Assessment of Weibull Parameter by Five Numerical Methods and Estimation of Wind Speed at Rotterdam, Netherland

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Abstract: In this paper Weibull parameters(c and k) have been estimated on wind speed data of Rotterdam, Netherland. We have applied five numerical methods i.e. Modified Maximum Likelihood Method, Maximum Likelihood Method, Energy Pattern Method, Empirical Method and Method of Moments, to calculate the values of c and k. The parameters k and c have used to estimate the probability distribution function and average wind speed. The wind speed data on hourly basis from 2005-2014 have obtained from "Royal Netherlands Meteorological Institute".

Keywords: Wind Energy, Weibull Distribution, Numerical Methods, Rotterdam.

INTRODUCTION

Energy crises in the world are demanding to bring renewable energies so as to fulfill the requirement of the world. Small windmills have been started to be use for electricity production, particularly in remote countryside zones, in 20th century. Energy constraint is increasing gradually due to population growth and industrialization. Due to the use of fossil fuels, the atmosphere's lower layer is getting polluted which bring into being greenhouse effect. Energy crises was observed in the mid of 70s, so world start exploring other energy sources such as coal and natural gas; coal and hydro turn out to be sustainable [1].

Presently the world is focusing on feasible and better renewable energy sources. The world is shifting to renewable energy sources for energy generation, because of its distinctive properties. Renewable energy sources such as ocean thermal energy, biomass, hydro, geothermal wind and solar energy are attracting the intentions of all over the world. The incorporation of renewable electric generation resources, particularly wind and solar, into energy production and distribution systems, is recently deliberated to be a main technical and economic challenge [2].

Wind energy is the most suitable, cheapest and most appropriate source for the generation of electricity; it is strappingly followed in so many countries [3]. In order to generate low-cost energy, wind is considered to be the most abundant, inexhaustible and clean source of energy [4]. Currently the consumption of wind power in the world scale-up enhancement, presently 36.67% installed by Europe, trailed by 35.62% in Asia, 24.92% in North America, 1.34% in Latin American and Caribbean, 1.17% in pacific region and 0.45% in Middle East and Africa [5].

Wind energy is an alternate source of energy to conventional energy. The recent wind energy data for Pakistan cities was not available, Netherland has been installing wind turbines in many cities and the wind data is available online. We sought their consent for using online data. After their permission we analyzed this data.

Wind Power in Netherland

The core longitude of Netherland is 52^{o}23′N and latitude is and 4^{o}55′E. The country is positioned in between Germany and Belgium. The area linking the latitude and longitude is approx.41,528sq/km. The latitude of the Netherland exists in the middle of the Arctic and Tropic of cancer. In season of summer, temperature remains cool and breezy throughout the country, whereas in season of winter, temperature is not formal due to its position.

The Netherland have both onshore and offshore wind turbines. At the end of 2011, the ability of installed wind turbines was 2238 megawatts (MW). It was supposed to be about 3.38 percent of whole annual electricity generation [6]. The major reason behind the latent onshore competence is the confrontation offered by the Dutch people to the wind turbines. In order to meet the requirement of European Union's 25% renewable energy target, at least additional 3000MW, 460-foot wind turbine be installed at the rate of 6.5 billion dollars. An added 3100MW offshore turbine was also rejected. Because the investment cost was approximately 12 to 13 billion dollars. The installation cost was estimated to be too high as compared to the production of wind energy.

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Rotterdam Netherland

Rotterdam is the city of South Holland. Rotterdam has the largest cargo port in Europe. River Nieuwe Maas divided the Rotterdam' into a southern part and a northern part. The climate of Rotterdam is almost similar to the climate of all Netherland. According to recent studies, Rotterdam has the maximum percentage of foreigners from non-industrialized nations. The latitude of Rotterdam is 51°55' N and the longitude is 4°28' E.

