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A python program to model and analyze wind speed data

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ABSTRACT

A python program has been developed to analyze wind distributions using the Weibull density function. A two-parameter Weibull function is frequently used to model and assess wind potential and wind distribution. This python program finds first Weibull parameters from the recorded wind data by five different methods, namely, Empirical Method (EPM), Method of Moment (MoM), Energy Pattern Factor Method (EPFM), Maximum Likelihood Method (MLM), Modified Maximum Likelihood Method (MMLM), the parameters are then used to find theoretically fitted pdfs. The program is implemented on wind distribution of two cities of Pakistan (Chakri and Sadiq Abad). The program-generated pdfs were plotted with the histogram of recorded data, the fitting was excellent. To check the validity of the fitted pdfs, statistical errors Root Mean Square (RMSE), Mean Absolute Percent Error (MAPE), Mean Absolute Error (MABE), and Chi-square statistic are calculated. In all cases, these statistical errors are well below the acceptance range. Both pictorial results and numerical values of statistical errors indicate the performance of the python program to analyze wind speed data.

Key words: Python, Wind speed data, RMSE, MAPE, MABE

1. INTRODUCTION

Wind energy, which is among the most promising renewable energy resources, is used throughout the world as an alternative to fossil fuels [1-4]. Due to rising population, urbanization, and industrialization, a country's socio-economic progress is strongly linked to a reliable and affordable energy supply [5, 6]. Most countries throughout the world rely on fossil fuels to meet their energy needs, with non-renewable fossil fuels such as coal, oil, and gas accounting for 87 percent of total energy consumption in 2014, while renewable energy and nuclear power accounted for 9 percent and 4 percent, respectively [7].Natural gas, liquid gasoline, and oil are the main sources of energy in Pakistan [8-10]. Wind's energy is determined by its speed, which fluctuates constantly.The use of a two-parameter (scale parameter k and shape parameter c) Weibull distribution in calculating wind energy for a region is a useful technique. The standard function used by the wind energy community to simulate the wind speed distribution is the Weibull distribution. Maximum likelihood method (MLM), Method of Moment (MOM), Energy Pattern factor Method (EPF), Empirical Method (EM), and Modified Maximum likelihood Method are the five methods described in this paper to estimate Weibull parameters (MMLM). To compare the methodologies, daily averages of wind speed data from Chakri and Sadiqabad cities were used for one year (2017).The scale parameter and form parameter were calculated using several ways, but we discovered that the graphical technique was less accurate than the other techniques, so we had to discard it in favor of the greatest probability technique for wind energy analysis.Using a variety of probability distribution functions, we can also forecast wind speed in two separate cities. There are a variety of probability distribution functions to choose from (Rayleigh, Weibull, Lognormal, Gamma, and others) [11,12]. The two-parameter Weibull distribution was chosen because it is the most error-free for estimating wind speed.

2. TWO PARAMETERS WEIBULL DISTRIBUTION

In real-world applications usually, two-parameter Weibull Distribution is used for modeling wind speed data. This distribution was first introduced by WaloddiWeibull a Swedish Physicist. The wind speed distribution of a given location can be described by Weibull [13-15]

2.1. Probability Density Function

The probability distribution function of two-parameter Weibull distribution is expressed as:

$$f(v) = \left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{k-1} e^{-\left(\frac{v}{c}\right)^{k}}$$

Where $f(v)$ represents the probability of occurrence for v wind speed and k is the dimensionless Weibullparameter which determines the shape of the curve and is called a shape factor [16-19].

2.2. Cumulative Distribution Function

The Weibull cumulative function can be obtained by taking an integral of $f(v)$ and denoted by $F(v)$ is given as:

$$F(v) = 1 - e^{-\left(\frac{v}{c}\right)^{k}}$$

Where $F(v)$represents the CDF of the wind distribution, k is the shape parameter and c is called scale parameter.If we show the power values as frequencies, we can easily obtain the variables of the Weibull function of the given data[20-22].

3. METHODS FOR CALCULATION OF WEIBULL PARAMETERS

Weibull parameters are calculated by several methods, some of them which are employed in this work are Maximum likelihood method (MLM), Method of Moment (MOM), Energy Pattern factor Method (EPF), Empirical Method (EM), and Modified Maximum likelihood Method (MMLM) are five approaches used to estimate Weibull parameters in this paper [23]. The following is a description of each of these six methods:

3.1. Maximum likelihood method (MLM)

The maximum likelihood method is one of the most frequently used methods, it is an iterative method. MLM has severalsample properties that make approximation touches to the true values k and c [24,25]. The following equation is used to obtain the shape parameter k:

$$k = \left[\frac{\sum_{i=1}^{n} f_i v_i^k \ln(v_i)}{\sum_{i=1}^{n} v_i^k} - \frac{\sum_{i=1}^{n} f_i \ln(v_i)}{\sum_{i=1}^{n} f_i}\right]^{-1}$$

here $f\ (v_i)$ is the frequency of wind speed v_i, and f $(v \geq 0)$ is the probability for all $v \geq 0$. Zero wind speeds are rule out from the data due to the use of logarithmic function in the formula [7]. When k is determined, c can be calculated by the specific equation:

$$c = (\frac{1}{\sum_{i=1}^{n} f_i} \sum_{i=1}^{n} f_i v_i^k)$$

3.2. Modified Maximum likelihood Method (MMLM).

The observed wind speed data must be converted into a frequency distribution in both MLM and MMLM approaches for the estimation of parameters k and c. The following formulae can be used to compute the Weibull parameters (k and c) individually [26-27]:

$$k = \left[\frac{\sum_{i=1}^{n} v_{\mathrm{i}}^k \ln(v_{\mathrm{i}}) f(v_{\mathrm{i}})}{\sum_{\mathrm{i}=0}^{\mathrm{n}} v_{\mathrm{i}}^{\mathrm{k}} f(v_{\mathrm{i}})} - \frac{\sum_{i=1}^{n} \ln(v_{\mathrm{i}}) f(v_{\mathrm{i}})}{f(v \geq 0)}\right]^{-1}$$

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

here$f\ (v_i)$ is the frequency of wind speed v_i, and f $(v \geq 0)$ is the probability for all $v \geq 0$.

