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Research Article

Probability Modelling of Wind Velocity for Assessment of Wind Energy at Alexandria Coast

A.A.H. El-gindy and Elham S. El-nashar
Department of Physical Oceanography, Faculty of Science, Alexandria University, Alexandria, Egypt

Abstract: For the wind energy assessment, it is important to know the probability density distribution of the wind speed in order to calculate the mean power of a wind. In this study wind data, for the period from January 2000 to December 2002, hourly records of speed and direction at Alexandria coast are analyzed as random monthly observations. Statistical methods are used for determination of best fit random distributions of wind speed and direction using statistical standard software that helps in evaluation of wind speed energy potential in a study area. In the present paper, different theoretical Probability Density Functions (PDF) have been tried to determine the appropriate models, including Weibull distribution and their parameters. The minimum wind power density at Alexandria found in July and August (2000-2002) were 20.41 and 21.34 w/m^2 and the maximum was in December and January (110.81 and 123.34 w/m^2). The most important distributions of the wind speed were Weibull and Dagum and the direction followed mostly the Johnson SB model.

Keywords: Alexandria Egypt, probability modelling, wind energy, wind power density

INTRODUCTION

The world energy need increases every year by 4-5% whereas fossil fuel reserves decrease much faster than the need. In addition, with increasing negative effects of fossil fuels on environment, mainly developed countries and others have begun using renewable energy sources. Wind energy is a form of solar energy; it is an air current created by the balance between pressure and temperature differences due to the different distribution of solar heat coming to Earth. Nowadays, the fastest developing and most common used energy source is the wind energy. It is a clean and renewable alternative source of energy potential to fossils based energy sources polluting the lower layer atmosphere. Therefore, wind energy systems transforming wind power to electrical energy has been developing quite fast (Aras *et al*., 2003). Alexandria is a rapidly growing energy consumer and the use of renewable energy, such as wind energy will be of great importance as friendly source to environment.

Alexandria city is located in the south of the eastern Mediterranean at the Egyptian coast. It lies at (lat. 31°12' N, long. 29°57' E), shown in Fig. 1 is in the southern part of the Levantine Sea and it is one of the most important Egyptian cities that is affected by prevailing winds from north west with exceptional strong wind in winter during storms.

LITERATURE REVIEW

The minimum wind speed values occurred during night from 9.00 p.m. to 6.00 a.m. The monthly mean wind speed has the highest values during winter when it reached its maximum in January 1978 (9.2 knots) and in March 1978 (11.6 knots) for the meteorological station under study, Ras El-tin (Sabra, 1979).

According to Shalaby (1999), the wind speed along the Egyptian coast of the Mediterranean Sea, during the period from January 1961 to January 1990, the daily speed records showed higher values in winter season and lower ones in the autumn. The monthly means of the wind speed reached 11-16 knots at Alexandria during January and has minimum values during October, 7-10 knots. The high wind speed ranges, 17-21 and >22 knots, had higher percentage ratio during the winter season at Alexandria. During spring season at Alexandria, the wind speed ranges of 11-16 and 17-21 knots, had high percentage ratio and values>22 knots showed less frequent percentage. During summer season, the wind speed range, 7-10 knots, represented the high percentage at Alexandria. During autumn season, the wind speed ranges 7-10 and 11-16 knots had the high percentage with less frequent high values in the ranges 17-21 and greater than 22 knots. The maximum wind speed occurred during July 1977 to June 1978 round afternoon from 12.00 to 3.00 p.m.

During winter season, the prevailing winds were between south west, west and North West. They were

Corresponding Author: A.A.H. El-Gindy, Department of Physical Oceanography, Faculty of Science, Alexandria University, Alexandria, Egypt, Tel.: 0203484372

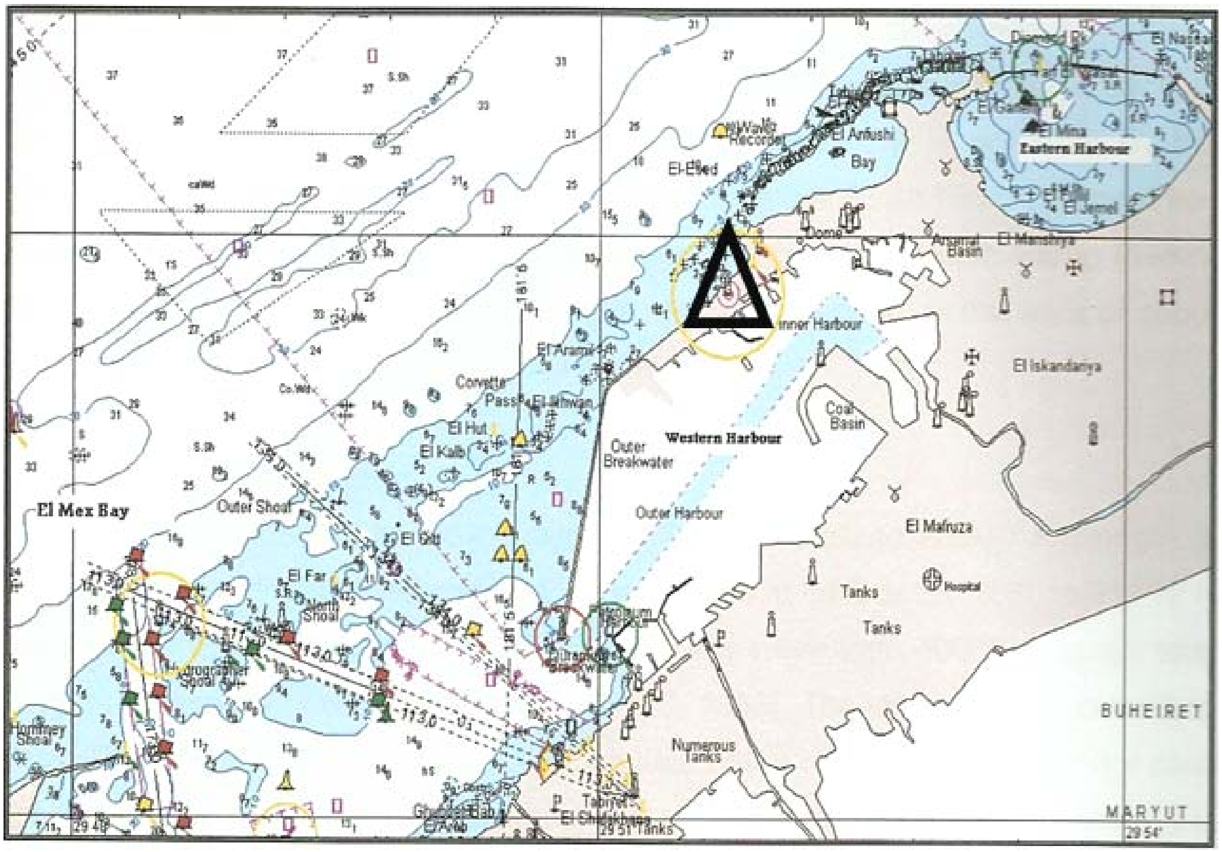


Fig. 1: Alexandria map (admiralty chart), black triangle shows the meteorological station

between north west, north and north east during spring season. Sometimes, strong winds blow between from south east and south west. The prevailing winds were mainly from the North West direction and frequently from west and north directions during summer season. During the autumn season, the prevailing winds were mainly between north west, north and north east with same occasional blow from south west and west directions. The most prevailing direction of wind was north west and north directions (Sabra, 1979; Shalaby, 1999).

Some authors have shown that the wind speed is fitting to the Weibull and other distributions for producing wind energy such as Lun and Lan (2000), Quine (2000), Toure (2005) and Zhou and Yang (2006). Quine (2000) estimated the mean wind climate and the probability of strong winds for wind risk assessment. He found that the relationship between wind strength and probability is commonly derived from several years of measurements at the site of interest. This relationship can be derived from the mean wind climate and represented by parameters of the parent Weibull distribution.

Mortensen *et al*. (2006) provided a coherent and consistent overview of the wind energy resource over the land and sea of Egypt. The wind resource assessments and the site of wind turbines and wind farms may be employed directly by the mesoscale modelling results of the numerical wind atlas database. Yilmaz and Çelik (2008) estimated the wind speed probabilities using the probability distributions of Beta, Erlang, Exponential, Gamma, Log-Logistic, Lognormal, Pearson V, Pearson VI, Uniform and Weibull. Baran *et al*. (2013) described two possible Bayesian Averaging (BMA) models for wind speed data of the Hungarian Meteorological Service and showed that BMA post-processing significantly improves the calibration and precision of forecasts.

This study deals with the statistical analysis of hourly wind speed and direction data using probability models and the descriptive statistical measures at Alexandria Egypt.