Weibull's Distribution

The Weibull's distribution is considered as continuous probability distribution as per statistics and probability theory. The Weibull's distribution is providing a vital role to anticipate wind power and its distribution. Weibull's distribution is exceptionally adjustable and simpler to apply [8-11]. The distribution is based on two parameters one is dimensionless known as shape parameter 'k' and the second is known as scale parameter 'c', it has dimension of velocity [4].

Probability Density Function (PDF)

The Weibull's form of PDF is [4]

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

The parameters (k and c) can be analyzed by several ways. In this study, the methods that are discussed here are Empirical method (EM), Modified Maximum Likelihood Method (MMLM), Maximum Likelihood Method (MLM), Energy Pattern factor Method (EPM), and Method of Moment (MoM).

Method of Moment

The method of moments is a technique of estimation of population parameters. Evaluation by the method of moments can be used as the initial approximation to the explanation of the likelihood equations. The initial two moments of the Weibull density function are used to conclude the parameters 'k' and 'c'. The two moments of the distribution are given in following mathematical equations which are used in the estimation of shape and scale parameters.

$$\bar{v} = c\Gamma\left(1+\frac{1}{k}\right) \quad (2)$$

$$\sigma = c\left[\Gamma\left(1+\frac{2}{k}\right) - \Gamma^2\left(1+\frac{1}{k}\right)\right]^{\frac{1}{2}} \quad (3)$$

Empirical Method

Special form of moment method is empirical method. In this technique, the Weibull's parameters 'c' and 'k' can be able to estimate by the following equations {4} and {2}[7].

$$k = \left(\frac{\sigma}{\bar{v}}\right)^{-1.086} \quad (4)$$

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

Energy Pattern Factor Methods

Energy pattern method is also termed as Power density method. This method is associated with average wind speed data. The EPM is identified with the help of averaged wind speed data and is well-defined by the help of subsequent mathematical equations [12].

$$E_{pf} = \frac{\overline{v^3}}{\bar{v}^3} \quad (5)$$

$$k = 1 + \frac{3.69}{\left(E_{pf}\right)^2} \quad (6)$$

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

Maximum Likelihood Method

While applied to data and specified statistical model, Maximum-likelihood estimation provides assessment for the model's parameters. Since the solution found by using maximum likelihood relatively complicated with other methods, therefore, numerical iterations are obligatory to control Weibull's distribution parameters [13]. Following equation will be used to determine the parameters k and c [14].

$$k = \left[\frac{\sum_{i=1}^{n} v_i^k \ln v_i}{\sum_{i=1}^{n} v_i^k} - \frac{\sum_{i=1}^{n} \ln v_i}{n}\right] \quad (7)$$

$$c = \left(\frac{1}{n}\sum_{i=1}^{n} v_i^k\right)^{\frac{1}{k}} \quad (8)$$

Modified Maximum Likelihood Method

The wind speed data manageable in the Weibull's distribution is analyzed by using Modified Maximum

Likelihood Estimation method (MMLE). Numerical iteration is also used in this method similar to maximum likelihood method [10, 15].

$$k = \left[\frac{\sum_{i=1}^{n} v_i^k \ln v_i \; f(v_i)}{\sum_{i=1}^{n} v_i^k f(v_i)} - \frac{\sum_{i=1}^{n} \ln v_i f(v_i)}{f(v) \geq 0} \right]^{-1} \quad (9)$$

$$c = \left(\frac{1}{f(v) \geq 0} \sum_{i=1}^{n} v_i^k f(v_i) \right)^{\frac{1}{k}} \quad (10)$$

RESULTS AND DISCUSSION

The hourly averaged Wind data from 2005-2014 is used in this study to assess Weibull distribution and estimate its corresponding parameters. Aforesaid five methods are applied to find the k and c parameters. The mean wind speed for the decade 2005-2014 is also calculated on monthly basis, which specifies the wind speed at Rotterdam is high from November to March as shown in Table **1**. The predicted wind speed and absolute deviation for estimated and measured value of wind speed by five numerical methods are also shown in Table **1**.

