of Momemt (MoM) (equations 12-15).

$$k = \left(\frac{\sum_{i=1}^{n} v_i^k \ln(v_i) f(v_i)}{\sum_{i=1}^{n} v_i^k f(v_i)} - \frac{\sum_{i=1}^{n} \ln(v_i) f(v_i)}{f(v \geq 0)}\right)^{-1} \quad (8)$$

$$c = \left(\frac{1}{f(v \geq 0)}\sum_{i=1}^{n} v_i^k f(v_i)\right)^{1/k} \quad (9)$$

$$k = \left(\frac{\sum_{i=1}^{n} v_i^k \ln(v_i)}{\sum_{i=1}^{n} v_i^k} - \frac{\sum_{i=1}^{n} \ln(v_i)}{n}\right)^{-1} \quad (10)$$

$$c = \left(\frac{1}{n}\sum_{i=1}^{n} v_i^k\right)^{1/k} \quad (11)$$

$$V_m = c\Gamma(1+1/k) \quad (12)$$

$$\sigma_m = c\left[\Gamma(1+1/k) - \Gamma^2(1+1/k)\right]^{1/2} \quad (13)$$

where V_m and σ_m are estimated Weibull mean velocity and standard deviation based on Weibull parameters and for measured wind speed data are calculated using the following equations, i.e.,

$$V_m = \bar{v} = \frac{1}{n}\sum_{i=1}^{n} v_i \quad (14)$$

$$\sigma_m = \sigma = \left[\frac{1}{n-1}\sum_{i=1}^{n}(v_i - \bar{v})^2\right]^{1/2} \quad (15)$$

where v_i is the wind speed in the ith bin and n the number of data points ($v > 0$). $f(v_i)$ is the frequency of wind speeds lying in the ith bin, and $f(v \geq 0)$ is the wind speed_probability for values equal to or greater than zero. $\bar{v}$ and σ are the mean wind speed and standard deviation from mean for measured wind speed data.

4. RANDOM GENERATION OF WIND SPEED POINTS

Random generation of wind speed data points is performed by using a cumulative distribution function having a continuous random variable, R_n, lying uniformly in the range (0,1). Wind speed v is generated by using equation 16 with specific shape (k) and scale (c) parameters.

$$v = c\left[ln\left(\frac{1}{1-R_n}\right)\right]^{1/k} \quad (16)$$

5. GOODNESS-OF-FIT TESTS

The agreement between theoretical probability distribution function and the recorded wind speed data distribution is tested by using the Kolmogorov–Smirnov test, Root Mean Square Error (RMSE) and coefficient of determination (R^2). The Kolmogorov–Smirnov test statistics Q is evaluated using equation 17 and is a maximum error estimate between two cumulative functions.

$$Q = \max[F(v) - G(v)] \quad (17)$$

where F(v) is the cumulative distribution function evaluated using specified Weibull parameters and G(v) is a cumulative distribution evaluated by using either observed wind speed data or by generated wind speed data. The critical value Kolmogorov–Smirnov test for identical sample sizes at 95 % Confidence level is determined by

$$Q_{95} = \frac{1.36}{\sqrt{n}} \tag{18}$$

A Q value greater than the critical value, Q_{95}, implies that there is a disagreement between the fitted model and the recorded time series data under a given confidence level.

RMSE is a measure of the residuals of predicted values from the model and the values actually observed. A lower RMSE value means a good fit. RMSE test is given by

$$RMSE = \left[\frac{1}{n} \sum_{i=1}^{n} \left(y_i - x_i \right)^2 \right]^{1/2} \tag{19}$$

R^2 is the square of correlation between the predicted values and the actual observed values. R^2 value is between 0 and 1 and a value closer to 1 indicates a good fit. R^2 test is given by

$$R^2 = \frac{\sum_{i=1}^{n} \left(y_i - z_i \right)^2 - \sum_{i=1}^{n} \left(y_i - x_i \right)^2}{\sum_{i=1}^{n} \left(y_i - z_i \right)^2} \tag{20}$$

n is the total number of observations, y_i and x_i are the observed and Weibull frequencies whereas z_i is the wind speed mean.

6. RESULTS AND DISCUSSION

Gharo is located near the coast of Arabian sea in the district Thatta Sindh Pakistan. Gharo surface profile is generally mud flat with no prominent structures and due to this has a strong unobstructed wind. Gharo is located at about 30 Km from Bhanmbore city on the coastal highway (latitude 24° 44.22′ N and longitude 67° 35.52′ E). Wind speed data for Gharo was obtained from AEDB-PMD, Government of Pakistan. The data set consists of 527040 data points recorded in one minute interval at a mast height of 30 m for the period January 2004 to December 2004.