MATERIALS AND METHODS

The data for speed and direction are obtained at Alexandria western harbour (Ras el Tin station), for the period of three years from January 2000 to December 2002, as hourly records. The western harbour lies at latitude 31°10' N and longitude 29°52.5 E with 7500000 m^2 surface area, 7 km length, 2 km maximum width and average 5.5 m depth (MRCC, 1993). It consists of two main basins, the inner basin and the outer basin (Fig. 1).

The data of wind speed and direction are modelled mathematically by the Probability distributions. This analysis was done on monthly bases from January to December. Foreach month, the data of the 3 years of analysis in the years 2000-2002 are used. In addition, the seasonal data for each year separately: winter (January, February and March), spring (April, May and June), summer (July, August and September) and autumn (October, November and December) are analyzed. For wind velocity, the proper distributions are determined by comparing 14 PDF (Weibull, Burr, Dagum, Gamma, Generalized (Gen.) Gamma, Gumbel Max, Maximum Extreme Value Type 1, Normal, Pearson Type 6, Johnson SB, Generalized Extreme Value, Nakagami, Beta and Cauchy) in the study area. The proper PDF was chosen by comparing with the most matching theoretical distributions with the observations. The goodness of fit plots (the Probability-Probability (P-P) and the Quantile-Quantile (Q-Q)) was used to find the convenient theoretical PDF distribution. The Easy Fit 5.5 Professional software (www.qweas.com) was used for these calculations.

Theory/calculation: The equations of the used distributions of the wind velocity probability.

Weibull distribution: The parameters: α-continuous shape parameter (α>0), β-continuous scale parameter (β>0) where 0≤χ<∞, the random variable and the Probability Density Function can be expressed by Eq. (1):

$$f(x) = \frac{\alpha}{\beta} + \left(\frac{\chi}{\beta}\right)^{\alpha-1} exp\left(-\left(\frac{\chi}{\beta}\right)^{\alpha}\right) \quad (1)$$

And the Cumulative Distribution Function (CDF) Eq. (2):

$$F(x) = 1 - exp\left(-\left(\frac{\chi}{\beta}\right)^{\alpha}\right) \quad (2)$$

Burr distribution: The parameters: *k*-continuous shape parameter (*k*>0), α-continuous shape parameter (α>0), β-continuous scale parameter (β>0) where 0≤χ<+∞. Probability Density Function can be expressed by Eq. (3):

$$f(x) = \frac{ak\left(\frac{x}{\beta}\right)^{\alpha-1}}{\beta\left(1+\left(\frac{x}{\beta}\right)^{\alpha}\right)^{k+1}} \quad (3)$$

And the Cumulative Distribution Function Eq. (4):

$$F(x) = 1 - \left(1 + \left(\frac{x}{\beta}\right)^{\alpha}\right)^{-k} \quad (4)$$

Dagum distribution: The parameters: *k*-continuous shape parameter (*k*>0), α-continuous shape parameter (α>0), β-continuous scale parameter (β>0) where 0≤χ<+∞. Probability Density Function can be expressed by Eq. (5):

$$f(x) = \frac{ak\left(\frac{x}{\beta}\right)^{\alpha k-1}}{\beta\left(1+\left(\frac{x}{\beta}\right)^{\alpha}\right)^{k+1}} \quad (5)$$

And the Cumulative Distribution Function Eq. (6):

$$F(x) = \left(1 + \left(\frac{x}{\beta}\right)^{-\alpha}\right)^{-k} \quad (6)$$

Gamma distribution: The parameters: α-continuous shape parameter (α>0), β-continuous scale parameter (β>0) where 0≤χ<+∞. Probability Density Function can be expressed by Eq. (7):

$$f(x) = \frac{(x)^{\alpha-1}}{\beta^{\alpha}\Gamma(\alpha)} exp\left(-\frac{x}{\beta}\right) \quad (7)$$

And the Cumulative Distribution Function Eq. (8):

$$F(x) = \frac{\frac{\Gamma x}{\beta(\alpha)}}{\Gamma(\alpha)} \quad (8)$$

where, Γ is the Gamma Function.

Generalized gamma distribution: The parameters: k-continuous shape parameter (k>0), α-continuous shape parameter (α>0), β-continuous scale parameter (β>0) where 0≤χ<+∞. Probability Density Function can be expressed by Eq. (9):

$$f(x) = \frac{kx^{k\alpha-1}}{\beta^{k\alpha}\Gamma(\alpha)} exp\left(-(\frac{x}{\beta})\,^\wedge k\right) \quad (9)$$

The Cumulative Distribution Function can be expressed by Eq. (10):

$$F(x) = \frac{\Gamma\left(\frac{x}{\beta}\right)^{k(\alpha)}}{\Gamma(\alpha)} \quad (10)$$

Gumbel max (maximum extreme value type 1) distribution: The parameters: σ-continuous scale parameter (σ>0), μ-continuous location parameter, where, $-\infty < x < +\infty$. Probability Density Function can be expressed by Eq. (11):

$$f(x) = \frac{1}{\sigma} exp\left(-z - exp(-z)\right) \quad (11)$$

The Cumulative Distribution Function is given by Eq. (12):

$$f(x) = exp\left(-exp(-z)\right) \quad (12)$$

where, $z \equiv \frac{x-\mu}{\sigma}$.

Normal distribution:
The parameters: σ-continuous scale parameter (σ>0), μ-continuous location parameter where, $-\infty < x < +\infty$. Probability Density Function can be expressed by Eq. (13):

$$f(x) = \frac{exp(-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2}{\sigma\sqrt{2\pi}} \quad (13)$$

The Cumulative Distribution Function is calculated by Eq. (14):

$$f(x) = \Phi\left(\frac{x-\mu}{\sigma}\right) \quad (14)$$

where, Φ is the Laplace integral.

Pearson type 6 distribution:
The parameters: α1-continuous shape parameter (α1>0), α2-continuous shape parameter (α2>0), β-continuous scale parameter (β>0) where $0 \leq x \leq +\infty$. Probability Density Function can be expressed by Eq. (15):

$$f(x) = \frac{\left(\frac{x}{\beta}\right)^{\alpha1-1}}{\beta B(\alpha1,\alpha2)\left(1+\frac{x}{\beta}\right)^{\alpha1+\alpha2}} \quad (15)$$

And the Cumulative Distribution Function Eq. (16):

$$F(x) = \frac{\mathrm{I}x}{(x+\beta)^{(\alpha1,\alpha2)}} \quad (16)$$

where, β is the Beta Function.

Beta distribution: The parameters: α1-continuous shape parameter (α1>0), α^2-continuous shape parameter (α^2>0), a, b-continuous boundary parameters (a<b) where a$\leq x \leq b$. Probability Density Function can be expressed by Eq. (17):

$$f(x) = \frac{1}{B(\alpha1,\alpha2)}\frac{(x-a)^{\alpha1-1}(b-x)^{\alpha2-1}}{(b-a)^{\alpha1+\alpha2-1}} \quad (17)$$

The Cumulative Distribution Function is given by Eq. (18):

$$F(x) = \mathrm{I}z(\alpha1, \alpha2) \quad (18)$$

where, $z \equiv \frac{x-a}{b-a}$, B is the Beta Function and Iz is the Regularized Incomplete Beta Function.

Cauchy distribution: The parameters: σ-continuous scale parameter (σ>0), μ-continuous location parameter where $-\infty < x < +\infty$. Probability Density Function can be expressed by Eq. (19):

$$f(x) = \left(\pi\sigma\left(1+\left(\frac{x-\mu}{\sigma}\right)^2\right)\right)^{-1} \quad (19)$$

And the Cumulative Distribution Function Eq. (20):

$$F(x) = \frac{1}{\pi}arctan\left(\frac{x-\mu}{\sigma}\right) + 0.5 \quad (20)$$

Johnson SB distribution:
The parameters: γ-continuous shape parameter, δ-continuous shape parameter ($\delta > 0$), λ-continuous scale parameter ($\lambda > 0$), ξ-continuous location parameter where, $\xi \leq x \leq \xi + \lambda$. Probability Density Function can be expressed by Eq. (21):

$$f(x) = \frac{\delta}{\lambda\sqrt{2\pi}z(1-z)} exp\left(-\frac{1}{2}\left(\gamma + \delta ln\left(\frac{z}{1-z}\right)\right)^2\right) \quad (21)$$

And the Cumulative Distribution Function Eq. (22):

$$F(x) = \Phi\left(\gamma + \delta ln\left(\frac{z}{1-z}\right)\right) \quad (22)$$

where, $z \equiv \frac{x-\xi}{\lambda}$ and Φ is the Laplace Integral.