The comparison of shape parameter and scale parameter by five numerical methods i.e. MMLM, MOM, EmM, EPM and MLM from the month January to December for the decade 2005-2014 are shown in Table **2**. The probability distribution function along-with histogram for the month January to December is shown in Figure **1**.

Table 1: The Averaged and Estimated Wind Speed for the Decade (2005-2014) and Absolute Error

MONTH	Average Wind Speed	Predicted Wind Speed By Five Different Method					Absolute Error in Observed and Predicted Wind Speed				
	Period 2005-2014	MMLM	MOM	EmM	EPM	MLM	MMLM	MOM	EmM	EPM	MLM
JANUARY	5.954045699	5.95655	5.93771	5.939247	5.935764	5.952994858	0.002504317	0.01633867	0.0147983	0.018281271	0.001050841
FEBRUARY	5.380274823	5.38575	5.37566	5.376187	5.373932	5.382150109	0.005479967	0.00461176	0.0040879	0.006342485	0.001875286
MARCH	5.119354839	5.12426	5.10834	5.109385	5.105237	5.1206186	0.004906516	0.01101828	0.0099703	0.014118135	0.001263761
APRIL	4.333958333	4.33831	4.33218	4.332279	4.330604	4.335890473	0.004348391	0.00178288	0.0016789	0.003354293	0.001932139
MAY	4.576142473	4.58446	4.5754	4.575411	4.575171	4.581832479	0.008317794	0.00074496	0.0007311	0.000971617	0.005690006
JUNE	4.088888889	4.09739	4.08715	4.087291	4.085398	4.099983974	0.008496656	0.00173513	0.0015975	0.003491325	0.011095085
JULY	4.17422043	4.18194	4.17294	4.173009	4.172045	4.179474145	0.007723437	0.00128431	0.0012113	0.002175639	0.005253715
AUGUST	4.227217742	4.23216	4.22636	4.226385	4.225694	4.234658322	0.004942184	0.00085625	0.0008324	0.001524146	0.00744058
SEPTEMBER	4.010722222	4.01913	4.0032	4.004101	4.000479	4.021837346	0.008404563	0.00751722	0.0066212	0.010242772	0.011115123
OCTOBER	4.675282258	4.6799	4.6733	4.673481	4.672955	4.682324154	0.004622366	0.00197822	0.0018017	0.002327381	0.007041896
NOVEMBER	5.103222222	5.10587	5.09094	5.092135	5.089369	5.102361157	0.002647064	0.0122797	0.0110872	0.013853334	0.000861065
DECEMBER	5.668602151	5.67501	5.66032	5.661189	5.660512	5.678107772	0.006404969	0.00828208	0.0074136	0.008089835	0.009505622

Table 2: Comparison of Weibull's Parameters k and c

2005-2014	k					c (m/s)				
	MMLM	MOM	EmM	EPM	MLM	MMLM	MOM	EmM	EPM	MLM
JANUARY	2.339043	2.31654	2.3357223	2.294521	2.33934	6.738251	6.719182	6.7184436	6.719937	6.734051
FEBRUARY	2.281901	2.27897	2.2988363	2.2268374	2.28226	6.084154	6.072787	6.0722334	6.073854	6.080012
MARCH	2.355422	2.34151	2.3602168	2.2943212	2.35583	5.79348	5.77639	5.7756955	5.777883	5.789201
APRIL	2.605774	2.6465	2.6587388	2.5273861	2.60618	4.885833	4.876072	4.8753503	4.882575	4.883063
MAY	2.586383	2.61828	2.631163	2.5065009	2.58677	5.16241	5.150269	5.1494899	5.156503	5.159425
JUNE	2.452953	2.48293	2.4987917	2.3595584	2.45249	4.621746	4.608507	4.6078035	4.613136	4.624724
JULY	2.577781	2.60262	2.6158607	2.4984032	2.5782	4.710457	4.698771	4.6980531	4.703982	4.707637
AUGUST	2.69095	2.74798	2.757838	2.6034124	2.6905	4.760133	4.749915	4.7492993	4.758384	4.762979
SEPTEMBER	2.207056	2.18187	2.2033611	2.128518	2.20664	4.545144	4.528067	4.527961	4.527936	4.548303
OCTOBER	2.408746	2.404	2.421491	2.3748472	2.40845	5.280254	5.273019	5.2722825	5.274159	5.283015
NOVEMBER	2.332787	2.31255	2.3318001	2.2895714	2.33316	5.774426	5.759145	5.7585232	5.759803	5.770298
DECEMBER	2.33764	2.31142	2.3306898	2.3155187	2.33738	6.411843	6.397233	6.3965449	6.397092	6.415435

