Accuracy of Eight Probability Distribution Functions for Modeling Wind Speed Data in Djibouti.

Abdoulkader Ibrahim Idriss[1,*], Abdoulhamid Awalo Mohamed[1], Tahir Cetin Akinçi[2], Ramadan Ali Ahmed[1], Abdou Idris Omar[1], Ramazan Caglar[2], Serhat Seker[2]

[1] Laboratoire de Recherche en Science et Technologies Industrielles (GRE), Faculty of Engineering, Department of Electrical and Energy Engineering, Université de Djibouti, B.P. 1904, Djibouti;
[2] Department of Electrical Engineering, Istanbul Technical University, 34469, Istanbul, Turkey

(abdoulkader_ibrahim_idriss@univ.edu.dj, abdoulhamid.awalo@gmail.com, akincitc@itu.edu.tr, ramadan_ali@univ.edu.dj, abdou_idris_omar@univ.edu.dj, caglarr@itu.edu.tr, sekers@itu.edu.fr)

[‡] Corresponding Author; Abdoulkader Ibrahim Idriss; Tel.: +253 21 35 21 66,

Fax: +253 21 25 04 74, abdoulkader_ibrahim_idriss@univ.edu.dj

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Abstract- In this paper, the regional assessment on the performance of eight different probability distributions functions is investigated and compared for estimating wind speed distributions in Republic of Djibouti; the stations are located in the rural areas which are Ghoubet and Bada Wein, and urban areas which are University of Djibouti and International Airport of Djibouti. To achieve this aim, the statistical test for ranking the selected probability distributions functions, is evaluated based on the coefficient of determination, the root mean square error and the index of agreement. It has been shown from the statistical results that Weibull, Rayleigh and Gamma distributions can generally considered as the appropriate distributions and are generally provide the best fit for all stations; however Nakagami distribution gave the best results for Ghoubet rural station compared to the others used distributions.

Keywords: Urban and rural wind speed, statistical analysis, Nakagami distribution, Djibouti, goodness-of-fit tests.

1. Introduction

The characterization of wind speeds depending on the topography and climate of a particular region is essential and it is a crucial step for the evaluation of wind energy applications. In fact, it is also important to have knowledge of wind speed distribution. Therefore, since 10 years ago, the suitability of several Probability Density Functions (PDFs) has been investigated in the world to identify the more appropriate ones for wind analysis, see [1-10]. Generally, the 2-parameter Weibull and the Rayleigh distribution methods are considered as the most precise distribution methods to model wind characteristics comparing to many other PDFs such as 2 and 3-parameter Lognormal, Erlang, Pearson type III, Generalized Gamma distribution, Nakagami, and Gumbel distributions [11-17]. There are many statistical studies in the literature on the analysis of wind speed data [2]. In most of the studies determining the statistical characteristics of wind speed, while a group of studies have focused on wind speed forecast [3]. Zhou et al. [10] compare six different PDFs to assess the wind characteristics in Dakota using the statistical goodness-of-fit indicators. The results of their study conclude that there was no distribution function suitable for all studied sites. Masseran et al. [4] compared nine PDFs distributions to demonstrate that the Gamma, Inverse Gamma and Weibull distributions performed better results for wind energy potential in Malaysian regions.

The choice of the appropriate distribution models is important to describe wind data for wind energy assessment in a given area. In Eastern part of Africa such as Ethiopia, Kenya, Eritrea, Somalia and Djibouti, no detailed analyse has been investigated on the assessment of PDFs to characterize wind speed distributions. In some studies in these countries, the researchers used widely 2-parameters Weibull and the Rayleigh distribution to assess the wind power potential [18, 19]. Nevertheless, the Weibull and Rayleigh distributions are not always enough and may not be suitable for modeling all the wind regimes. Consequently, for the first time, the aim of this paper is to assess eight different distributions methods employed for modeling the wind probability distribution. Another original point of this study consists in the used wind speed data, collected in the urban stations which are University of Djibouti (UD), International Airport of Djibouti (IAD) and the rural stations which are Ghoubet and Bada Wein. The stations are located in the south-western (Ghoubet and Bada Wein) and south-east (UD and IAD) of Djibouti. The PDFs distributions considered in this work are the Weibull (W), the Rayleigh (R), the Gamma (G), the Gumbel (Gu), the Inverse Gaussian (IG), the Lognormal (LN), the Nakagami (Nak) and the Exponential (Exp) distributions. The evaluation of the goodness-of-fit indicators tests of the PDFs to the measured wind speed data is carried out through the use of the RMSE, R^2 and IA. Due to lack of wind power development in the rural and urban areas of Djibouti, the results of this study may give a helpful diagnosis for the wind energy applications.

The present paper is organized as follows: Section 2 presents the sites information and description of data source. Section 3 describes the eight statistical probability density functions used for describing the wind speed probability distribution. The monthly, yearly and seasonal basic statistical quantities are calculated for each station in detail. In Section 4 and 5, after the determination of the scale and shape parameters of all previously described probability distributions functions, the ranking of the PDF distributions were done by considering the three goodness-of-fit tests indicators. Section 6 shows the accuracy of the studied eight distribution functions methods for all stations. Section 7 concludes the paper.