Generalized extreme value distribution:
The parameters: k-continuous shape parameter, σ-continuous scale parameter (σ>0), μ-continuous location parameter, where, $1 + \mathrm{k}\frac{(\mathrm{x}-\mu)}{\sigma} > 0\ for\ k = 0 - \infty < x < +\infty\ for\ k = 0$. Probability Density Function can be expressed by Eq. (23):

$$f(x) = \begin{cases}\frac{1}{\sigma}\exp(-(1+kz)^{-1/k})(1+kz)^{-1-1/k} & k \neq 0\end{cases} \quad (23)$$

$$f(x) = \begin{cases}\frac{1}{\sigma}\exp(-z - exp(-z)) & k = 0\end{cases}$$

And the Cumulative Distribution Function Eq. (24):

$$F(x) = \begin{cases}\exp\left(-(1+kz)^{-1/k}\right) & k \neq 0 \\ \exp(-exp(-z)) & k = 0\end{cases} \quad (24)$$

where, $z \equiv \frac{x-\mu}{\sigma}$.

Nakagami distribution:
The parameters: m-continuous parameter (m≥0.5), Ω-continuous parameter (Ω>0), where 0≤x≤∞. Probability Density Function can be expressed by Eq. (25):

$$f(x) = \frac{2m^m}{\Gamma(m)\Omega^m}x^{2m-1}exp\left(\frac{-m}{\Omega}x^2\right) \quad (25)$$

And the Cumulative Distribution Function Eq. (26):

$$F(x) = \frac{\Gamma mx^2/\Omega(m)}{\Gamma(m)} \quad (26)$$

Wind power density: Wind power density is proportional to the mean of wind speed cu $\overline{v^3}$ be. It can be calculated by:

$$P = \frac{1}{2}\,\rho\overline{v^3} \tag{27}$$

where, ρ (kg/m^3) is the mean air density (1.069 kg/m^3) is used in this study. This depends on altitude, air pressure and temperature (Chang, 2010).

Testing of fitting of the probability distributions with observations has been done by:

- The Probability-Probability (P-P) plot which is a graph of the empirical CDF values plotted against the theoretical CDF values. It is used to determine how well a specific distribution fits to the observed data. This plot will be approximately linear if the specified theoretical distribution is the correct model.
- The Quantile-Quantile (Q-Q) plot which is produced by plotting the observed data values x_i (i = 1, ... , n) along the X-axis, against:

$$F^{-1}(Fn(Xi) - \frac{0.5}{n} \text{ as Y-axis}$$

where, F^{1} (x) is Inverse Cumulative Distribution Function (ICDF), Fn (x) is empirical CDF and n is sample size. The Q-Q plot will be approximately linear if the specified theoretical distribution is the correct model.

RESULTS AND DISCUSSION

The above methods of analysis have been applied at Alexandria, Egypt, meteorological station in the study period on monthly and seasonal bases and the main results are shown below.

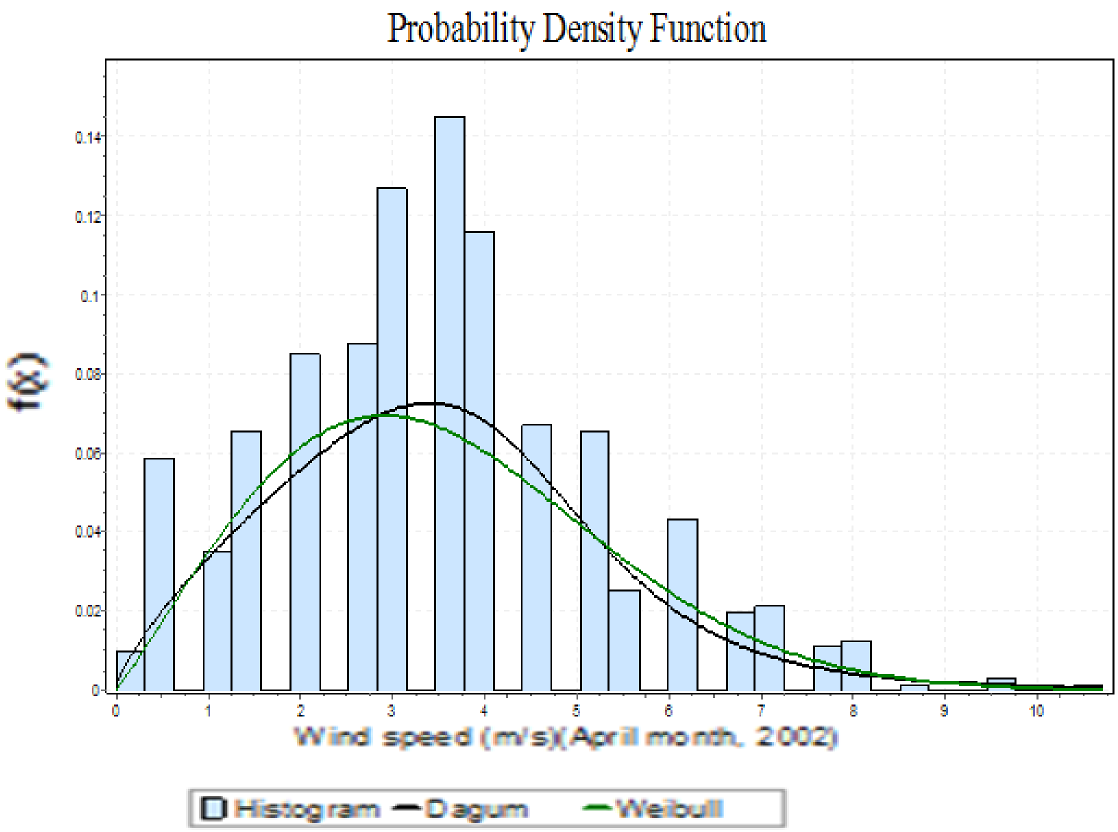
Probability distributions of wind velocity:
Probability distributions of wind speed:
Monthly wind speed for the period of study: The Weibull probability distribution was good for all months of the study period. In addition to this model. Other models were also found to be in good fitting with data. During January 2000, the Dagum model was good fitting, during January, July and October 2001, the Burr model had good fitting, during January 2002, December

Table 1: Parameters of wind speed probability distributions and all the years mean and standard deviations at Alexandria Egypt in the period 2000-2002 months individually

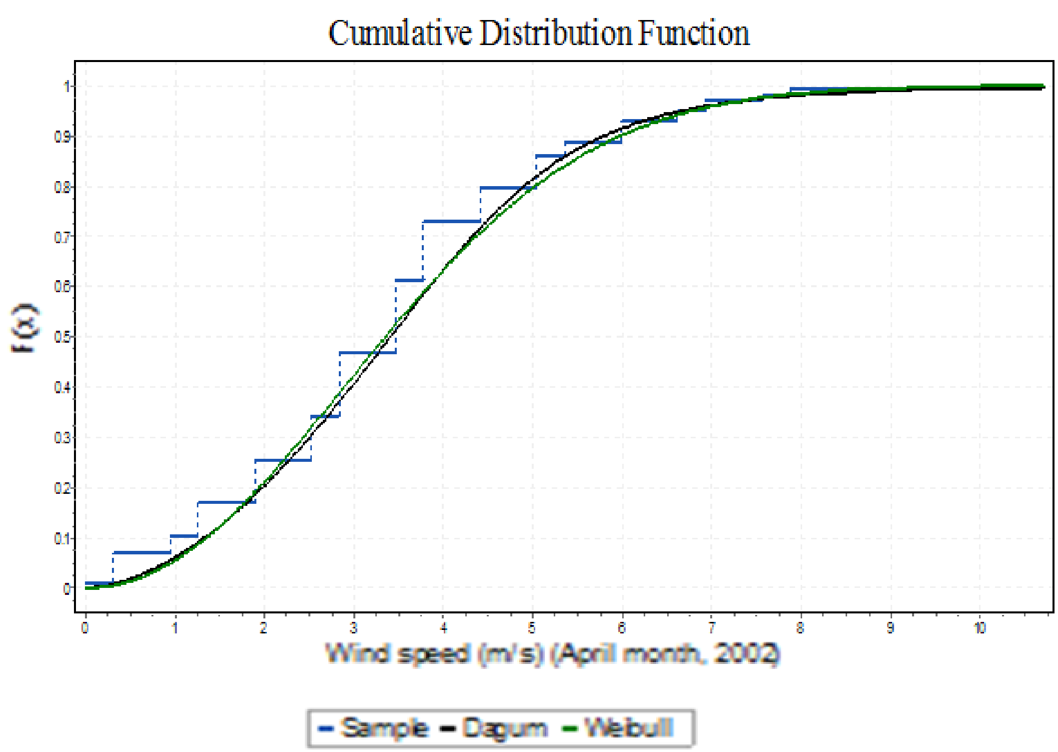
Month	Year	Weibull model α	β	Other models	
January	2000	1.2916	4.5343	Dagum	K = 0.4061, α = 2.9004 β = 5.7374
	2001	1.6243	3.4189	Burr	K = 1393.3000, α = 1.6244 β = 294.5300
	2002	1.0106	4.6741	Pearson 6	α1 = 1.3106, α2 = 5.8314E+7 β = 2.0503E+8
	Average of the three months±S.D.	1.3088± 0.3072	4.2091 ±0.6879		
	The three years value (2000-2002)	1.0964	4.3140	Gen. gamma	k = 0.9627, α = 1.5497 β = 2.6200
February	2000	1.3282	3.6971	Gumbel max	σ = 1.9837, μ = 2.0381
	2001	1.7732	3.9537	Dagum	K = 0.3407, α = 4.6131 β = 4.9018
	2002	1.8986	4.8452	Dagum	K = 0.3836, α = 4.7460 β = 5.5887
	Average±S.D.	1.6667±0.2998	4.1653±0.6026		
	2000-2002	1.7201	4.4476	Dagum	k = 0.2946, α = 4.8949 β = 5.8254
March	2000	1.4726	3.7170	Dagum	K = 0.3390, α = 3.7994 β = 4.8782
	2001	1.6707	3.7535	Nakagami	m = 0.8451, Ω = 15.3150
	2002	2.1952	4.7990	Gen. extreme value	K = -0.1230, σ = 1.8379 μ = 3.3562
	Average±S.D.	1.7795±0.3734	4.0898±0.6144		
	2000-2002	1.8683	4.3790	Dagum	k = 0.2845, α = 5.3296 β = 5.7362
April	2000	1.4553	3.8200	Gen. gamma	K = 1.9895, α = 0.6209 β = 5.3274
	2001	1.8814	3.9749	Dagum	k = 0.3509, α = 4.7302 β = 4.8604
	2002	2.0776	3.9938	Dagum	k = 0.3014, α = 5.7927 β = 4.9763
	Average±S.D.	1.8048±0.3181	3.9296±0.0954		
	2000-2002	1.8721	3.9675	Dagum	K = 0.2996, α = 5.2096 β = 5.1046