3.3.Method of Moment.

The MOM is an alternative to the MLM in which the Weibull parameters ‘k' and ‘c' are computed using the second moment about mean and the first moments about the origin. The following equations are used to compute the Weibull parameters ‘k' and ‘c': [26]

$$\bar{v} = c\Gamma(1 + \frac{1}{k})$$

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

Where Γ is the gamma function.

3.4. Energy Pattern factor Method (EPFM)

Determination of Weibull parameter through EPFM is an informal strategy that relies on wind speed and its cube. The energy pattern factor technique (E pf) begins with calculating the ratio of the mean of the cube of wind speed $(\overline{v^3})$ to the cube of mean wind speed $(\bar{v}^3)$. [28,29].

$$E_{pf} = \frac{\overline{v^3}}{\bar{v}^3}$$

Then the Weibull parameters k and c can be calculated as:

$$k = 1 + \frac{3.69}{{E_{pf}}^2}$$

$$c = \frac{\bar{v}}{\Gamma\left(1 + \frac{1}{k}\right)}$$

3.5 Empirical method.

This method is useful when the mean wind speed $(\bar{v})$ and standard deviation (σ) of wind speed data are given, Weibull parameters can be computed using the following Equations. [30].

$$k = (\frac{\sigma}{\bar{v}})^{-1.086}$$

$$c = \frac{\bar{v}}{\Gamma\left(1 + \frac{1}{k}\right)}$$

4. POTENTIAL SITES

4.1. Chakri

Chakri is a town of Punjab situated at 54 Km of South-west of Islamabad (see fig. 1). The latitude of Chakri, Pakistan is 33.5509, and longitude is 73.0072. The temperature at Chakri ranges from 4°Cto 38°C. Chakri has a semi-arid climate prevailing. It stays warm all year round. The site of the wind measurement at Chakri is mostly flat and elevation of 360m. The average wind speed of Chakri is 2.94 m/s, the most probable wind speed is 2.0 m/s and the wind speed carrying maximum speed is 6.2 m/s [31]. The maximum daily wind speed is expected to range between 7km/h and 9km/h. Chakri corridors had the highest wind potential with an average wind speed of 7.5 m/s. Wind speeds were measured at this site using an anemometer with the capability to measure from 0.3-40 m/s [32].

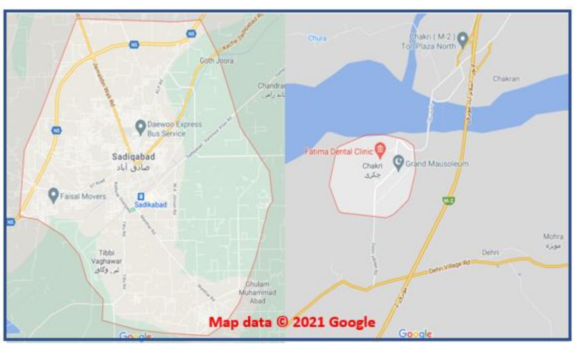

Fig. 1. Maps showing locations of Chakri and Sadiq Abad

4.2.Sadiq Abad

Sadiq Abad is located in Punjab's Rahim Yar Khan district (see fig. 1). The wind mast is located in the Cholistan desert, which is generally flat with a few dunes. The Longitude and Latitude of the Sadiq Abad are 70 and 28.21 respectively. The elevation is 76m. The hottest month in Sadiq Abad is June, with an average temperature of 43 degrees Celsius, and the coldest month is January, with an average temperature of 9 degrees Celsius. [33]. The minimum value of wind speed in the year 2017 is 0.0101 and the maximum value of wind speed of the same year is 9.0248, whereas the mean wind speed is 3.301032.The hourly average values of solar and wind Capacity Factors (CFs) for Sadiq Abadare given as 0.237 and 0.346 respectively, while the complementarity value is -0.309. The solar-wind complementarity study described here can be used to plan a solar-wind hybrid power system rollout [34].

5. RESULTS AND DISCUSSION

An attempt has been made to develop a python program to model and analyze wind speed data. The program has the following major portions, (1) it reads data from an excel file according to the input given by the user, (ii), the data is employed in the program to calculate shape and scale parameters of the Weibull distribution using five methods EPM, MoM, EPFM, MLM, and MMLM, (iii) the parameters ‘k’ and ‘c’ are used to generate five pdfs, (iv) to check the validity of these pdf statistical errors RMSE, MAPE, MABE, and Chi-Square statistic are calculated, (v) the data is recorded in an output file, (vi) and finally the theoretically generated pdfs are plotted on a histogram of recorded data. The Program is implemented to analyze and compare the potential of two potential sited Chakri and Sadiq Abad of Pakistan. In fig.2, the shape parameters calculated by five methods have been plotted. There is no significant difference between the values calculated by these methods, except the energy pattern factor method, which calculates the lower value of the shape parameter. In fig. 3, the scale parameters for Sadiq Abad calculated by five methods have been plotted. The plot shows that the wind potential in

May to August is higher as compared to the corresponding values in other months. However, the wind potential throughout the year is sufficient to install a wind turbine as the least value of c is greater than 3. The highest potential occurs in June, the least potential occurs in October.