Analysis is performed in the following manner: One minute raw wind speed data is first processed by calculating hourly averages and then segregated into two groups, a monthly and yearly groups of data points. Monthly wind speed processed data is analysed and monthly descriptive statistics of 12 months is given in Table **1**. The table lists number of analysed data points, mean wind speed, wind speed range, standard deviation, kurtosis, skewness, power density, coefficient of variation and confidence level for each month. In the months from March to September wind speeds are lying between 5 m/s to 8 m/s and consequently higher wind power densities are expected in these months.

Weibull shape (k) and scale (c) parameters are estimated using three estimation methods (MMLM, MLM, MoM). Weibull functions are evaluated for monthly processed and generated wind speed data using estimated shape and scale parameters. In the study generated wind speed data points are same as the monthly recorded number of data points. Weibull wind characteristics are presented in Tables **2-4** for the three methods of estimation of Weibull parameters. In these tables column 2 lists the number of data points,

Table 1: Descriptive Statistics for Gharo-Sindh for Processed Wind Speed Data

Period	# Data Points	Mean V (m/s)	Range (m/s)	σ (m/s)	K	S	PD (W/m^2)	CV %	C.L. (95.0%)
Jan	645	4.4617	13.9153	2.5336	2.0376	1.3778	54.3994	56.7864	0.1959
Feb	653	4.7769	11.4313	2.2025	0.8830	0.9922	66.7632	46.1086	0.1692
Mar	695	5.2765	12.5689	2.2174	2.5592	1.4575	89.9801	42.0240	0.1651
Apr	715	6.5192	13.3650	2.4415	0.1907	0.5407	169.7021	37.4513	0.1793
May	721	7.5965	12.6365	2.7269	-0.5036	-0.3939	268.5059	35.8964	0.1994
Jun	698	7.4899	14.6296	3.4077	-0.7805	0.2107	257.3585	45.4972	0.2532
Jul	736	7.3950	11.7931	2.3879	-0.5332	-0.2561	247.6920	32.2910	0.1728
Aug	724	8.1156	14.0391	2.8095	-0.4178	0.0561	327.3893	34.6185	0.2050
Sep	681	5.8242	13.5782	2.5371	0.7518	0.8199	121.0110	43.5612	0.1909
Oct	652	4.4321	12.9412	2.6002	1.2295	1.2844	53.3249	58.6680	0.2000
Nov	647	4.1829	12.4246	2.4081	2.7154	1.6699	44.8280	57.5688	0.1859
Dec	694	4.8309	12.5719	2.3612	0.4850	0.8297	69.0542	48.8774	0.1760

Table 2: Wind Characteristics Using MMLM for Estimation of Weibull Parameters

Month	Hours	*k*	*c* (m/s)	V_m (m/s)	V_{mp} (m/s)	PD (W/m^2)	R^2	RMSE
Jan	643	1.62	4.59	4.07	2.53	102.58	0.990	3.79E-03
Feb	651	2.04	5.05	4.43	3.62	101.67	0.988	3.65E-03
Mar	693	2.42	6.00	5.27	4.81	147.49	0.991	6.11E-03
Apr	713	2.78	7.33	6.46	6.24	246.75	0.994	2.25E-03
May	719	2.95	8.28	7.31	7.19	346.12	0.994	4.56E-03
Jun	696	2.22	8.09	7.09	6.18	386.19	0.995	3.25E-03
Jul	734	3.43	8.24	7.33	7.45	323.35	0.993	6.50E-03
Aug	722	3.08	8.92	7.90	7.86	425.87	0.994	3.12E-03
Sep	679	2.17	6.06	5.32	4.56	166.37	0.992	2.56E-03
Oct	650	1.50	4.33	3.87	2.08	98.80	0.988	3.40E-03
Nov	645	1.59	4.20	3.73	2.25	80.95	0.989	6.07E-03
Dec	692	1.87	5.01	4.41	3.33	109.70	0.990	2.21E-03