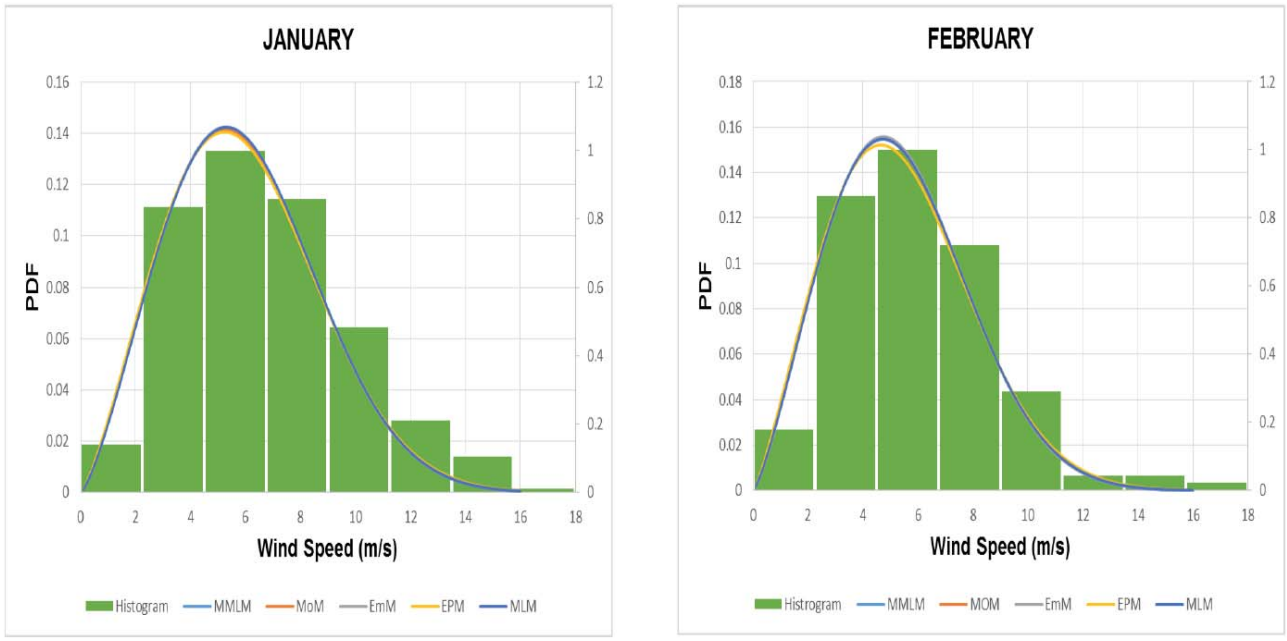

Figure 1: a. Histogram of recorded wind speed data and Weibull plots using MLM, MMLM, MoM, EPM, and EmM for January and February.