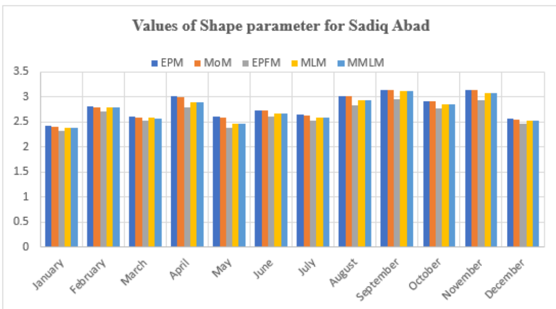

Fig. 2. The plot of the shape parameter of Weibull distribution for Sadiq Abad

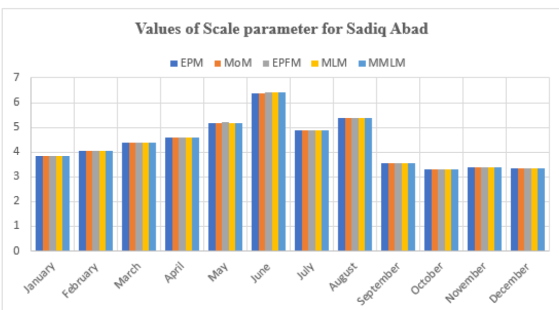

Fig. 3. The plot of the scale parameter of Weibull distribution for Sadiq Abad

In fig.4, the shape parameters for Chakri calculated by five methods have been plotted. The behavior of the plot is the same as what we see for the same plot for Sadiq Abad. There is no significant difference between the values calculated by these methods, except the energy pattern factor method, which calculates the lower value of the shape parameter. In fig. 5, the scale parameters for Chakri calculated by five methods have been plotted. The plot shows that the wind potential in April to July is higher as compared to the corresponding values in other months. However, the wind potential throughout the year is not sufficiently higher to install a wind turbine as the least value of c is less than 3. The highest potential occurs in June, the least potential occurs in October, which is the same for Sadiq Abad.

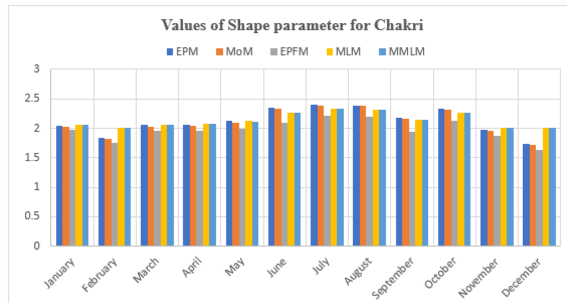

Fig. 4. The plot of shape parameter of Weibull distribution for Chakri

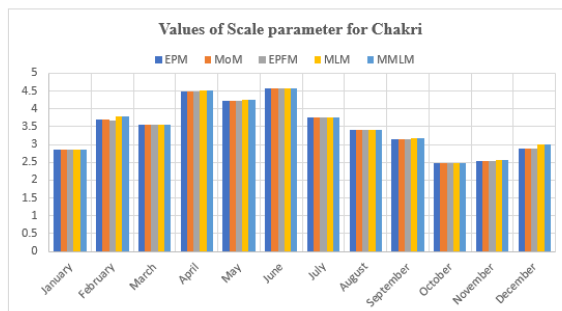

Fig. 5. The plot of the scale parameter of Weibull distribution for Chakri

To validate the results of the python program statistical errors RMSE, MAPE, MABE, Chi-Square statistic have been calculated, eqs. 1-4 shows the mathematical formulas of these errors.

$$\boldsymbol{RMSE} = \sqrt{\frac{\sum_1^n (W_i - Pi)^2}{n}} \#(1)$$

$$\boldsymbol{MABE} = \frac{|\sum_1^n (Wi - Pi)|}{n} \#(2)$$

$$\boldsymbol{MAPE} =: \frac{1}{n}\left|\sum_1^n \frac{Pi - Wi}{Pi}\right| \#(3)$$

$$\chi2 = \frac{1}{n}\sum_{1}^{n}\frac{(|Wi - Pi|)^2}{Pi} \#(4)$$

The statistical errors in both cases are well below the acceptance range of 10%. Table 1 and 2 show the values of these errors for five different methods for Chakri and Sadiq Abad, respectively. It can be seen in tables that all errors are less than 0.5, except MAPE whose values are upto 9% for Chakri wind speed data in December, nevertheless, the errors are below the acceptance range. This shows the program is implemented successfully on wind speed data of Chakri and Sadiq Abad.

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	January					May					September				
	EPM	MoM	EPFM	MLM	MMLM	EPM	MoM	EPFM	MLM	MMLM	EPM	MoM	EPFM	MLM	MMLM
RMSE	0.289	0.289	0.291	0.289	0.289	0.292	0.293	0.295	0.293	0.293	0.311	0.312	0.318	0.312	0.312
MABE	0.189	0.189	0.189	0.189	0.189	0.164	0.164	0.165	0.164	0.164	0.153	0.153	0.155	0.153	0.153
MAPE	3.243	3.479	4.089	3.010	3.002	0.824	0.872	1.219	0.822	0.826	4.739	4.996	9.690	5.242	5.296
CHI	0.127	0.129	0.132	0.126	0.126	0.120	0.120	0.121	0.120	0.120	0.127	0.129	0.199	0.132	0.132
	February					June					October				
	EPM	MoM	EPFM	MLM	MMLM	EPM	MoM	EPFM	MLM	MMLM	EPM	MoM	EPFM	MLM	MMLM
RMSE	0.314	0.314	0.316	0.313	0.313	0.341	0.341	0.345	0.342	0.342	0.224	0.224	0.231	0.226	0.226
MABE	0.199	0.199	0.200	0.197	0.197	0.169	0.169	0.170	0.169	0.169	0.113	0.113	0.114	0.114	0.114
MAPE	5.876	6.334	8.320	3.267	3.267	3.643	3.788	6.419	4.348	4.368	0.630	0.654	1.138	0.757	0.756
CHI	0.169	0.174	0.200	0.149	0.149	0.143	0.144	0.171	0.148	0.149	0.064	0.064	0.067	0.065	0.065
	March					July					November				
	EPM	MoM	EPFM	MLM	MMLM	EPM	MoM	EPFM	MLM	MMLM	EPM	MoM	EPFM	MLM	MMLM
RMSE	0.305	0.306	0.307	0.305	0.305	0.256	0.257	0.261	0.258	0.258	0.300	0.300	0.302	0.299	0.299
MABE	0.186	0.186	0.186	0.185	0.185	0.131	0.131	0.132	0.132	0.132	0.169	0.169	0.169	0.168	0.168
MAPE	1.247	1.364	1.770	1.189	1.179	4.028	4.181	6.312	4.805	4.768	0.706	0.744	0.957	0.645	0.649
CHI	0.133	0.133	0.134	0.133	0.133	0.101	0.102	0.126	0.108	0.108	0.111	0.111	0.112	0.111	0.111
	April					August					December				
	EPM	MoM	EPFM	MLM	MMLM	EPM	MoM	EPFM	MLM	MMLM	EPM	MoM	EPFM	MLM	MMLM
RMSE	0.347	0.347	0.349	0.347	0.347	0.253	0.253	0.258	0.255	0.255	0.308	0.308	0.310	0.306	0.306
MABE	0.214	0.215	0.215	0.214	0.214	0.128	0.128	0.129	0.128	0.128	0.183	0.184	0.185	0.180	0.180
MAPE	3.674	3.887	5.058	3.562	3.518	1.297	1.337	2.173	1.552	1.568	6.383	7.178	9.823	2.075	2.075
CHI	0.175	0.176	0.185	0.174	0.174	0.085	0.085	0.089	0.086	0.086	0.154	0.162	0.200	0.125	0.125

