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Evaluation of Wind Potential at Eight Selected Locations in Northern Lebanon Using Open Source Data

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Abstract

In this study, ten distribution models were used to analyze the wind speed characteristics and wind energy potential at eight selected locations in Northern Lebanon. The wind speed data were collected from the meteorological department located in Lebanon, Northern Lebanon. The data recorded over various periods to experience different climatic environments and measured at 10m height. The results showed that the annual mean wind speed in the regions is greater than 2 m/s at 10m height. The maximum-likelihood method was being used for calculating the parameters of the distribution functions. Based on the results, it was observed that Generalized Extreme Value distribution provided the best fit to the actual data for the regions of, Aabboudiye, Darine, Hekr El Dahri, saadine, Semmaqiyeh, Tal Aabbas El Gharbi& charqi, Tal El Bireh, Tal Keri. While, Log-Logistic, Weibull and Gamma distributions give a better fit to the actual data of Beirut, and Salamis, respectively. The Rayleigh distribution does not fit actual data from all regions. Moreover, the wind power density values at the studied regions were ranged from 38.76 W/m^2 and 134.29W/m^2 at 50m height, which indicated that wind energy sources in these selected regions, is classified to be poor. Consequently, it is concluded that small-scale wind turbine use can be suitable for generating electricity in the studied regions.

Keywords: Northern Lebanon, Probability density functions; Statistical modeling; Wind speed characterization

1. INTRODUCTION

Renewable energies are considered as important sources for generating electricity because of their advantages such as reducing global warming, air pollution and fossils fuels [1-3]. Therefore, renewable energies such as wind, solar, geothermal and hydro are clean, environmentally friendly and inexhaustible [1-4].

The wind speed characteristics are essential for the investigation of the wind power potential in the specific region [5, 6]. In this regard, probability density functions (PDFs) and cumulative distribution functions (CDFs) are usually used for describing the wind speed and wind power distribution in many regions [7-11]. In the literature, varying of PDFs and CDFs, such as Weibull, Lognormal, Gamma and so on, are used to describe the frequency distributions of wind speed [12-15].

Meanwhile, in Northern Lebanon, the electricity is mainly produced by using fossil fuels, i.e., the electrical demand in Northern Lebanon is covered by using diesel generators power Locations. Additionally, the growth of population and other factors in Northern Lebanon leads to an increase in the demand for fossil fuels. As a result, alternative energy sources such as wind and solar energy can be considered as an alternative energy resource for generating electricity.

It is significant to evaluate the wind potential in Northern Lebanon and select the proper distribution function for analyzing the wind speed characteristics. However, the literature shows the lack of study on analyzing the wind power potential in Northern Lebanon therefore much attention is required to assess wind energy resource to provide a suitable data for estimating the wind power potential.

Consequently, this paper aims to analyze the wind speed characteristics in eight regions, namely, Aabboudiye, Darine, Hekr El Dahri, Saadine, Semmaqiyeh, Tal Aabbas El Gharbi& charqi, Tal El Bireh, Tal Keri in Northern Lebanon. The data consist of monthly, annual and direction wind speed. In particular, the analysis of wind speeds for each region was done at various periods. Thus, the wind speed data were collected from the Meteorology Department located in Beirut. Ten distribution functions were applied to explore the wind speed characteristics and determine the wind power potential in each region. The wind power density as a function of hub height is studied in order to classify the wind energy resource in Northern Lebanon.

2. PROBABILITY DISTRIBUTION FUNCTIONS

Knowledge of wind speed data is required for renewable resource assessment. Several distribution functions are given in the literature to present wind speed data of the selected region [12, 14-16]. In this paper, ten probability distribution functions are used to analyze distributions of wind speed at selected regions. Furthermore, In literature, there are various methods available to compute the parameters of the distribution functions such as the graphical method, the method of moments, and the maximum likelihood method [16]. In this study, the parameter values for each distribution function were calculated using the Maximum likelihood method. In this paper, Easy fit, and Matlab R2015a software were used in order to get the parameters of distribution functions.

3. DATA

The wind data that were collected from historical open source data have been analyzed. The data used for this work are monthly data using a simple statistical method to calculate the average monthly wind speed. The coordinates, records period and characteristics of the selected Location are presented in Table 1.