Table 1: Continue

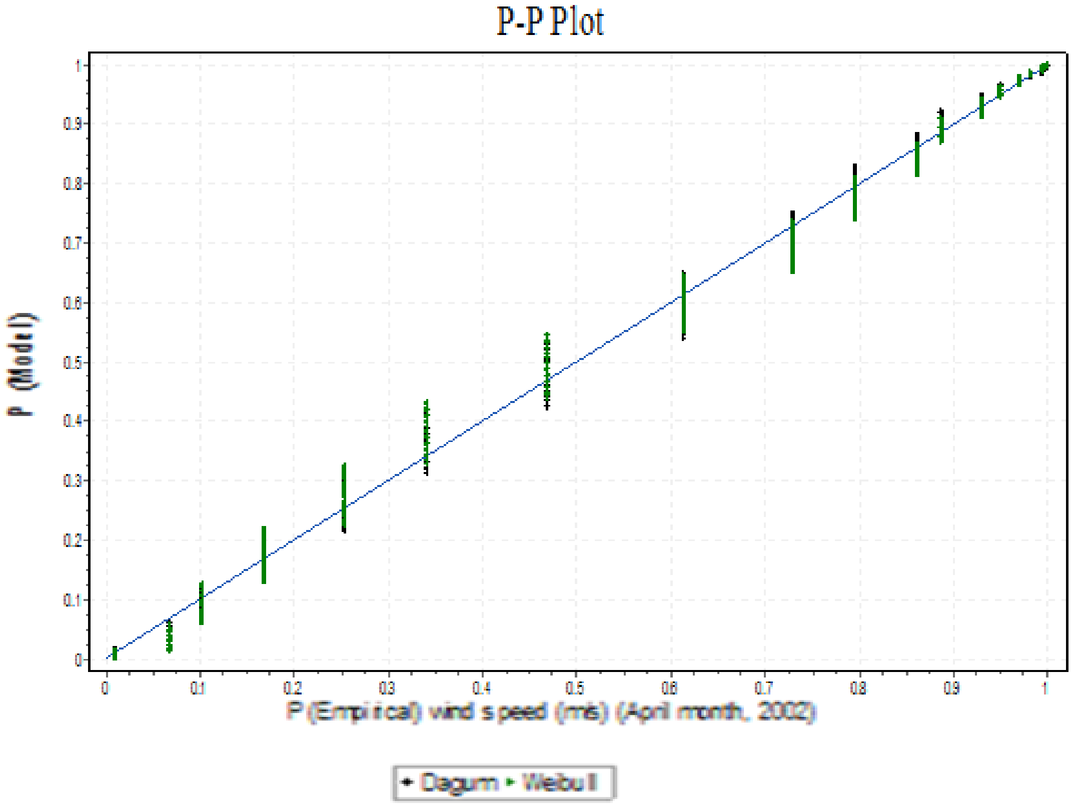
Month	Year	Weibull model α	β	Other models	
May	2000	1.6056	3.2163	Dagum	k = 0.1960, α = 5.9346 β = 4.9949
	2001	1.8800	3.9957	Dagum	k = 0.3148, α = 5.2284 β = 4.9662
	2002	1.7398	3.2911	Dagum	k = 0.2750, α = 5.0892 β = 4.4705
	Average±S.D.	1.7418±0.1372	3.5010±0.4300		
	2000-2002	1.7553	3.5837	Dagum	K = 0.2687, α = 5.3031 β = 4.8311
June	2000	2.0210	3.2331	Dagum	K = 0.19019, α = 7.6388 β = 4.5774
	2001	1.7659	2.9430	Dagum	k = 0.2771, α = 5.4416 β = 3.8798
	2002	1.7988	3.3620	Dagum	K = 0.2280, α = 6.0488 β = 4.7152
	Average±S.D.	1.8619±0.1388	3.1794±0.2146		
	2000-2002	1.8247	3.1637	Dagum	k = 0.2447, α = 5.8514 β = 4.3399
July	2000	2.8717	3.9945	Dagum	k = 0.2767, α = 8.4402 β = 4.7618
	2001	2.0640	2.6399	Burr	k = 836.8100, α = 2.2324 β = 53.3290
	2002	1.8005	3.1613	Gen. gamma	k = 2.1081, α = 0.7798 β = 3.6936
	Average±S.D.	2.2454±0.5582	3.2652±0.6833		
	2000-2002	1.9644	3.0533	Dagum	k = 0.2608, α = 5.9970 β = 4.0518
August	2000	3.1729	4.2098	Normal	σ = 1.2906, μ = 3.7777
	2001	1.5991	2.0961	Nakagami	m = 0.7421, Ω = 4.8944
	2002	2.5886	3.6825	Normal	σ = 1.3730, μ = 3.2670
	Average±S.D.	2.4535±0.7955	3.3295±1.1002		
	2000-2002	1.9367	3.1143	Gen. gamma	K = 3.3066, α = 0.4536 β = 4.4516
September	2000	2.9462	3.8895	Dagum	k = 0.1788, α = 11.6490 β = 4.9946
	2001	1.6230	2.4360	Gen. extreme value	K = -0.0688, σ =1.1288 μ = 1.5762
	2002	1.6483	3.5442	Gen. gamma	K = 2.3213, α = 0.5926 β = 4.8570
	Average±S.D.	2.0725±0.7568	3.2899±0.7594		
	2000-2002	1.6654	3.1086	Dagum	K = 0.2172, α = 5.7833 β = 4.5969
October	2000	1.5798	4.6952	Dagum	k = 0.3544, α =3.9948 β = 5.8925
	2001	1.3933	2.2901	Burr	k = 1371.7000, α = 1.4504 β = 331.7400
	2002	1.7202	3.5409	Gen. gamma	k =3.8992, α = 0.3165 β = 5.8001
	Average±S.D.	1.5644±0.1640	3.5087±1.2029		
	2000-2002	1.4413	3.1343	Dagum	k = 0.2137, α = 5.1067 β = 4.9556
November	2000	1.4056	3.5020	Dagum	k = 0.4006, α = 3.5247 β = 4.2810
	2001	1.2205	3.4037	Nakagami	m = 0.5348, Ω = 15.5640
	2002	1.1639	3.2199	Gen. gamma	k = 2.1513, α = 0.5128 β = 5.2476
	Average±S.D.	1.2633±0.1264	3.3752±0.1432		
	2000-2002	1.2202	3.3436	Nakagami	m = 0.5156, Ω = 14.9180
December	2000	1.2309	4.3250	Gamma	α = 1.7250, β = 2.3180
	2001	1.1283	3.9303	Pearson 6	α1 = 1.2158, α2 = 4.0038E+7 β = 1.2383E+8
	2002	1.4581	4.9076	Dagum	K = 0.2057, α = 5.2266 β = 7.7915
	Average±S.D.	1.2724±0.1688	4.3876±0.4917		
	2000-2002	1.2881	4.4212	Nakagami	m = 0.5492, Ω = 25.9670