Table 1: Statistical Errors in calculated pdfs generated by five methods for Chakri

Table 2: Statistical Errors in calculated pdfs generated by five methods for Sadiq Abad.

January						May					September				
	EPM	MoM	EPFM	MLM	MMLM	EPM	MoM	EPFM	MLM	MMLM	EPM	MoM	EPFM	MLM	MMLM
RMSE	0.320	0.321	0.323	0.322	0.321	0.289	0.289	0.293	0.291	0.291	0.349	0.349	0.354	0.350	0.350
MABE	0.210	0.210	0.210	0.210	0.210	0.151	0.151	0.152	0.152	0.152	0.244	0.244	0.244	0.244	0.244
MAPE	0.407	0.401	0.368	0.387	0.388	1.806	1.844	2.855	2.334	2.354	0.377	0.377	0.464	0.380	0.379
CHI	0.145	0.145	0.146	0.145	0.145	0.114	0.115	0.120	0.117	0.117	0.162	0.162	0.162	0.162	0.162
February						June					October				
	EPM	MoM	EPFM	MLM	MMLM	EPM	MoM	EPFM	MLM	MMLM	EPM	MoM	EPFM	MLM	MMLM
RMSE	0.401	0.401	0.403	0.402	0.402	0.336	0.336	0.338	0.337	0.337	0.321	0.321	0.325	0.322	0.322
MABE	0.285	0.285	0.285	0.285	0.285	0.200	0.200	0.200	0.200	0.200	0.215	0.215	0.215	0.215	0.215
MAPE	0.246	0.241	0.212	0.236	0.235	1.279	1.299	1.579	1.393	1.399	0.461	0.459	0.421	0.443	0.443
CHI	0.210	0.210	0.210	0.210	0.210	0.161	0.161	0.162	0.162	0.162	0.137	0.137	0.137	0.137	0.137
March						July					November				
	EPM	MoM	EPFM	MLM	MMLM	EPM	MoM	EPFM	MLM	MMLM	EPM	MoM	EPFM	MLM	MMLM
RMSE	0.392	0.392	0.394	0.393	0.393	0.380	0.380	0.382	0.381	0.381	0.279	0.279	0.285	0.281	0.281
MABE	0.261	0.261	0.261	0.261	0.261	0.265	0.265	0.265	0.265	0.265	0.190	0.190	0.190	0.190	0.190
MAPE	0.414	0.409	0.381	0.401	0.401	1.368	1.396	1.817	1.523	1.522	0.436	0.437	0.439	0.428	0.428
CHI	0.198	0.199	0.199	0.199	0.199	0.202	0.202	0.203	0.202	0.202	0.113	0.113	0.113	0.113	0.113
April						August					December				
	EPM	MoM	EPFM	MLM	MMLM	EPM	MoM	EPFM	MLM	MMLM	EPM	MoM	EPFM	MLM	MMLM
RMSE	0.341	0.342	0.346	0.344	0.344	0.385	0.385	0.388	0.386	0.386	0.340	0.341	0.343	0.341	0.341
MABE	0.218	0.218	0.218	0.218	0.218	0.254	0.254	0.254	0.254	0.254	0.237	0.237	0.237	0.237	0.237
MAPE	0.766	0.772	1.151	0.956	0.961	0.451	0.452	0.439	0.447	0.447	0.446	0.457	0.531	0.472	0.475
CHI	0.157	0.157	0.158	0.158	0.158	0.197	0.197	0.197	0.197	0.197	0.157	0.157	0.158	0.158	0.158

In figs. 6. and 7.pdfs, Generated by five methods (EPM. MoM. EPFM, MLM, MMLM) of determining Weibull parameters, are shown. These plots are generated from the recorded data of wind speed at Chakri and Sadiq Abad at a height of 20 m at a regular interval of 10 seconds, for 2017. The plots also show the histogram generated by the recorded data, the pdfs completely cover the histogram in each of the plots, showing the effectiveness of the modeling. The results also show that the python program works well.