2. Description of the Location and Wind Data

Djibouti is a small country situated in the Horn of Africa with an area of 23,000 km². It has borders with Ethiopia from the south side, Eritrea from the east side and Somalia from the west side. Djibouti is strategically positioned with access to the Red Sea and the Indian Ocean. The climate of Djibouti is called hot desert climate [20]. There is hardly any rain during the year in Djibouti. The average annual rainfall is 121 mm. The average temperature in Djibouti is 30.1 °C. The country has two different seasons' namely hot season from May to September and cold season from October to April. The warmest month of the year is July, with an average temperature of 36 °C. At an average temperature of 25.8 °C, January is the coldest month. The wind data are measured at 10 m height for 2 stations which are University of Djibouti (UD) and International Airport of Djibouti (IAD). A similar wind data are measured at 20 m height for two others stations called Ghoubet and Bara Wein. The locations of selected regions on map of Djibouti given in Fig.1 provide an opportunity for comparison as they are urban and rural sites.

Also, Table 1 provides the details of selected sites. For UD and IAD, the wind speeds were collected hourly and every 10-min at 10 m height for the period of five years (Jan 2014 – Jan 2018) and for ten years (Jan 2005 – Jan 2014) respectively. For Ghoubet and Bara Wein, the wind speeds were collected at 20 m height for the period of one year from January 2015 to December 2015. For Ghoubet, approximately 21 days data between October and November 2015 are missing. During these months, the data losses are often due to the violent wind of the site of Ghoubet.

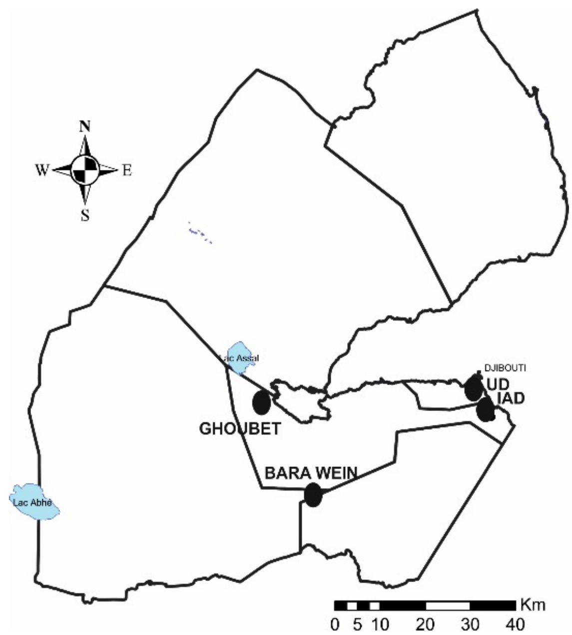

Fig.1. Locations of selected sites on the map of Republic of Djibouti.

Table 1. Coordinates of the selected sites for wind measurement.

Station	Latitude	Longitude	Altitude (m)	Wind data period	Time intervals (min)
UD	11.5946° N	43.1500° E	7	Jan 2014 – Jan 2018	10
IAD	11.5504° N	43.1537° E	8	Jan 2005 – Jan 2014	10
Ghoubet	11.5615° N	42.6036° E	160	Jan 2015 – Dec 2015	10
Bara Wein	11.2439° N	42.6017° E	539	Jan 2015 – Dec 2015	10

Table 2. Descriptive statistics functions.

Arithmetic mean	$\bar{v} = \frac{v_1 + v_2 + \cdots + v_N}{N} = \frac{1}{N}\sum_{i=1}^{N} v_i$
Variance	$\sigma^2 = \frac{1}{N}\sum_{i=1}^{N}(v_i - \bar{v})^2$
Standard deviation	$\sigma = \sqrt{\left[\sum_{i=1}^{N}(v_i - \bar{v})^2\right]/(n-1)}$
Skewness	$\frac{N}{(N-1)(N-2)}\frac{1}{\sigma^3}\sum_{i=1}^{N}(v_i - \bar{v})^3$
Kurtosis	$\frac{N(N+1)}{(N-1)(N-2)(N-3)}\frac{\sum_{i=1}^{N}(v_i - \overline{v})^4}{\sigma^4} - 3\frac{(N-1)^2}{(N-2)(N-3)}$

Using the statistics functions definitions reported in Table 2, Table 3 presents the monthly, yearly and seasonal basic statistical quantities of the measured wind data for all sites. The maximum arithmetic mean value of wind speed was 7.78 m/s obtained for Ghoubet station that has a variance of 18.42, which is the greatest. The value of skewness is always positive for all stations, except for Bara Wein. The Ghoubet is the windiest station comparing to Bara Wein during the entire period. For all stations, hot period is windier than cold one, except for Ghoubet.