Probability Density Function
f(x)
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0
1
2
3
4
5
6
7
8
9
10
Wind speed (m/s)(April month, 2002)
Histogram
Dagum
Weibull

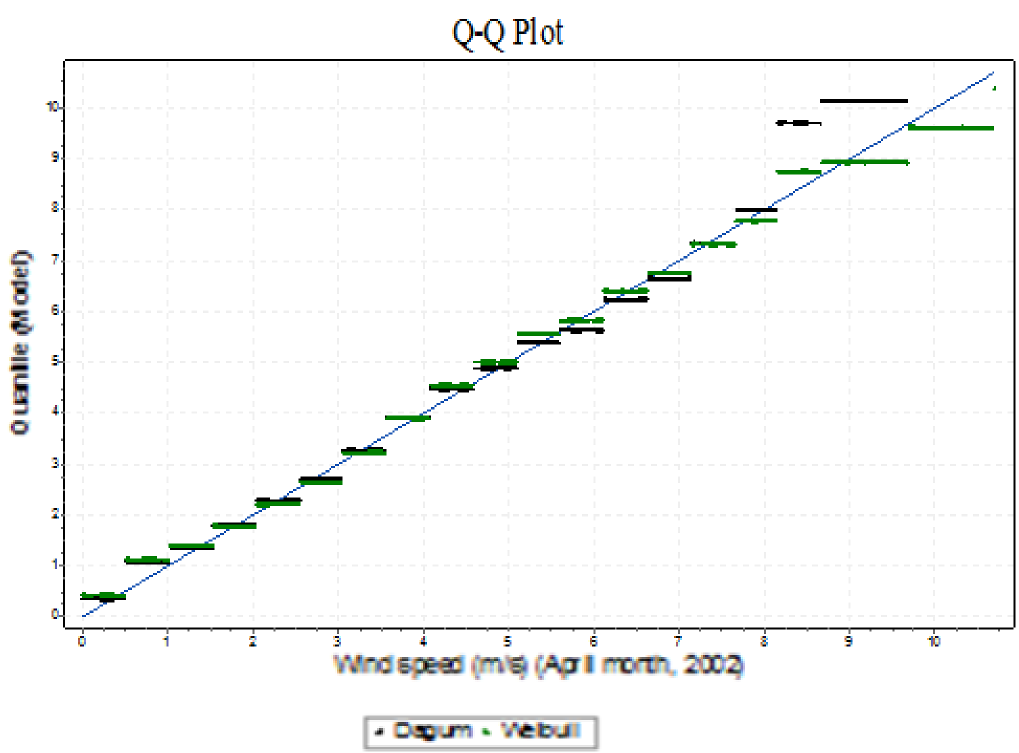
(a)


Cumulative Distribution Function
f(x)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
1
2
3
4
5
6
7
8
9
10
Wind speed (m/s) (April month, 2002)
Sample
Dagum
Weibull

(b)



(c)



(d)

Fig. 2: April 2002 wind speed probabilities, at Alexandria, Egypt. This Figure shows Dagum model is more proper than Weibull

2001, the Pearson 6 model was good fitting, during March 2001, august 2001 and November 2001, the Nakagami model was good, during March 2002, the Gen. Extreme Value model had a good fitting with data. During April 2000, July and September 2002, the Gen. Gamma model had similarity to actual data and in August 2000, the good model was Normal, while Dagum model was the best during February (2001, 2002), March 2000, April 2002, May (2000, 2001, 2002), June (2001, 2002), July 2000, September 2000, October 2000, November 2000 and December 2002. The Normal distribution and Gen. Extreme Value and Gamma models were the best than Weibull during August 2002, September 2001 and December 2000. Gen Gamma model was the best during July 2002 and November 2002. The parameters of the good fitting models are mentioned in Table 1. Examples of the best fit distributions, Fig. 2 shows April 2002 results of wind speed probabilities. This Figure indicates that Dagum model is probably more proper than Weibull.

The Weibull probability distribution was in good fitting for all months of the study period. In addition to this model, other model (Nakagami) was applicable during November and December. During February, March, April, May, June, July and October, Dagum distribution was in good fitting better than Weibull distribution. Gen. Gamma model was the best during January and August. The Weibull model parameters of monthly wind speed for the period 2000-2002 means and standard deviations of the monthly wind speed of the period of study are shown in Table 1.

Seasonal wind speed: During all seasons of the study period, the Weibull distribution was the best fitting one. However, during winter 2000, summer 2000 and autumn 2001, Dagum, Johnson SB and Gamma models were comparable in their fitting. During winter (2001, 2002), spring (2000, 2001, 2002), summer (2001, 2002) and autumn (2000, 2002), the Dagum model was better fitting than Weibull. Table 2 shows the parameters of the good models.

Descriptive statistics of wind speed and wind generation possibility at Alexandria, Egypt: The amount of energy harvestable from a wind turbine in a particular location depends on the characteristics of the wind turbine and wind conditions. It is based on the output power curve of a wind turbine and wind speed statistics.

It is important to know the minimum and the maximum mean wind speed for the generation of wind energy by using turbines. For Alexandria coast, during the years months 2000, 2001 and 2002 and the period from 2000 to 2002 of all months of the year are illustrated in Table 3. From this table, the minimum wind power density was found in July and August (2000-2002) were 20.41 and 21.34 w/m^2 respectively that the corresponding mean wind speed were 2.70±1.45 and 2.74±1.49 m/sec. respectively, the maximum power in the months December and January (110.81 and 123.34 w/m^2) and the corresponding mean wind speed were (4.05±3.10 and 4.11±3.28 m/sec).

Table 2: Parameters of wind speed probability distributions at Alexandria, Egypt, in the period 2000-2002 seasons

		Weibull model			
Season	Year	α	β	Other models	
Winter (Jan., Feb., March)	2000	1.3390	3.9872	Dagum	k = 0.3187, α = 3.5268 β = 5.6258
	2001	1.6790	3.6995	Dagum	k = 0.2587, α = 5.1288 β = 5.1660
	2002	1.6356	4.8878	Dagum	K = 0.2983, α = 4.5046 β = 6.5708
Spring (April, May, June)	2000	1.6088	3.4267	Dagum	k = 0.2365, α = 5.2609 β = 4.9867
	2001	1.8007	3.6348	Dagum	K = 0.3245, α = 4.8452 β = 4.5667
	2002	1.8447	3.5458	Dagum	K = 0.2557, α = 5.7044 β = 4.7974
Summer (July, August, Sep.)	2000	2.9866	4.0363	Johnson SB	γ = -1.1374, δ = 6.0998 λ = 33.3590, ξ = -14.6330
	2001	1.8377	2.3967	Dagum	k = 0.2036, α = 6.6209 β = 3.5063
	2002	1.9096	3.4737	Dagum	k = 0.2174, α = 6.6418 β = 4.8498
Autumn (Oct., Nov., Dec.)	2000	1.4674	4.2309	Nakagami	m = 0.5558, Ω = 21.5260
	2001	1.1562	3.1160	Gamma	α = 1.3428, β = 2.2107
	2002	1.4320	3.9239	Dagum	k = 0.2069, α = 5.1904 β = 6.2401

Table 3: The mean and the standard deviation of the wind speed data in m/sec and the wind power in w/m^2 at Alexandria, Egypt, during different months of the years 2000, 2001 and 2002 individually and in the total period (2000-2002)

	Mean wind speed (m/sec) (year)				Wind power density (w/m^2) (year)	
	2000	2001	2002	2000-2002	2000, 2001, 2002	
Month	Mean±S.D.	Mean±S.D.	Mean±S.D.	Mean±S.D.	Mean±S.D.	2000-2002
Jan.	4.10±3.30	3.01±1.95	4.48±3.54	4.11±3.28	104.83±61.14	123.34
Feb.	3.18±2.54	3.44±2.10	4.29±2.36	3.89±2.40	64.12±20.11	73.20
March	3.34±2.35	3.35±2.03	4.22±2.07	3.87±2.16	57.44±13.38	62.94
April	3.43±2.39	3.52±1.96	3.51±1.80	3.50±1.96	49.80±7.93	47.32
May	2.84±1.83	3.54±1.96	2.87±1.77	3.15±1.89	35.61±11.42	37.48
June	2.86±1.48	2.60±1.48	2.96±1.72	2.79±1.60	24.00±4.75	24.40
July	3.54±1.38	2.32±1.10	2.79±1.62	2.70±1.45	23.52±11.60	20.41
Aug.	3.78±1.29	1.88±1.17	3.27±1.37	2.74±1.49	25.28±15.65	21.34
Sep	3.44±1.35	2.16±1.31	3.15±1.96	2.77±1.71	27.31±13.80	26.13
Oct.	4.20±2.75	2.06±1.46	3.16±1.85	2.83±2.01	49.94±46.16	35.17
Nov.	3.22±2.43	3.17±2.36	2.99±2.22	3.10±2.31	51.29±9.25	48.70
Dec.	3.95±2.73	3.69±3.26	4.43±3.01	4.05±3.10	105.08±18.39	110.81