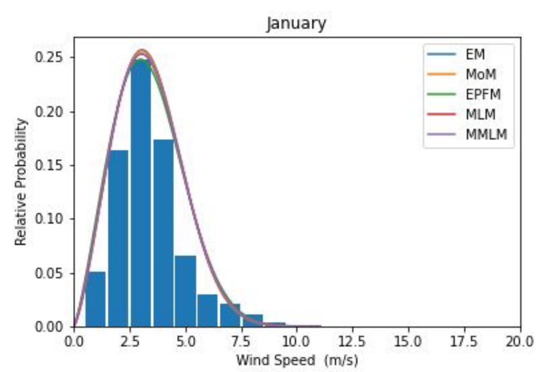


Fig. 6(a)

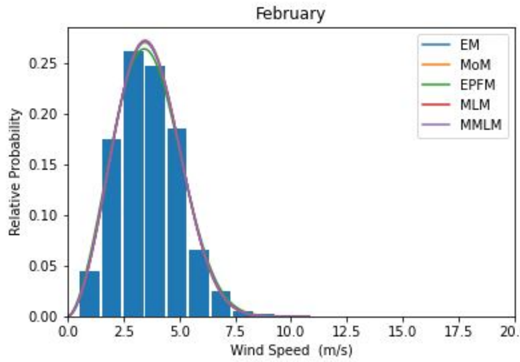


Fig. 6(b)

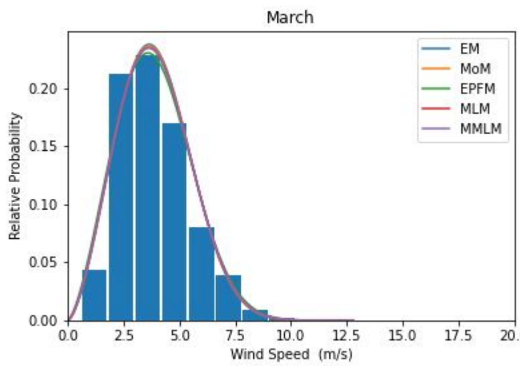
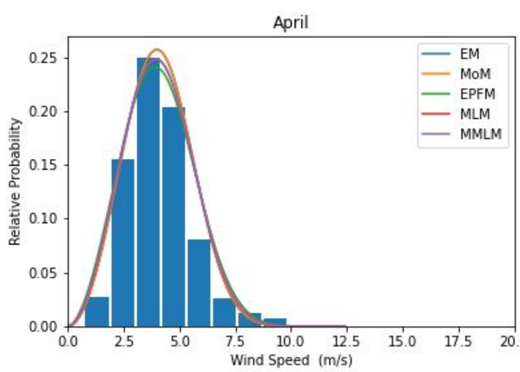


Fig. 6(c)



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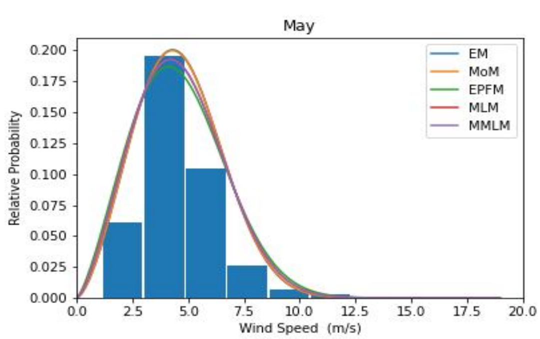

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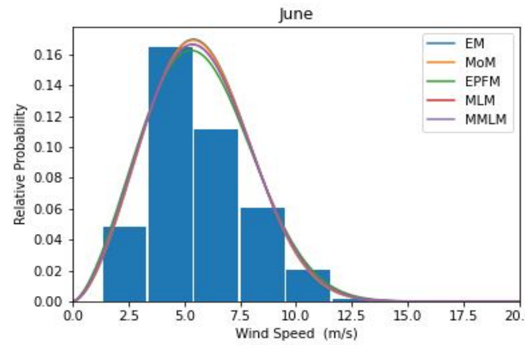

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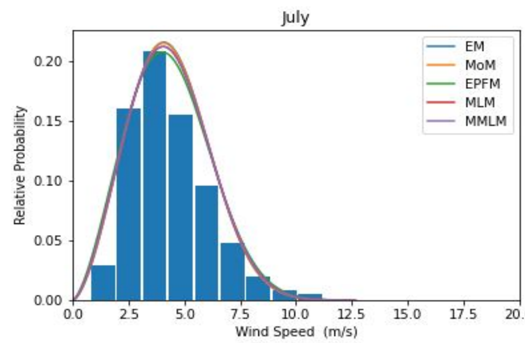

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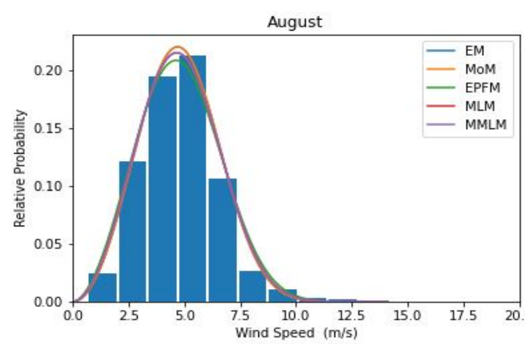

Fig. 6(h)

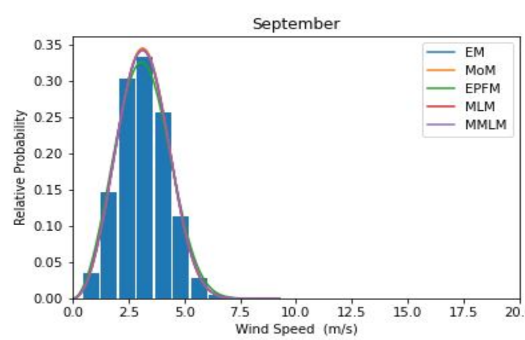

Fig. 6(i)

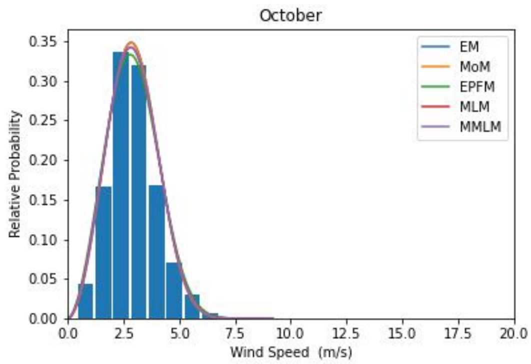

Fig. 6(j)