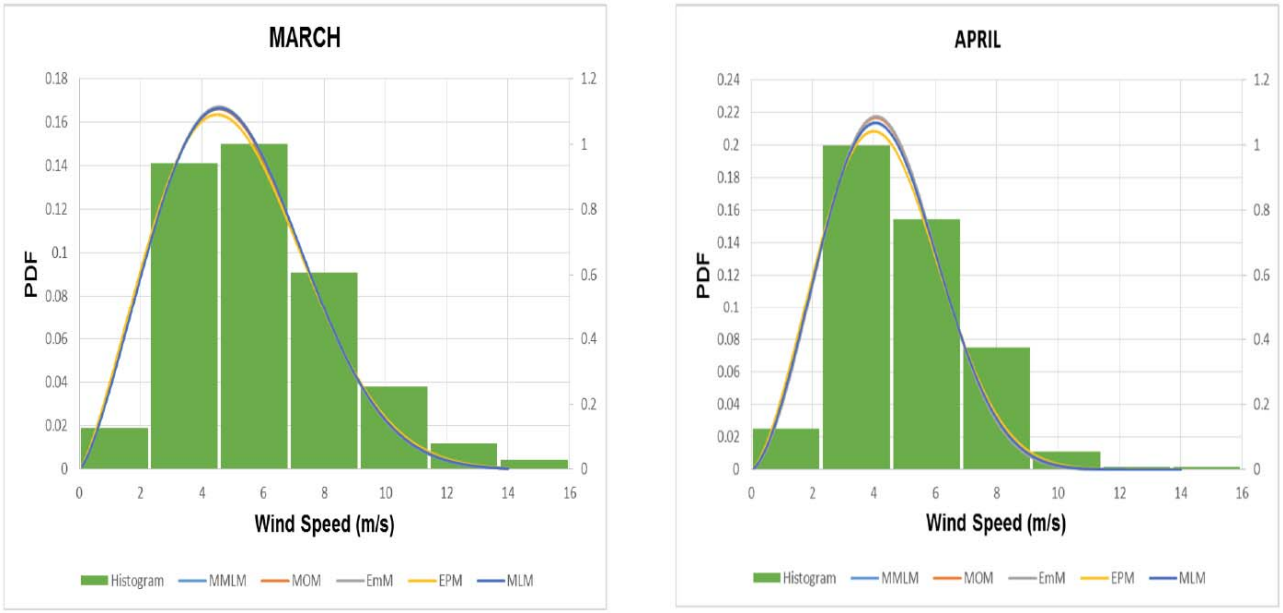

Figure 1: b. Histogram of recorded wind speed data and Weibull plots using MLM, MMLM, MoM, EPM, and EmM for March and April.

CONCLUSION

The modified maximum likelihood method, maximum likelihood method, energy pattern factor method, empirical method and method of moment are applied to calculate parameters 'k and 'c'. The hourly averaged wind speed data of Rotterdam for the decade 2005 to 2014 is used to scrutinize the results of five models.

(i) The five methods provide almost identical values and are apposite for the assessment of Weibull distribution.

(ii) It is observed that the predictable values of 'c' calculated by the five methods is marginally greater than the hourly averaged wind speed.

(iii) MLM is comparatively in a superior agreement with the hourly averaged wind speed among the other four methods.