S.D.: Standard deviation

Table 4: Parameters of wind direction probability distributions at Alexandria, Egypt, in the period 2000-2002

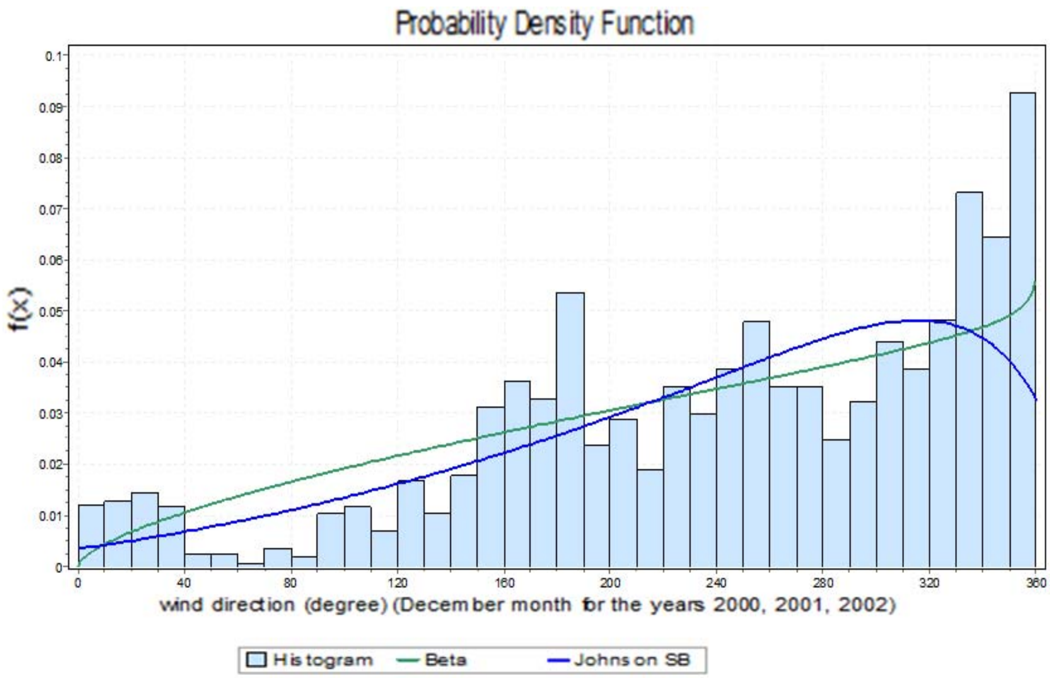
Period (2000, 2001, 2002)	Other models	
January	Johnson SB	γ = -0.4892, δ = 0.3951 λ = 347.8000, ξ = 7.0712
February	Johnson SB	γ = -0.1163, δ = 0.2790 λ = 337.2700, ξ = 9.3194
March	Johnson SB	γ = -0.1518, δ = 0.1932 λ = 320.0000, ξ = 20.2800
April	Johnson SB	γ = -0.1917, δ = 0.2408 λ = 333.3600, ξ = 15.9420
May	Johnson SB	γ = -0.4769, δ = 0.1645 λ = 334.0300, ξ = 14.1770
June	Johnson SB	γ = -0.8955, δ = 0.0689 λ = 334.7100, ξ = 6.1472
July	Johnson SB	γ = -1.0301, δ = 0.1579 λ = 339.4500, ξ = -0.6234
August	Johnson SB	γ = -1.1179, δ = 0.1835 λ = 346.0900, ξ = -8.9997
September	Johnson SB	γ = -0.5673, δ = 0.2016 λ = 331.4000, ξ = 15.9710
October	Johnson SB	γ = -0.5805, δ = 0.2305 λ = 344.5600, ξ = 3.9738
November	Johnson SB	γ = -0.0443, δ = 0.3774 λ = 355.2500, ξ = 9.0940
December	Beta	α1 = 1.6439, α2 = 0.9583 a = -1.0287E-14, b = 360.0000
	Johnson SB	γ = -0.9794, δ = 0.9810 λ = 490.9600, ξ = -101.0500

Table 5: Parameters of wind direction seasonal probability distributions at Alexandria, Egypt, in the period 2000-2002

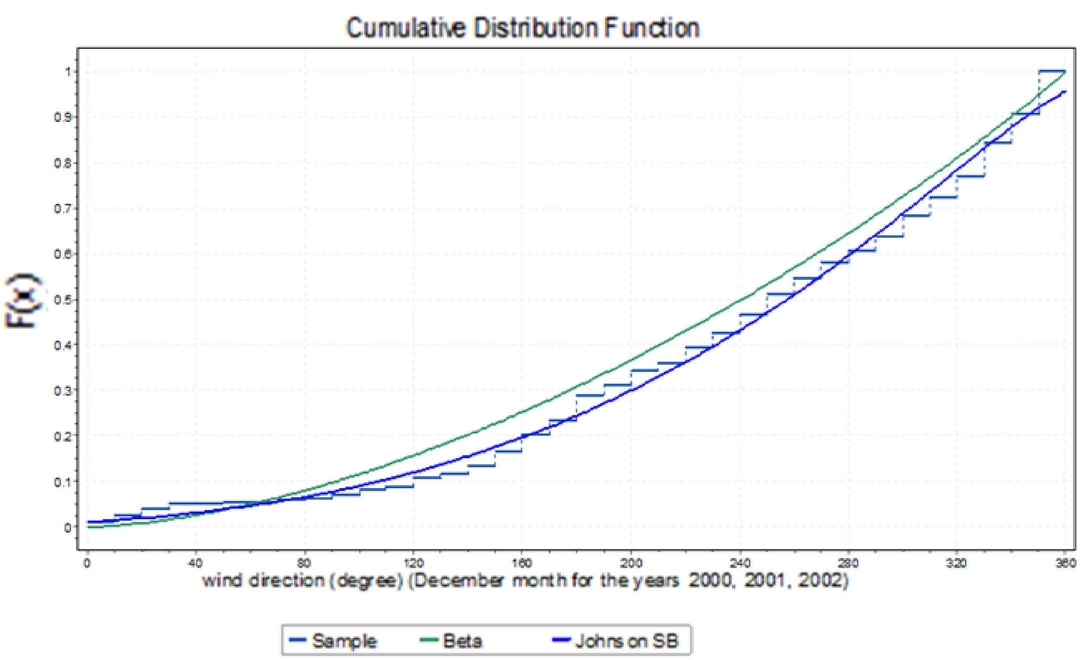
Season	Year	Other models	
Winter (Jan., Feb., March)	2000	Johnson SB	γ = -0.7125, δ = 0.3446 λ = 346.9300, ξ = -1.1945
	2001	Beta	α1 = 0.6529, α2 = 0.4410 a = -1.1516E-14, b = 360.0000
		Johnson SB	γ = -0.1139, δ = 0.2526 λ = 331.4900, ξ = 14.5590
	2002	Johnson SB	γ = -0.1139, δ = 0.2526 λ = 331.4900, ξ = 14.5590
Spring (April, May, June)	2000	Johnson SB	γ = -0.8515, δ = 0.2418 λ = 338.3900, ξ = 2.7015
	2001	Johnson SB	γ = -0.5984, δ = 0.1735 λ = 330.6400, ξ = 13.8800
	2002	Johnson SB	γ = -0.3321, δ = 0.1327 λ = 334.3700, ξ = 14.5180
Summer (July, August, Sep.)	2000	Cauchy	σ = 14.2020, μ = 325.1600
	2001	Johnson SB	γ = -1.3579, δ = 0.2787 λ = 360.0000, ξ = -22.5650

Table: 5 Continue

Season	Year	Other models	
	2002	Johnson SB	$\gamma = -0.4325$, $\delta = 0.1338$ $\lambda = 332.7400$, $\xi = 16.6010$
Autumn (Oct., Nov., Dec.)	2000	Johnson SB	$\gamma = -0.3975$, $\delta = 0.3663$ $\lambda = 349.2000$, $\xi = 2.5341$
	2001	Johnson SB	$\gamma = -0.8062$, $\delta = 0.6998$ $\lambda = 433.1000$, $\xi = -58.2250$
	2002	Johnson SB	$\gamma = -0.2212$, $\delta = 0.2953$ $\lambda = 345.8300$, $\xi = 9.8202$



(a)