Table 3: Wind Characteristics Using MLM for Estimation of Weibull Parameters

Month	Hours	*k*	*c* (m/s)	Vm (m/s)	Vmp (m/s)	PD (W/m^2)	R^2	RMSE
Jan	643	1.92	5.05	4.44	3.44	108.79	0.990	5.28E-03
Feb	651	2.33	5.40	4.73	4.24	110.55	0.988	3.22E-03
Mar	693	2.49	5.94	5.22	4.84	140.04	0.991	6.53E-03
Apr	713	2.88	7.31	6.45	6.30	240.78	0.994	2.19E-03
May	719	3.17	8.48	7.51	7.52	361.55	0.994	4.14E-03
Jun	696	2.37	8.45	7.42	6.71	418.38	0.995	2.68E-03
Jul	734	3.55	8.21	7.32	7.48	317.16	0.993	6.59E-03
Aug	722	3.20	9.06	8.03	8.06	439.39	0.994	4.87E-03
Sep	679	2.45	6.57	5.77	5.30	191.52	0.992	2.43E-03
Oct	650	1.85	5.01	4.41	3.30	110.75	0.988	6.76E-03
Nov	645	1.90	4.74	4.16	3.19	90.72	0.989	5.46E-03
Dec	692	2.20	5.46	4.79	4.15	119.88	0.990	4.60E-03

Table 4: Wind Characteristics Using MoM for Estimation of Weibull Parameters

Month	Hours	*k*	*c* (m/s)	Vm (m/s)	Vmp (m/s)	PD (W/m^2)	R^2	RMSE
Jan	643	1.87	5.09	4.47	3.39	114.27	0.990	5.43E-03
Feb	651	2.39	5.45	4.79	4.34	111.72	0.988	4.09E-03
Mar	693	2.66	6.00	5.28	5.03	139.03	0.991	6.99E-03
Apr	713	3.06	7.38	6.53	6.48	241.72	0.994	2.53E-03
May	719	3.23	8.58	7.61	7.65	372.38	0.994	4.48E-03
Jun	696	2.43	8.54	7.50	6.87	425.08	0.995	3.36E-03
Jul	734	3.67	8.29	7.40	7.60	323.28	0.993	3.05E-03
Aug	722	3.37	9.14	8.13	8.24	444.29	0.994	4.34E-03
Sep	679	2.56	6.64	5.84	5.47	192.59	0.992	2.84E-03
Oct	650	1.80	5.04	4.44	3.22	116.92	0.988	5.86E-03
Nov	645	1.84	4.76	4.19	3.11	95.86	0.989	7.14E-03
Dec	692	2.23	5.52	4.84	4.23	122.14	0.990	4.75E-03

Table 5: Yearly Wind Characteristics for Estimation of Weibull Parameters

Method	Hours	*k*	*c* (m/s)	V_m (m/s)	V_{mp} (m/s)	PD (W/m^2)	R^2	RMSE
MLM	8260	2.18	6.76	5.92	5.10	228.24	0.99366	5.91E-04
MMLM	8260	2.26	7.04	6.17	5.44	250.75	0.99381	5.80E-04
MoM	8260	2.22	6.80	5.96	5.19	229.99	0.99367	5.94E-04

Table 6: The Kolmogorov–Smirnov Test Based on Yearly Processed Wind Speed Data for Three Methods (Q_{95} = 0.014961, # Points = 8263)

Method	Test Statistic *Q*	Estimated		Generated		Null Hypothesis
		k	*c* (m/s)	*k*	*c* (m/s)	
MLM	0.000997816	2.18	6.76	2.21	6.76	Accepted
MMLM	0.000996712	2.26	7.04	2.31	7.05	Accepted
MoM	0.009995504	2.22	6.80	2.34	6.86	Accepted

columns 3 and 4 list Weibull shape and scale parameter (*k* and *c*) values. Columns 5 and 6 list the Weibull mean wind speed and most probable wind speeds for each month. Column 7 gives power density determined using the Weibull function. Columns 8 and 9 list RMSE and R^2 tests values. The Kolmogorov–Smirnov test is performed on yearly data. The test is performed to assess the goodness-of-fit of theoretical model by evaluating the maximum error between the two cumulative distribution function, one based on processed yearly wind speed data points and the other on randomly generated wind speed data points. Table **5** lists yearly wind characteristics based on the Weibull distribution function with Weibull parameters estimated using three methods of estimation. Table **6** lists the results of the Kolmogorov–Smirnov test. In this table column 1 list methods of estimation of the Weibull parameters, column 2 lists test statistics values for three estimation methods. Columns 3 and 4 list *k* and *c* values estimated using yearly processed wind speed data, columns 5 and 6 list *k* and *c* values estimated using generated wind speed data and column 7 list the null hypothesis. Figures **1-12** show a comparison between the histogram of the processed wind speed data, various pdf and cdf profiles of the processed and generated wind speeds for 12 months and for three methods. In general, Weibull pdf and cdf profiles estimated using MMLM show a better agreement with the histogram of the recorded wind speed data in comparison to MLM and MoM. Figure **13** shows a comparison between histogram of the consolidated yearly processed wind speed data and pdf and cdf