Table 1. Details of each Location used in this study

Location	Coordinates		Period records	year	Characteristics of the Location
	Latitude [°N]	Longitude [°E]			
Abboudiye	34° 38' 21.12	36° 7' 8.4	2007-2016	10	Coastal
Tal keri	34° 35' 49.752	36° 2' 21.97	2007-2016	10	Coastal
Darine	34° 36' 13.553	36° 6' 26.459	2007-2016	10	Coastal
Heke El Dahri	34° 37' 48	36° 1' 24.6	2007-2016	10	coastal
Saadine	34° 35' 38	36° 5' 36.557	2007-2016	10	coastal
Semmaqiye	34° 38' 20.76	36° 0' 9.72	2007-2016	10	coastal
TalAbbas	34° 34' 577.654	36° 4' 38.301	2007-2016	10	coastal
Tal El Bireh	34° 37' 22.08	36° 3' 31.32	2007-2016	10	coastal

4. WIND CHARACTERISTICS ANALYSIS

4.1 Description of wind speed data

Table 2 presents the descriptive statistics of each Location including mean velocity, standard deviation, variance coefficient, minimum velocity, median velocity, maximum velocity, Skewness, and Kurtosis. For all Locations at 10 m, mean wind speeds vary from 1.931 m/s to 4.947 m/s. Mean speed and standard deviation values suggest that there is good consistency in the wind behavior. The coefficients of variation are moderately high, ranging from 7.08 to 32.58. During the investigation period, the Skewness value is negative at Aabboudiye and Darine, and saadine, and Semmaqiyeh which indicate that all distributions are left-skewed. While, Skewness values of Hekr El Dahri, Tal Aabbas El Gharbi& charqi, Tal Keri, Tal El Bireh, are positive indicating that all distributions are right-skewed.

4.2 Distribution function parameters and wind power density at 10m height

The parameters of ten distribution functions were estimated using monthly wind speed data with the maximum likelihood method. The best distribution among the ten distribution functions for each location was evaluated with their Kolmogorove-Smirnov tests.

The calculated parameters of each distribution function are presented in Table 3 for each selected location along with their mean velocity. Additionally, Figure 1 shows the fitted PDF and CDF model for the observed wind speed data for each Location. In addition, Table 4 presents the goodness-of-fit statistics in term of Kolmogorove-Smirnov tests for each distribution function. Moreover, a distribution with a minimum value of Kolmogorove-Smirnov will be selected to be the best model for the wind speed distribution in the studied location [12].

Table 2. Annual descriptive statistics of wind speed series at eight-selected Location

Location	Mean [m/s]	Standard Deviation	Variation coefficient	Minimum [m/s]	Median [m/s]	Maximum [m/s]	Skewness	Kurtosis
Aabboudiye	2.9404	0.1675	5.7	2.6201	3.0054	3.1548	-1	0.1
Darine	2.638	0.345	13.06	2.059	2.667	3.135	-0.21	-0.73
Hekr El Dahri	2.5984	0.1723	6.03	2.5659	2.9101	3.135	-0.22	-0.54
saadine	2.638	0.345	13.06	2.059	2.667	3.135	-0.21	-0.73
Semmaqiyeh	2.8594	0.1723	6.03	2.5659	2.9101	3.135	-0.21	-0.73
Tal Aabbas	2.638	0.345	13.06	2.059	2.667	3.135	-0.22	-0.54
Tal El Bireh	2.638	0.345	13.06	2.059	2.667	3.135	-0.21	-0.73
Tal Keri	2.638	0.345	13.06	2.059	2.667	3.135	-0.21	-0.73

Table 3. Parameter values of different distribution functions over the investigated period at 10 m height