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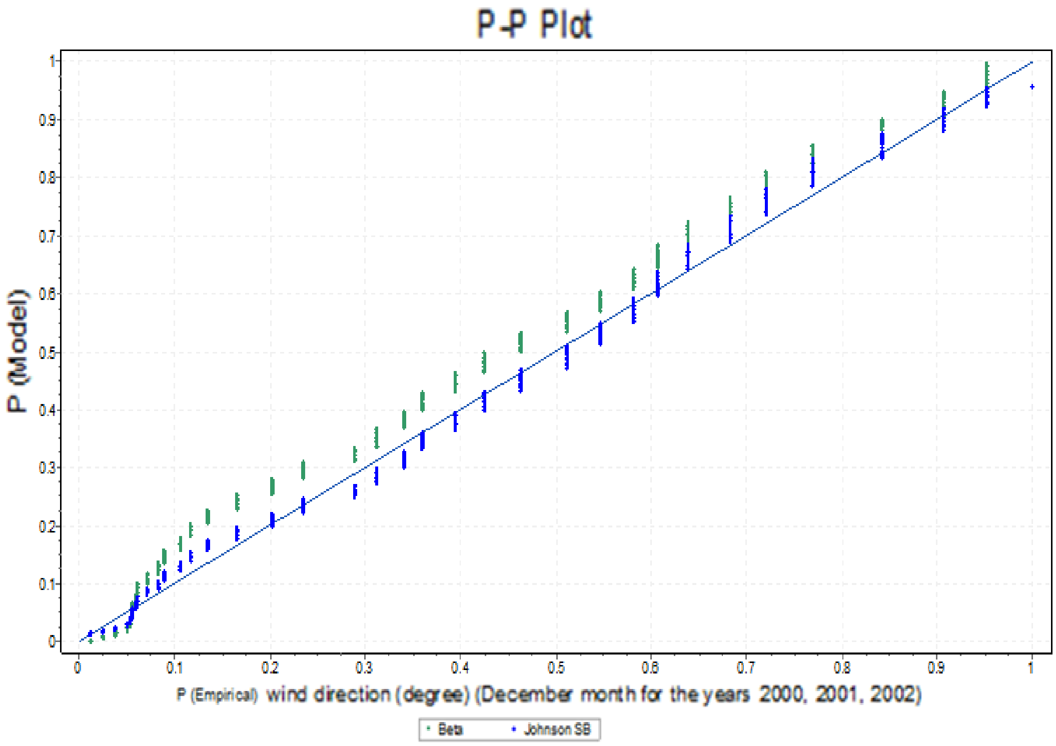

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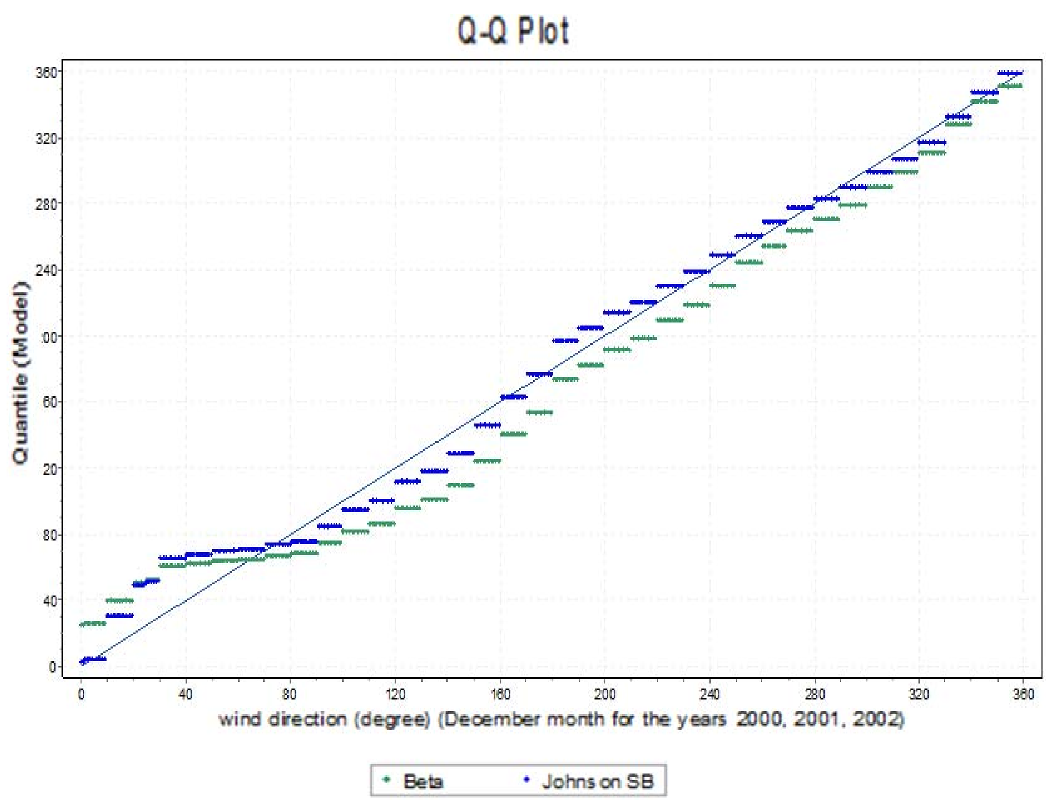


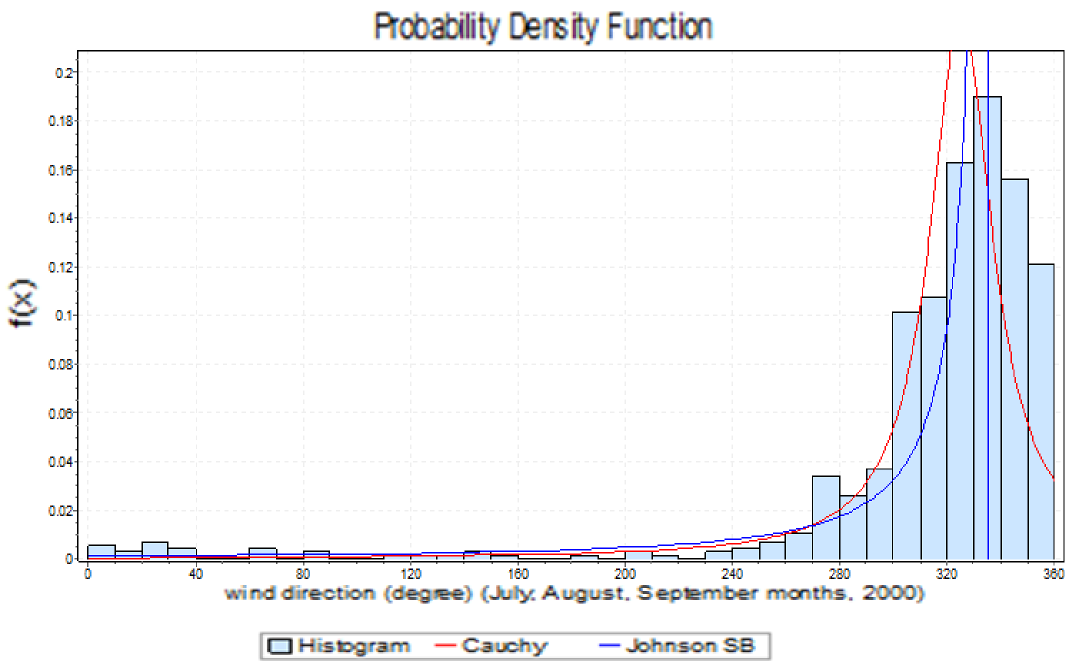
(d)

Fig. 3: December wind direction probabilities for the period 2000-2002, at Alexandria, Egypt. It shows that beta model is more proper than Johnson SB

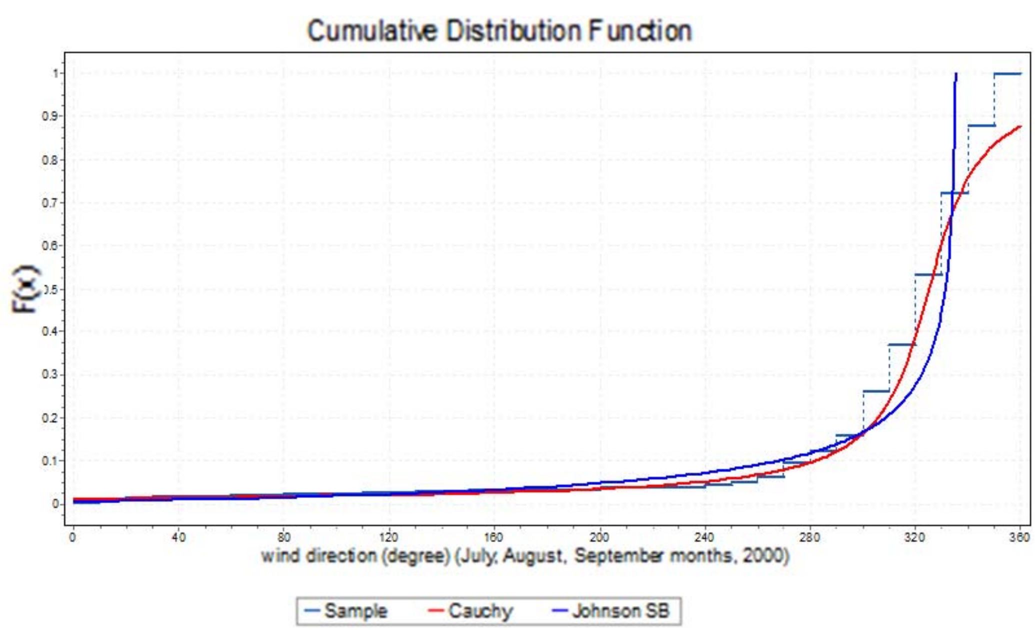
Probability distributions of wind direction:

Monthly probability distributions of wind direction: In all months of the period 2000-2002, the Weibull distribution was not proper for the wind direction data fitting. The Johnson SB model was good for all months. In addition, in December, the best models were Beta and Johnson SB. The parameters of the good fitting models are mentioned in Table 4. Examples of the best fit distributions are shown in Fig. 3 that shows December month results of best wind direction probabilities for the period 2000-2002. This Figure indicates that Beta model is probably more proper than Johnson SB.

Seasonal probability distributions of wind direction: The Weibull distribution does not fit the direction observations for all seasons during the period (2000-2002). The Johnson SB model was good for all seasons except in summer, 2000, the Cauchy model was more suitable than Johnson SB in summer, 2000. In winter,



(a)



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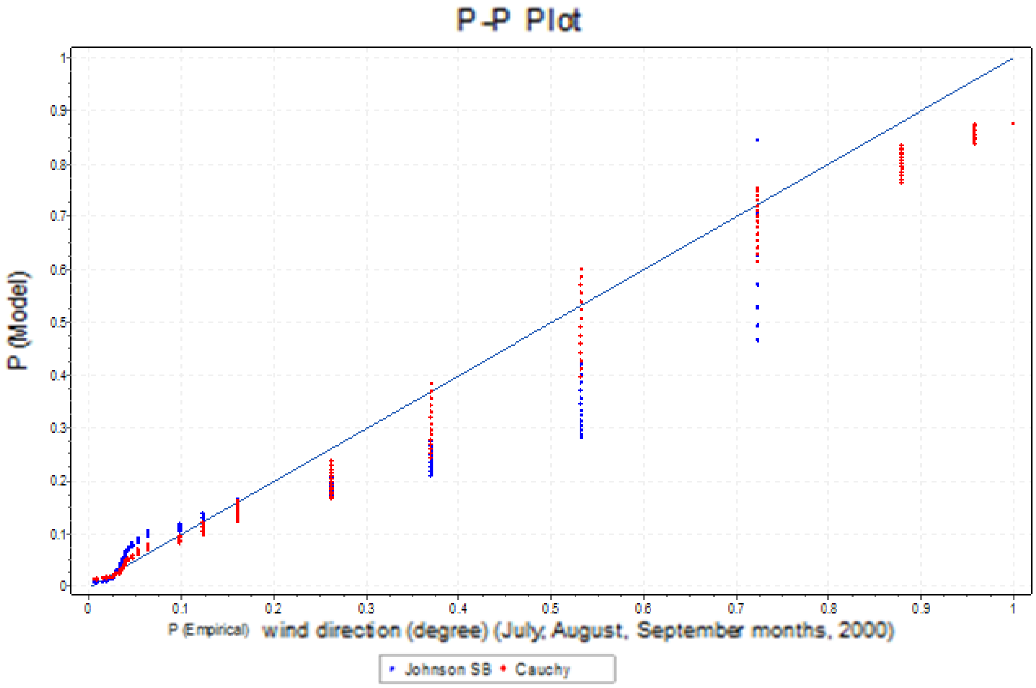

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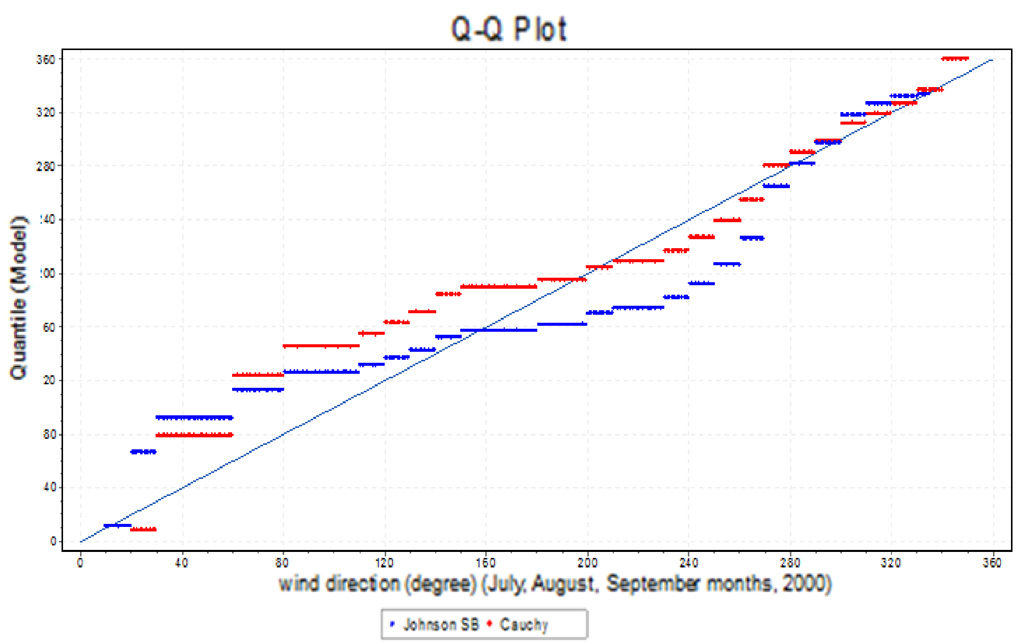

(d)

Fig. 4: Summer, 2000, wind direction probability distributions at Alexandria, Egypt. It shows that Cauchy model is more convenient than Johnson SB

2001, the Beta model was similar to Johnson SB. The parameters of the good fitting models are mentioned in Table 5 and examples of the best fit distributions are shown in Fig. 4 that indicates that Cauchy model is more convenient than Johnson SB during summer, 2000.

CONCLUSION

The off shore Wind speed and proximity of coasts is interest for producing energy. The wind energy resource assessments are important for sitting the wind turbines. The probability density distribution of the wind speed is used to calculate the mean power from a wind turbine over a range of mean wind speeds. In this study, the wind data for the period from January 2000 to December 2002, hourly records for speed and direction at Alexandria coast are analyzed as random monthly observations. The proper PDF's for both speed and direction were chosen by comparing the most matching theoretical distributions with the observations.

The results of monthly and seasonal probability distributions of wind speed indicated that the Weibull probability distribution was good for all months and seasons of the study period, in the study area. In addition, Dagum model was similar to Weibull in winter 2000. It is more fitting than Weibull in February (2001, 2000), March 2000, April 2002, May (2000, 2001, 2002), June (2001, 2002), July 2000, September 2000, October 2000, November 2000, December 2002, the months (February, March, April, May, June, July, August, October), winter (2001, 2002), spring (2000, 2001, 2002), summer (2001, 2002), autumn 2002. Burr model was similar to Weibull in January 2001, July 2001 and October 2001. Pearson 6 was similar to Weibull in January 2002 and December 2001. Nakagami model was similar to Weibull in March 2001, August 2001 and November 2001. The months November and December were the best in autumn 2000. Gen Extreme Value was similar to Weibull in March 2002. Gen. Gamma was similar to Weibull in April 2000, July 2002 and September 2002 and it was the best in October 2002, November 2002, the months January and august. Normal model was similar to Weibull in august 2000 and the best in August 2002. Gamma was similar to Weibull in autumn 2001 and the best in December 2000. Johnson SB was similar to Weibull in summer 2000. For wind direction, the Weibull model does not fit for all months and seasons of the period (2000-2002). In this period, Johnson SB, was good for all months and seasons except in summer, 2000, Cauchy model was the best. In addition to Johnson SB, Beta model was good in December of the study period and winter, 2001. The general descriptive monthly statistics of wind speed and direction are also presented.

The wind power density average of the three years was maximum in January and December (about 123 and 110 w/m^2) and minimum in July and august (about 20 to 22 w/m^2).

These results can be used for the calculation of the probability of occurrence of a certain speed that helps in the choice of the best wind generating device in the specific area to get maximum wind energy at the site.

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