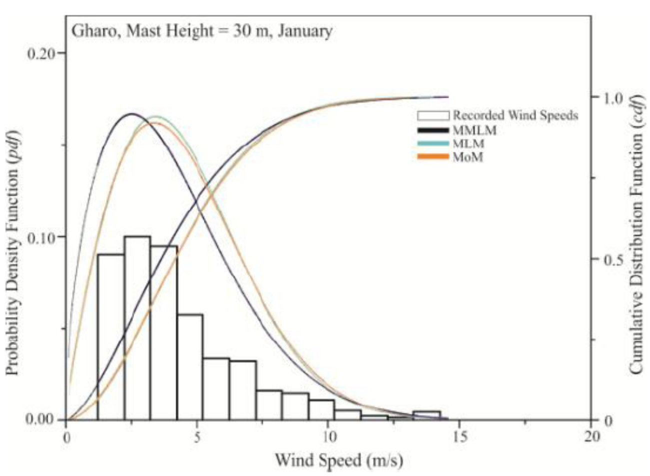

Figure 1: Histogram of recorded wind speed data and Weibull Functions for the month of January.

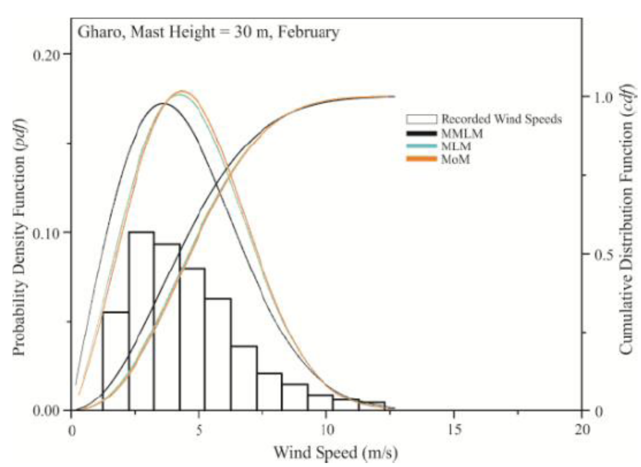

Figure 2: Histogram of recorded wind speed data and Weibull Functions for the month of February.

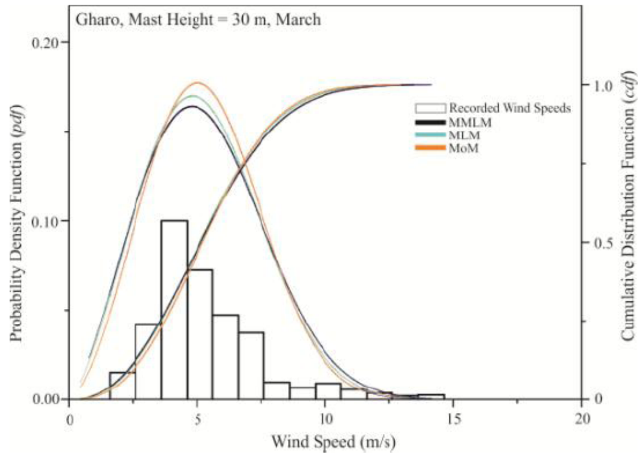

Figure 3: Histogram of recorded wind speed data and Weibull Functions for the month of March.

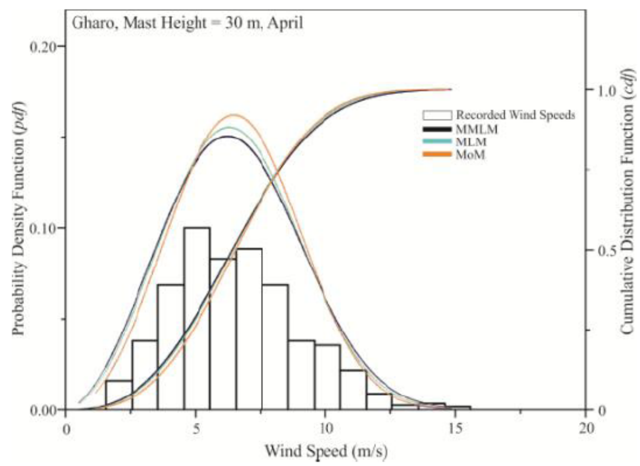

Figure 4: Histogram of recorded wind speed data and Weibull Functions for the month of April.