Distribution functions		Abboudiye	Darine	Hekr El Dahri	Saadine		Semmaqiyeh	Tal Abbass	Tal El Bireh	Tal Keri
	Actual mean	2.94037	2.638	2.8594	2.638	2.859	2.638	2.638	2.638	
G	Mean	2.94037	2.638	2.8594	2.638	2.859	2.638	2.638	2.638	
	a	308.23	35.343	100.19	35.427	101.1	35.33	35.338	35.338	
	b	0.0095	0.07332	0.03	0.0731	0.03	0.0733	0.07338	0.07338	
G(3p)	a	228.43	131.33	0.8856	188	0.89	131.03	131.03	131.03	
	b	0.01085	0.036678	0.37821	0.03	0.33	0.03727	0.03727	0.03727	
	g	0.46428	-2.237	2.62	-3.1625	2.62	-2.2875	-2.2875	-2.2875	
IG	I	906.32	91.583	301.08	91.808	303	91.631	91.631	91.631	
	m	2.9404	2.5913	3.0051	2.5915	3.1	2.593	2.593	2.593	
IG(3P)	m	25.298	72.66	0.73977	Inf	0.752	65.92	65.92	65.92	
	g	-22.357	-70.071	2.2654	61.35	2.252	-63.332	-63.332	63.332	
LL	a	22.036	7.7027	17.685	7.7126	17.7	7.6866	7.6866	7.6866	
	b	2.9126	2.4892	2.93	2.4895	2.93	2.4911	2.4911	2.4911	
LN	s	0.05542	0.16988	0.09305	0.1696	0.092	0.16993	0.16993	0.16993	
	m	1.077	0.93834	1.0959	0.9384	1.095	0.939	0.939	0.939	
LN(3P)	s	0.02751	0.03124	0.376977	0.0317	0.368	0.02963	0.02963	0.02963	
	m	1.7742	2.5874	0.33017	2.5713	-0.31	2.6328	2.6328	2.6328	
	g	-2.9581	-10.702	2.2347	-10.502	2.22	-11.327	-11.327	-11.327	
Na	m	81.106	9.9058	24.096	9.9267	24.3	9.9124	9.9124	9.9124	
	w	8.671	6.8856	9.112	6.8862	9.11	6.8949	6.8949	6.8949	
W	a	16.54	5.7081	12.615	5.716	12.68	5.6981	5.6981	5.6981	
	b	3	2.7124	3.0461	2.7124	3.045	2.7149	2.7149	2.7149	