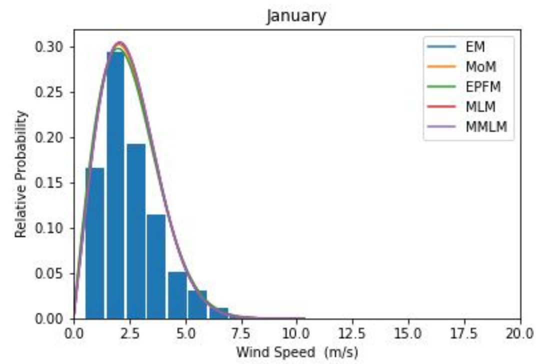

Fig. 7(a)

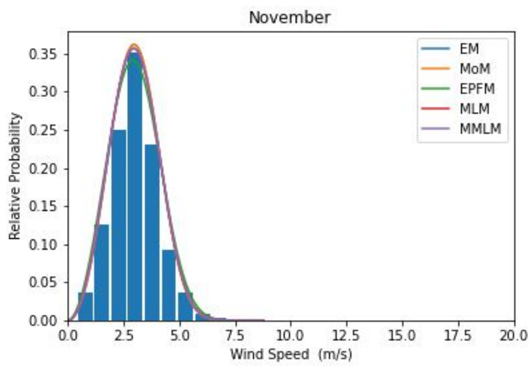

Fig. 6(k)

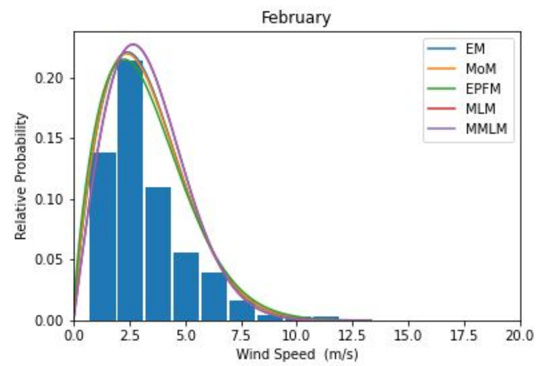

Fig. 7(b)

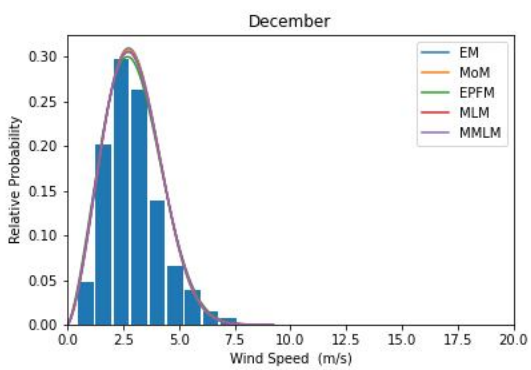

Fig. 6(l)

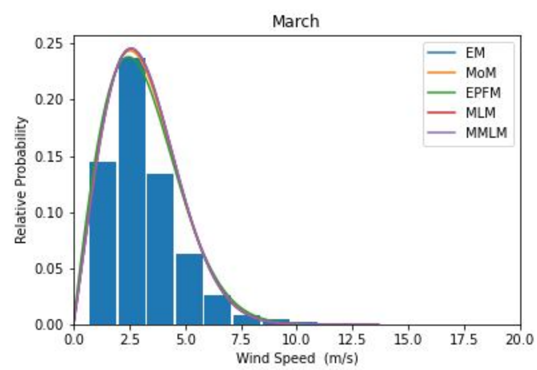

Fig. 7(c)

Fig. 6. The plot of pdfs generated by five methods of finding Weibull parameter representing recorded data as histogram for Sadiq Abad.

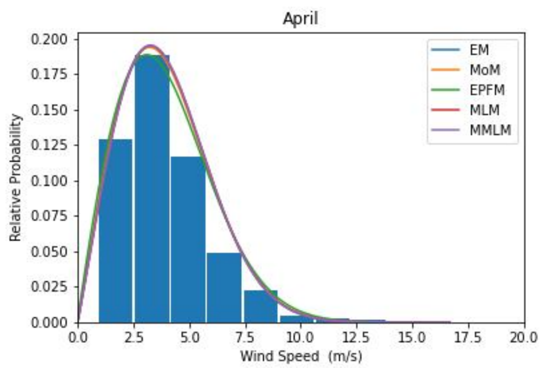

Fig. 7(d)

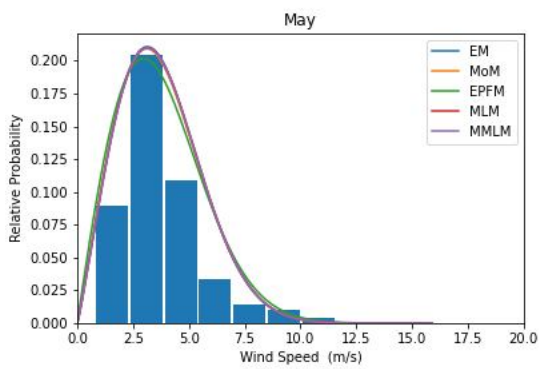

Fig. 7(e)

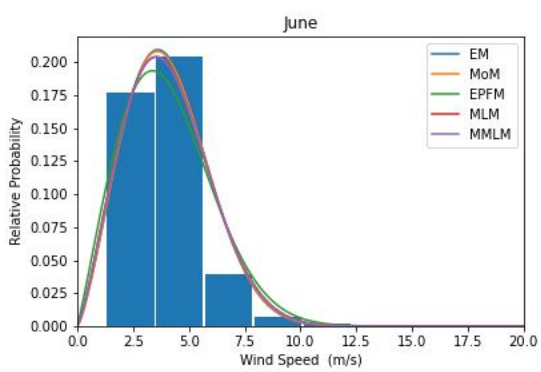

Fig. 7(f)

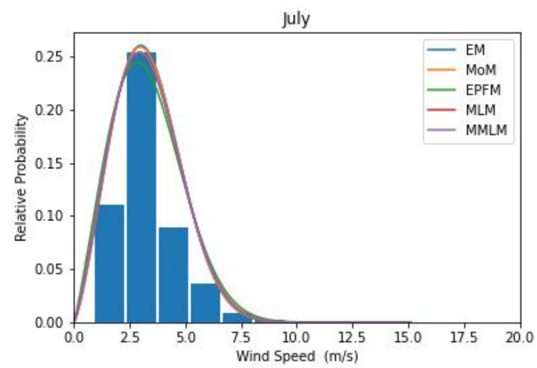

Fig. 7(g)