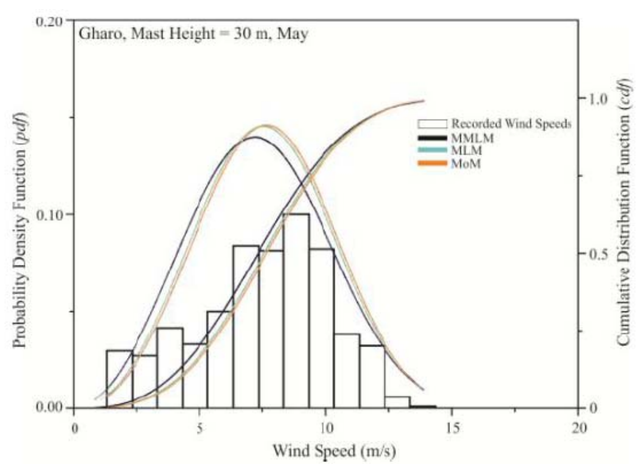

Figure 5: Histogram of recorded wind speed data and Weibull Functions for the month of May.

profiles of the consolidated yearly processed wind speed data and generated wind speed data. The values for Weibull parameters (*k* and *c*) estimated using all three methods are approximately similar and a good agreement is seen between the profiles of processed and generated wind speed data points. Figure **14** shows the histogram of monthly wind power density evaluated using the Weibull function for which Weibull parameters are estimated by MMLM, MLM and MoM.

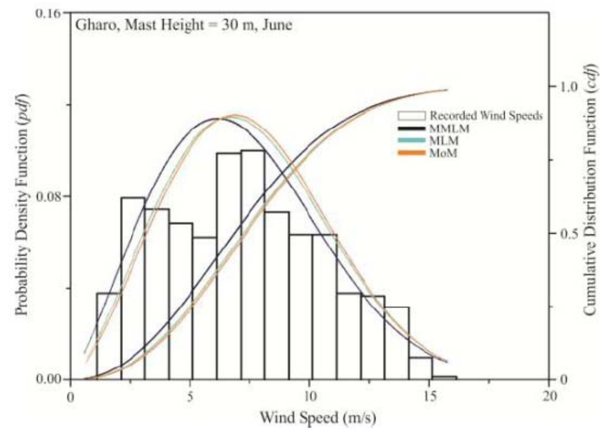

Figure 6: Histogram of recorded wind speed data and Weibull Functions for the month of June.

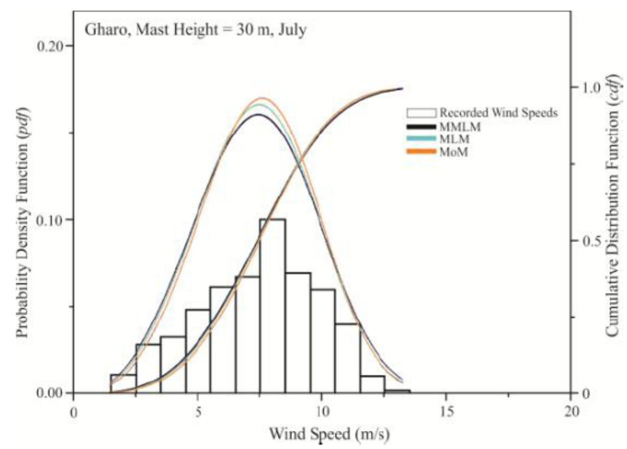

Figure 7: Histogram of recorded wind speed data and Weibull Functions for the month of July.

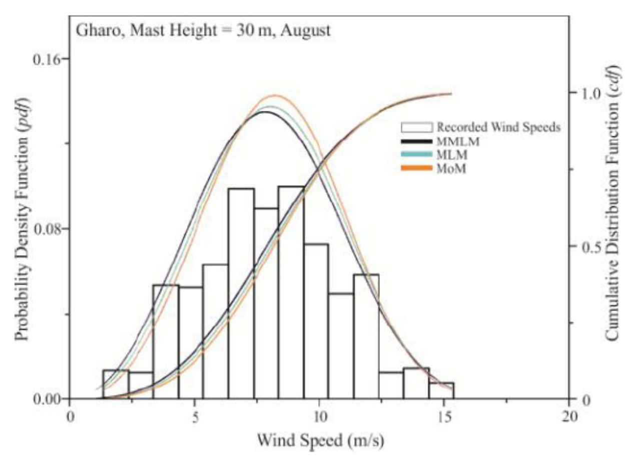

Figure 8: Histogram of recorded wind speed data and Weibull Functions for the month of August.