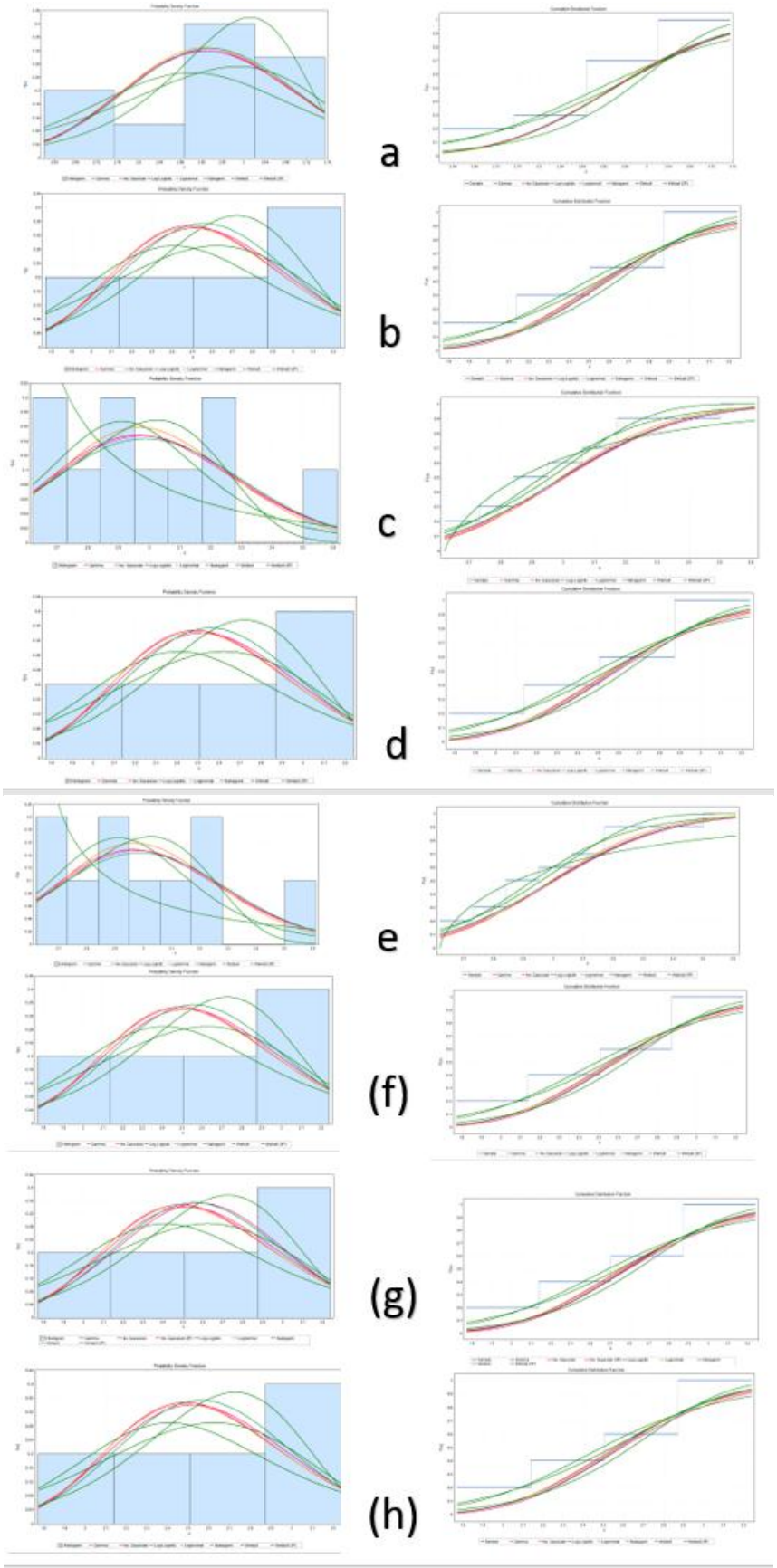

Figure 1. Fitting PDF and CDF models to the wind speed data at the 10m height of (a) Aabboudiye, (b) Darine, (c) Hekr El Dahri, (d) saadine, (e) Semmaqiyeh, (f) Tal Aabbas , (g) Tal El Bireh, and (h) Tal Keri

Table 4. Results of goodness-of-fit and the selected distribution (in bold) for each Location

Model	Abboudiye	Darine	Hekr El Dahri	Saadine	Tal Abbasss	Tal El Bireh	Tal Keri
G	0.29938	0.18783	0.2611	0.1878	0.1902	0.1902	0.1902
G(3P)	0.29725	0.18344	0.1375	0.1965	0.1838	0.1837	0.18377
IG	0.29184	0.16597	0.1375	0.1659	0.168	0.1683	0.16836
IG3P	0.29543	0.18242	0.12815	0.177	0.1859	0.1859	0.18593
LL	0.32265	0.20368	0.16313	0.204	0.2049	0.2049	0.2049
LN	0.24676	0.18704	0.12954	0.1935	0.1957	0.19574	0.19574
Na	0.29864	0.18704	0.12379	0.187	0.1896	0.18964	0.18964
LN(3P	0.30134	0.17734	0.12392	0.1878	0.1896	0.1895	0.18959
LL(3P	0.24676	0.16773	**0.12004**	**0.168**	0.1702	0.1702	0.17028
W(3P)	**0.2104**	**0.153**	0.151	0.188	**0.1535**	**0.1538**	**0.15384**
W	0.29018	0.18736	0.14199	0.187	0.1538	0.1890	0.18912

Table 5. Roughness values (α) , Mean wind speed and wind power density at a various height of the studied locations

Location	Abboudiye	Darine	Hekr El Dahri	Saadine	Semmaqiyeh	Tal Abbass	Tal El Bireh	Tal Keri
α	0.283838	0.288	0.2783	0.2597	0.27373	0.288	0.285	0.285
Mean [m/s] at 10 m	2.94037	2.638	2.8595	2.638008	2.859442	2.63801	2.63801	2.63801
the power density at 10 m [W/m^2]	16.62104	17.28103	18.521	19.722	17.2884	16.6241	16.6241	16.6244

Table 5 presents the surface roughness values of the eight-selected locations. Annual mean wind speeds values of these locations at heights (10m) are calculated using the power law method (Eq. 1) and tabulated in Table 8. It noticed that as the height above the ground increases, the wind speed would increase.

$$\frac{v}{v_{10}} = \left(\frac{z}{z_{10}}\right)^{\alpha} \quad (1)$$

where v is the wind speed at the wind turbine hub height z, v_{10} is the wind speed at original height z_{10}, and α is the surface roughness coefficient, which is depends on the characteristics of the region [17]. The value of α can be obtained from the following expressions [12, 18]

$$\alpha = \frac{0.37 - 0.088ln(v_{10})}{1 - 0.088ln(z_{10}/10)} \quad (2)$$

The best wind speed for installing wind turbine should be in the range of 6.7 and 11 m/s according to Mostafaeipour [19].

5. CONCLUSIONS

In this paper, the accuracy of 10 distribution functions for evaluating the wind speed characteristics at eight selected regions in Northern Lebanon was investigated. For this purpose, the maximum likelihood method was applied to calculate the distribution parameters. The following conclusions can be drawn from the obtained results:

- Results demonstrated that the Saadine location possesses a better wind energy prospect than the other sites.
- It is concluded that small-scale wind turbine use can be suitable for generating electricity in the studied regions. The performance of some small-scale turbines is planned to be evaluated in a future study in order to see how much electrical energy can be provided by the use of wind energy potential of the region.

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