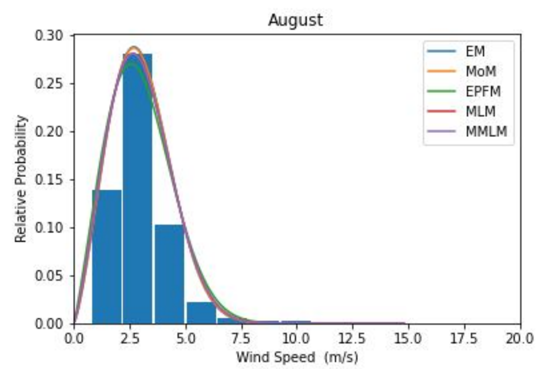

Fig. 7(h)

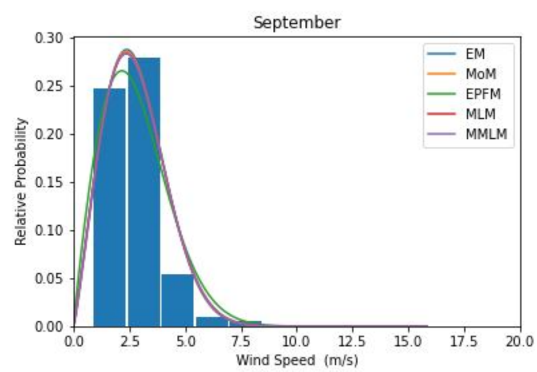

Fig. 7(i)

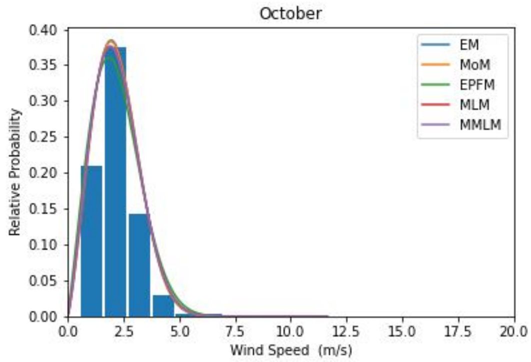

Fig. 7(j)

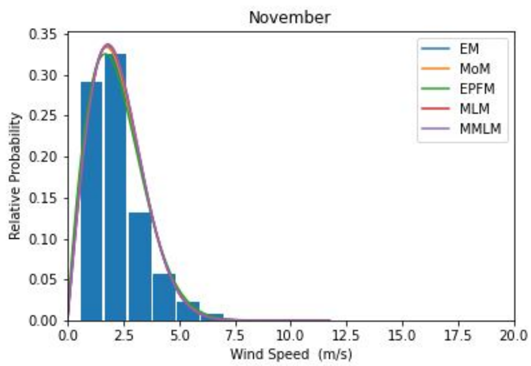

Fig. 7(k)

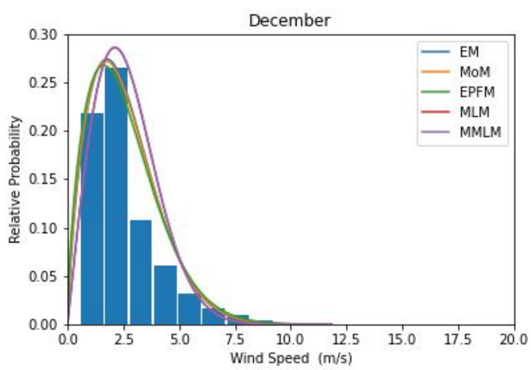

Fig. 7(l)

Fig. 7. The plot of pdfs, generated by five methods of finding Weibull parameter, representing recorded data as a histogram for Sadiq Abad.

5. CONCLUSION

In this manuscript we implemented a python program, to model, analyze wind speed data and to compare and assess the wind potential of two cities (Chakri and Sadiq Abad) of Pakistan. The python, developed for this work, is user friendly, it reads recorded wind speed from excel file, calculatesWeibull parameters by five methods& numerical values of pdfs generated by these parameters, compares the calculated and recorded wind speeds, checks the validity by calculating statistical errors (RMSE, MAPE, MABE, and Chi-Square statistic), and draws graphs of pdfs together with the histogram of recorded wind speed.The wind speed data used in the implementation is obtained from [35], and is recorded at a height of 20m at a regular interval of 10 minutes for 2017.

(i) The shape and scale parameters for Chakri and Sadiq Abad are calculated by five methods.

(ii) There is no significant difference between the values calculated by five methods, except the energy pattern factor method, which calculates the lower value of the shape parameter.

(iii) The behavior of the plots of shape parameters for Chakri and Sadiq Abad is the same.

(iv) The scale and shape parameters calculated numerically by the python program are used to generate pdfs which explains well the histogram of recorded wind speed data.

(v) The statistical errors also validate the results obtained by the python program.

(vi) The wind potential for Chakriis higher from April to July compared to the corresponding values in other months, the highest potential occurs in June,

(vii) The wind potential for Sadiq Abad is higher from May to August.

(viii) The highest and lowest potential for both Chakri and Sadiq Abad occurs in June and October, respectively.

(ix) The wind potential throughout the year is not sufficient to install a wind turbine in Chakri, so the potential site to install a wind turbine is Sadiq Abad.