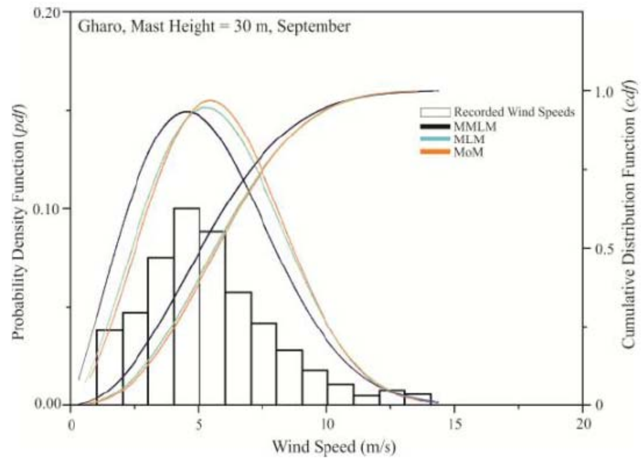

Figure 9: Histogram of recorded wind speed data and Weibull Functions for the month of September.

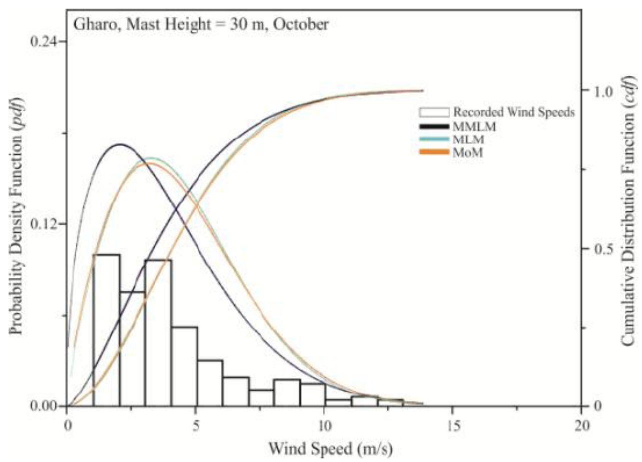

Figure 10: Histogram of recorded wind speed data and Weibull Functions for the month of October.

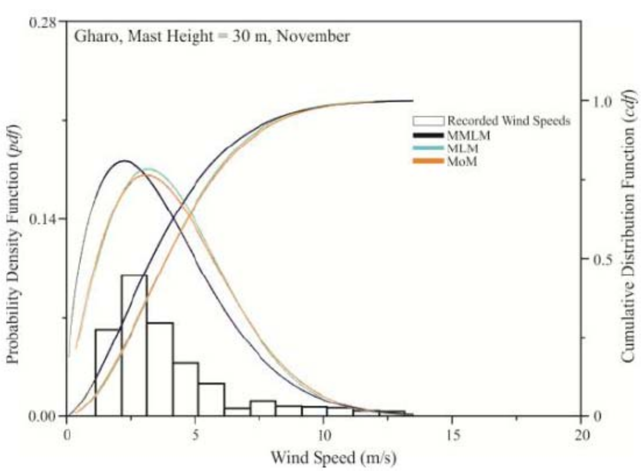

Figure 11: Histogram of recorded wind speed data and Weibull Functions for the month of November.

7. CONCLUSION

The present paper is mainly devoted to the theoretical fitting of the Weibull distribution function.

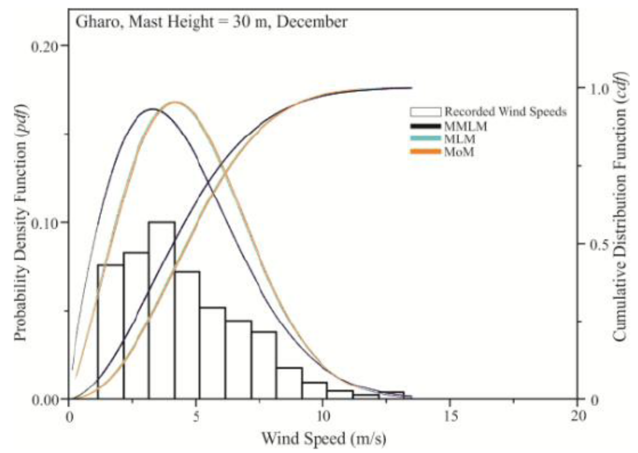

Figure 12: Histogram of recorded wind speed data and Weibull Functions for the month of December.

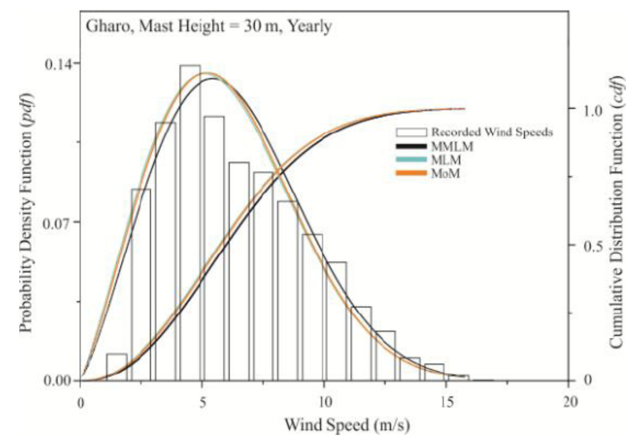

Figure 13: Histogram of yearly recorded wind speed data and Weibull Functions.