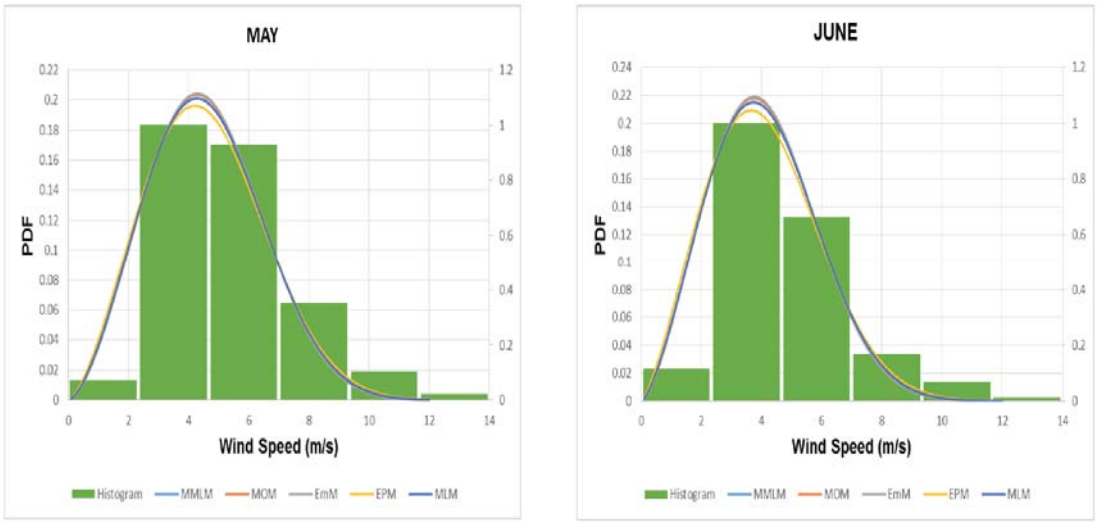

Figure 1: c. Histogram of recorded wind speed data and Weibull plots using MLM, MMLM, MoM, EPM, and EmM for May and June.

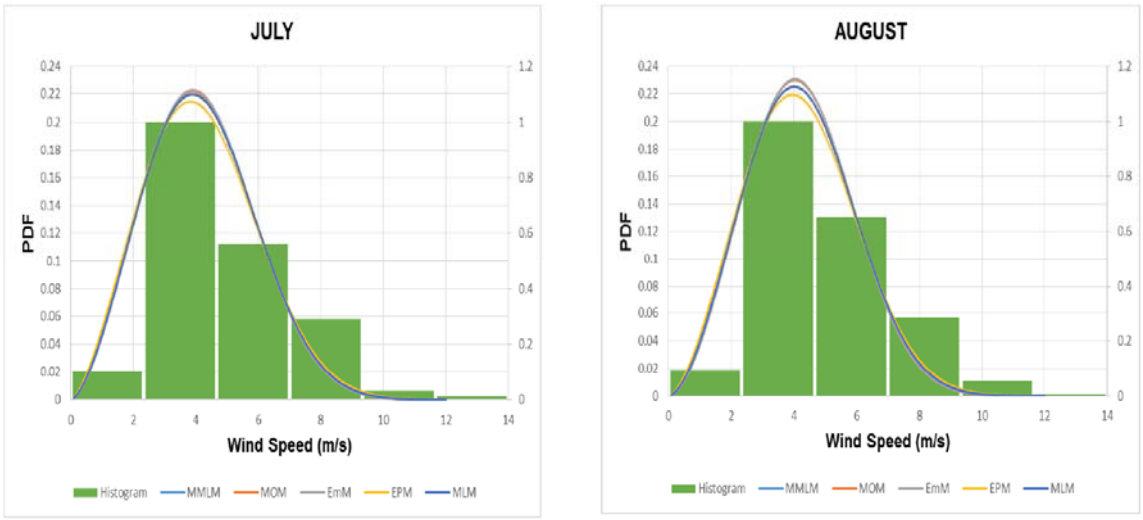

Figure 1: d. Histogram of recorded wind speed data and Weibull plots using MLM, MMLM, MoM, EPM, and EmM for July and August.