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Appendix A: Python Program

```
import numpy as np
import matplotlib.pyplot as plt
import math
import xlrd
import xlsxwriter
wb=xlrd.open_workbook("wind.xlsx")
sheet=wb.sheet_by_index(0)
workbook   = xlsxwriter.Workbook("wind_out.xlsx")
wsheet = workbook.add_worksheet()
months=['January', 'February', 'March', 'April', 'May', 'June', 'July', 'August', 'September', 'October', 'November', 'December']
month=int(input("enter month numnber"))
v2=[]
for row in range(sheet.nrows):
    month1=int(sheet.cell_value(row,0))
    if month1==month:
        v2.append(sheet.cell_value(row,1))
temp=0
f=[]
F=[]
v22=np.linspace(min(v2),max(v2),10)
v=[]
for i in range(0,len(v22)):
    sum=0
    for j in range(0,len(v2)):
        if v2[j]<=v22[i]:
            sum=sum+1
    if (sum-temp)!=0:
        f.append(sum-temp)
        F.append(sum)
        v.append(v22[i])
        temp=sum
f=np.array(f)
F=np.round(f/np.sum(f),6)
maxf=max(F)
```

```
MSE,MABE,MAPE,CHI,R2=[],[],[],[],[]
'========================================================'
'Statistical Error'
'========================================================'
def SE(k,c):

    W=((k/c)*np.power((v/c),k-1)*np.exp(-np.power((v/c),k)))
    F1=F/maxf
    MSE=np.average(np.power(W-F1,2))**0.5
    MABE=np.average(np.abs(W-F1))
    MAPE=np.average((W-F1)*100*np.power(F1,-1))
    chi=np.average(np.abs(W-F1)**2*np.power(F1,-1))
    sum=0
    for i in range(0,len(F)):
        sum=sum+np.abs((F[i]-((k/c)*np.power((v[i]/c),k-1)*np.exp(-np.power((v[i]/c),k))))/F[i])
        MAPE=sum/len(F)
    return [MSE,MABE,MAPE,chi,R2,sum]
v3=np.linspace(0,max(v2)+2, 200)
'========================================================'
'define function Weibull distribution'
'========================================================'
def W(k,c):
    W=((k/c)*np.power((v3/c),k-1)*np.exp(-np.power((v3/c),k)))
    return W
def Write(p):
    MSE.append(SE(k,c)[0])
    MABE.append(SE(k,c)[1])
    MAPE.append(SE(k,c)[2])
    CHI.append(SE(k,c)[3])
    wsheet.write(1,p,k)
    wsheet.write(2,p,c)
    wsheet.write(3,p,SE(k,c)[0])
    wsheet.write(4,p,SE(k,c)[1])
    wsheet.write(5,p,SE(k,c)[2])
```

```
    wsheet.write(6,p,SE(k,c)[3])

'======================================================'
'Empirical method'
'======================================================'
k=((np.sum(F*(v-np.dot(F,v))**2))**0.5/np.sum(F*v))**-1.086
#k=(np.std(v2)/np.average(v2))**-1.086
c=np.dot(v,F)/math.gamma(1+1/k)
y2=W(k,c)
Write(2)

print('Empirical method',k,c)
'======================================================'
'Method of moments'
'======================================================'
x=np.linspace(1,10,1000)
temp=[]
for i in range(0,len(x)):
    k=x[i]
    temp.append(abs(((np.sum(F*(v-np.dot(F,v))**2))**0.5/np.dot(v,F))-(math.gamma(1+2/k)-math.gamma(1+1/k)**2)**0.5/math.gamma(1+1/k)))
n=temp.index(min(temp))
k=x[n]
c=np.dot(v,F)/math.gamma(1+1/k)
y3=W(k,c)
Write(3)

print('Method of moments',k,c)

'======================================================'
'energy pattern factor method'
'======================================================'
k=1+3.69/(np.dot(F,np.power(v,3))/np.dot(v,F)**3)**2
c=np.dot(v,F)/math.gamma(1+1/k)
y4=W(k,c)
Write(4)

print('energy pattern factor method',k,c)
'======================================================'
'Maximum likelihood Method'
'======================================================'
x=np.linspace(2,10,1000)
temp=[]
for i in range(0,len(x)):
    k=x[i]
    temp.append(abs(k-(np.sum(F*np.power(v,k)*np.log(v))/np.sum(F*np.power(v,k))-np.sum(F*np.log(v)))**-1))
n=temp.index(min(temp))
k=x[n]
c=(np.sum(F*np.power(v,k)))**(1/k)
y5=W(k,c)
Write(5)

print('Maximum likelihood Method',k,c)

'======================================================'
' Modified maximum likelihood method'
'======================================================'
x=np.linspace(2,10,10000)
temp=[]
f=f/np.sum(f)
for i in range(0,len(x)):
    k=x[i]
    temp.append(abs(k-(np.sum(np.power(v,k)*np.log(v)*f)/np.sum(np.power(v,k)*f)-np.sum(np.log(v)*f))**-1))
n=temp.index(min(temp))
k=x[n]
c=(np.dot(F,np.power(v,k))**(1/k))
y6=W(k,c)
Write(6)
```

```
print('Modified Maximum likelihood Method',k,c)

'========================================================='
' Plotting Graphs'
'========================================================='
#plt.plot(v3,y1,label='graphical')
plt.plot(v3,y2,label='EM')
plt.plot(v3,y3,label='MoM')
plt.plot(v3,y4,label='EPFM')
plt.plot(v3,y5,label='MLM')
plt.plot(v3,y6,label='MMLM')
#plt.plot(v3,y7,label='EEM')
maxf=max(f)+0.01
f=f*max(y3)/maxf
plt.bar(v,f,v[1]-v[0]-0.1)
plt.legend()
plt.xlabel('Wind Speed  (m/s)')
plt.ylabel('Relative Probability')
month1=['January','February','March','April','May']
plt.title(months[month-1])
wsheet.write(0,2,'EPM')
wsheet.write(0,3,'MoM')
wsheet.write(0,4,'EPFM')
wsheet.write(0,5,'MLM')
wsheet.write(0,6,'MMLM')
plt.xlim(0,20)
wsheet.write(1,0,'k')
wsheet.write(2,0,'c')
wsheet.write(3,0,'RMSE')
wsheet.write(4,0,'MABE')
wsheet.write(5,0,'MAPE')
wsheet.write(6,0,'CHI')

workbook.close()
```