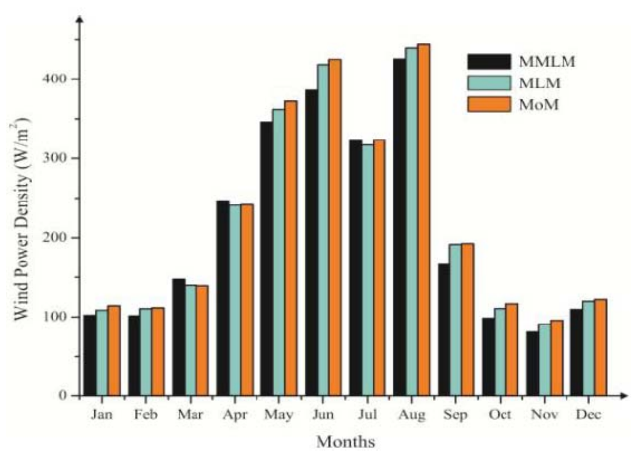

Figure 14: Monthly wind power density estimation based on three methods.

Three methods of estimation of Weibull parameters, viz., MMLM, MLM and MoM are employed and the fitted distribution is tested using goodness-of-fit tests. Following conclusions are drawn from the study.

a. In general, all three methods of estimation show consistency in estimation of shape and scale parameters. For each method RMSE test gives low values and R^2 test gives values closer to 1. These tests indicate that all three methods are suitable for estimation of the Weibull parameters.

b. In the Kolmogorov–Smirnov test for all three methods the test statistic, Q value, is less than the critical value, Q_{95}, under 95% confidence level and that the null hypothesis is accepted. Therefore the theoretical probability distribution function is in agreement with the recorded data distribution.

c. Although the null hypothesis is also accepted for MoM as a method of estimation of the Weibull parameters but for this method the magnitude of test statistic, Q is lower by one order of magnitude as compared to that of MMLM and MLM. On a very soft note and in contrast to point (a) and considering point (b), it can be concluded from the study that MMLM and MLM are more suited for the Weibull parameters estimation. Nevertheless, the null hypothesis for Kolmogorov–Smirnov test is accepted for all three methods, Weibull distribution function is appropriate for representing recorded wind speed data.

d. Monthly analysis indicates that the months from May to August are most windy with wind power densities ranging from ca. 317 W/m^2 to ca. 439 W/m^2 based on MMLM and MLM, whereas in case of MoM wind power densities range from ca. 323 W/m^2 to ca. 444 W/m^2.

e. Yearly analysis indicates Weibull mean velocity of 6 m/s and wind power densities ranging from ca. 228 W/m^2 to ca. 250 W/m^2.

REFERENCES

[1] World Wind Energy Report 2009, World Wind Energy Association, accessed August 2010.

[2] NEPRA Annual Report 2010-2011: http://www.nepra.org.pk

[3] Chaudhry QZ, Khan AH, Ahmad J. A Study Wind Power Potential At Sabzal Kot – Rajanpur. (Punjab) Pakistan Meteorological Department (PMD) Technical Report No. Sodar-01/2007, 2007.

[4] Chaudhry QZ, Khan AH, Ahmad J. A study of Wind Power Potential at Kallar-Chakwal (Punjab). Pakistan Meteorological Department (PMD) Technical Report No. Sodar-01/2007, 2007.

[5] Azmat H, Chaudhry QZ. Diagnostic study for wind power potential in FATA region in comparison to NRELs, Projections. Pakistan Journal of Meteorology 2009; 6(11): 1.

[6] Alternate Energy Development Board (AEDB): http://www.aedb.org

[7] Wind Power Potential of Sindh Pakistan Meteorological Department Technical Report No. 07, 2007.

[8] Smil V. Energy at the crossroads OECD Global Science Forum, 17-18 May Paris 2006.

[9] Weibull W. A statistical distribution function of wide applicability. J Appl Mech-Trans ASME 1951; 18(3): 293-297.