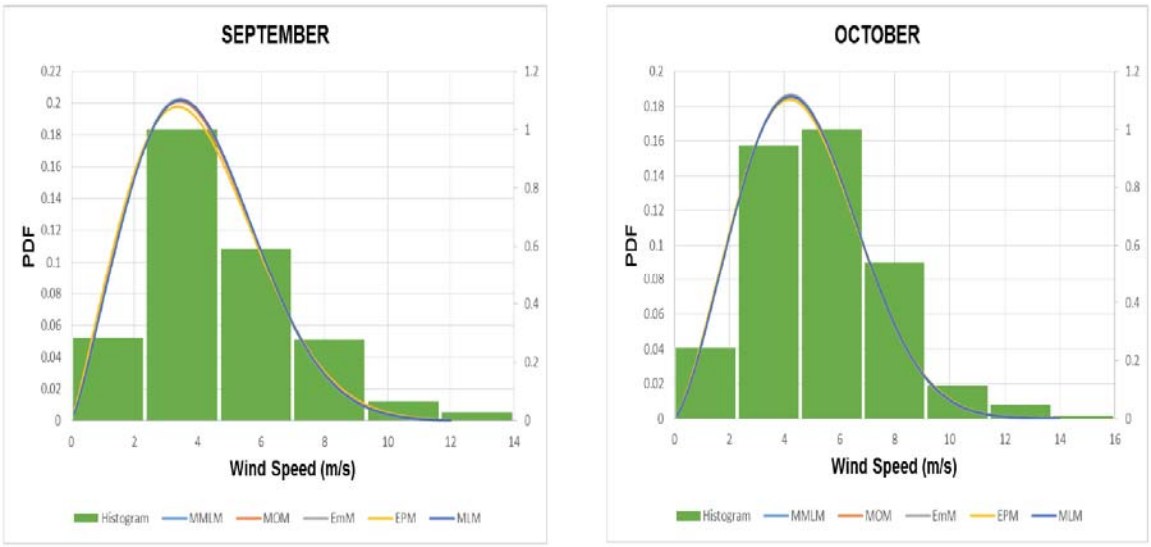

Figure 1: e. Histogram of recorded wind speed data and Weibull plots using MLM, MMLM, MoM, EPM, and EmM for September and October.

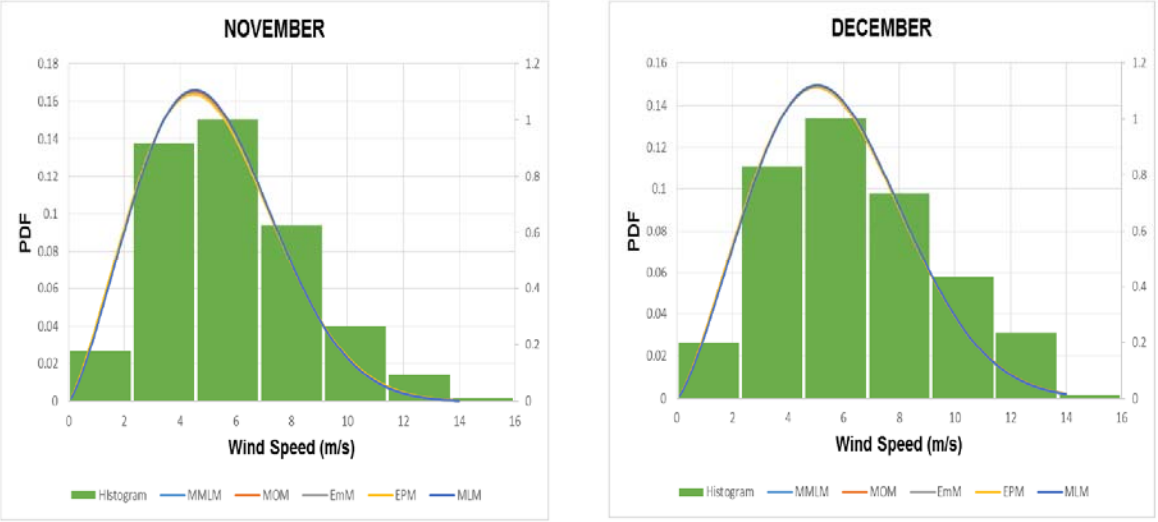

Figure 1: f. Histogram of recorded wind speed data and Weibull plots using MLM, MMLM, MoM, EPM, and EmM for November and December.

(iv) The empirical method (EPM) is reflected as an exceptional case of method of moments (MoM). The values of shape parameter and scale parameter calculated by these methods are very contiguous. Moreover, the expected averaged wind speeds are in virtuous agreement with each other. A Weibull distribution curves of these method reflects a good overlap.

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