[10] Sopian K, Othman MYH, Wirsat A. Data Bank, the wind energy potential of Malaysia. Renewable Energy 1995; 6(8): l005.
http://dx.doi.org/10.1016/0960-1481(95)00004-8

[11] Garcia A, Torres JL, Prieto E, Francisco AD. Fitting wind speed distributions: A case study. Solar Energy 1998; 62(2) 139.
http://dx.doi.org/10.1016/S0038-092X(97)00116-3

[12] Sulaiman MY, Akaak AM, Wahab MA, Zakaria A, Sulaiman ZA, Suradi J. Wind Characteristics of Oman. Energy 2002; 27: 35.
http://dx.doi.org/10.1016/S0360-5442(01)00055-X

[13] Seguro JV, Lambert TW. Modern Estimation of parameters of the Weibull wind speed distribution for wind energy analysis. Journal of Wind Engineering and Industrial Aerodynamics 2000; 85: 75.
http://dx.doi.org/10.1016/S0167-6105(99)00122-1

[14] Lai CM, Lin TH. Technical assessment of the use of a small-scale wind power system to meet the demand for electricity in a land aquafarm in Taiwan. Renewable Energy 2006; 31: 877.
http://dx.doi.org/10.1016/j.renene.2005.05.007

[15] Zhou W, Yang HX, Fang ZH. Wind power potential and characteristic analysis of the Pearl River Delta region. China Renewable Energy 2006; 31: 739.
http://dx.doi.org/10.1016/j.renene.2005.05.006

[16] Akpinar EK, Akpinar S. Determination of the wind energy potential for Maden- Elazig, Turkey. Energy Convers Manage 2004; 45: 2901.
http://dx.doi.org/10.1016/j.enconman.2003.12.016

[17] Celik AN. A statistical analysis of wind power density based on the Weibull and Rayleigh models at the southern region of Turkey. Renewable Energy 2003; 29: 593.
http://dx.doi.org/10.1016/j.renene.2003.07.002

[18] Ucar A, Balo F. Investigation of wind characteristics and assessment of wind generation potentiality in Uludag-Bursa, Turkey. Turkey Appl Energy 2009; 86: 333.
http://dx.doi.org/10.1016/j.apenergy.2008.05.001

[19] Chang TJ, Wu YT, Hsu HY, Chu CR, Liao CM. Assessment of wind characteristics and wind turbine characteristics in Taiwan. Renewable Energy 2003; 28: 851.
http://dx.doi.org/10.1016/S0960-1481(02)00184-2

[20] Kwon SD. Uncertainty analysis of wind energy potential assessment. Appl Energy 2010; 87: 856.
http://dx.doi.org/10.1016/j.apenergy.2009.08.038

[21] Thiaw L, Sow G, Fall SS, Kasse M, Sylla E, Thioye S. A neural network based approach for wind resource and wind generators production assessment. Appl Energy 2010; 87: 1744.
http://dx.doi.org/10.1016/j.apenergy.2009.10.001

[22] Seguro JV, Lambert TW. Modern estimation of the parameters of the Weibull wind speed distribution for wind energy analysis. J Wind Eng Ind Aerod 2000; 85: 75.
http://dx.doi.org/10.1016/S0167-6105(99)00122-1

[23] Akdag SA, Dinler A. A new method to estimate Weibull parameters for wind energy applications. Energy Convers Manage 2009; 50: 1761.
http://dx.doi.org/10.1016/j.enconman.2009.03.020

[24] Jowder FAL. Wind power analysis and site matching of wind turbine generators in Kingdom of Bahrain. Appl Energy 2009; 86: 538.
http://dx.doi.org/10.1016/j.apenergy.2008.08.006

[25] Dorvlo ASS. Estimating wind speed distribution. Energy Convers Manage 2002; 43: 2311.
http://dx.doi.org/10.1016/S0196-8904(01)00182-0

[26] Lun, Isaac YF, Lam, Joseph C. A Study of Weibull Parameters Using Long-Term Wind Observations. Renewable Energy 2000; 20(2): 145.
http://dx.doi.org/10.1016/S0960-1481(99)00103-2

[27] Justus CG, Hargraves WR, Mikhail A, Graber D. Methods for estimating wind speed frequency distributions. Journal of Applied Meteorology 1978; 17: 350.
http://dx.doi.org/10.1175/1520-0450(1978)017<0350:MFEWSF>2.0.CO;2

[28] Barthelmie RJ, Pryor SC. Can satellite sampling of offshore wind speeds realistically represent wind speed distribution. Journal of Applied Meteorology 2003; 42: 83.
http://dx.doi.org/10.1175/1520-0450(2003)042<0083:CSSOOW>2.0.CO;2

[29] Chang TP. Performance comparison of six numerical methods in estimating Weibull parameters for wind energy application. Applied Energy 2011; 88(1): 272.
http://dx.doi.org/10.1016/j.apenergy.2010.06.018

Received on 06-01-2015 Accepted on 28-01-2015 Published on 06-02-2015

http://dx.doi.org/10.6000/1927-5129.2015.11.14