3. Probability density functions and statistical properties

As reported by [18-23], the detailed assessment of wind speed probability distribution is necessary for the wind energy applications. In the current study, a selection of 8 probability distributions which are Weibull (W), Gamma (G), Rayleigh (R), Gumbel (Gu), Lognormal (LN), Inverse Gaussian (IG), Nakagami (Nak) and Exponential (Exp) were used to characterize the frequency distribution of wind speeds for all sites. Table 4 presents the statistical properties of the selected probability density functions (PDF) with their mean and variance for estimating their parameters c and k. The knowledge and performance analysis of these distributions are essential to determine the most accurate and suitable one that gives a better fit to the wind speed series in a given site. These eight distributions are investigated for the first time to characterize the wind data recorded at four stations, distributed over Djibouti.

The PDF functions analyzed in this paper are briefly discussed in the following subsections.

1.1. Weibull Distribution (W)

The two-parameter Weibull distribution is widely used for wind speed analysis [21-24]. In Table 4, the statistical properties such as variance and mean are used to determine the c and k parameters. Γ (.) is the Gamma Function.

1.2. Gamma Distribution (G)

The Gamma distribution is also applied for wind speed data analysis in several studies [4,9,25]. With the statistical properties, it can be identified two parameters in which β is the scale parameter and α is the shape parameter. Here, $\Gamma_{v/\beta}$ is the Incomplete Gamma Function.

1.3. Rayleigh Distribution (R)

Rayleigh distribution [26-28] is recognized as a particular case of Weibull distribution with the value of parameter k is equal 2. σ is the scale parameter.

1.4. Gumbel Distribution (Gu)

Gumbel distribution is also used to describe the wind speed series [29,30]. In Table 4, μ and β are the location and scale parameters respectively for Gumbel distribution. γ is the Euler's constant.

1.5. Lognormal Distribution (LN)

Lognormal is a statistical distribution of logarithmic values from a normal distribution [7,31,32]. The scale and the shape parameters of LN distribution are μ and σ, respectively. ϕ is the Error Function from the normal distribution.

1.6. Inverse Gaussian Distribution (IG)

The Inverse Gaussian distribution is an alternative distribution to 3-parameter Weibull and it is adequate to determine the low wind speeds with small frequencies [4,33,34]. λ and μ are the shape and the scale parameters respectively. ϕ is the Error Function.

1.7. Nakagami Distribution (Nak)

In 1945, the Nakagami distribution was first proposed in the communications fields [35,36]. It was also used for fitting wind speed assessment [9,37,38]. In Table 4, m and Ω are the shape and scale parameters in this case. $\gamma(.)$ is the upper Incomplete Gamma Function.

Table 3. Monthly, yearly and seasonal basic statistical quantities for each station.

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Oct.-Apr.	May.-Sep.	Yearly
UD															
Max. speed (m/s)	5.4	4.9	5.4	4.5	4.0	4.9	4.9	6.3	4.5	4.9	4.9	5.8	5.8	6.3	6.3
Arithmetic mean	1.7892	2.0852	1.9746	1.4599	1.7073	1.6156	1.5681	1.9648	1.6855	1.9867	1.7152	1.7727	1.8168	1.6946	1.7689
Variance (m/s)	1.7166	1.5116	1.4613	0.9607	0.9131	1.2612	1.2134	1.6809	0.9749	1.2091	1.4049	1.9265	1.4910	1.2215	1.3888
σ	1.3102	1.2295	1.2089	0.9802	0.9556	1.1230	1.1015	1.2965	0.9874	1.0996	1.1853	1.3880	1.2211	1.1052	1.1785
Skew.	0.2484	-0.0508	-0.0104	0.0153	-0.1324	0.4028	0.3899	0.2866	-0.0551	-0.0567	0.0320	0.3666	0.2083	0.2913	0.2083
Kurt.	-0.9488	-0.5748	-0.8921	-0.8779	-0.7805	-0.5256	-0.5652	-0.7416	-0.7307	-0.4492	-0.8329	-0.7451	-0.6243	-0.5015	-0.6243
IAD															
Max. speed (m/s)	15.5	14.4	14.5	12.8	13.6	14.5	18.0	18.0	13.6	14.5	14.5	13.7	15.5	18.0	18.0
Arithmetic mean	4.5983	4.0985	4.0926	3.5903	3.5940	4.0969	5.6937	5.7042	3.5968	4.1011	4.0954	4.1040	4.0995	4.5461	4.2867
Variance	6.9163	5.9524	5.9455	5.1069	5.1207	5.9797	9.4054	9.3888	5.1155	5.9689	5.9478	5.9486	6.0400	7.9522	6.8893
σ	2.6299	2.4397	2.4383	2.2599	2.2629	2.4454	3.0668	3.0641	2.2617	2.4431	2.4388	2.4390	2.4576	2.8200	2.6247
Skew.	0.7526	0.8303	0.8126	0.9180	0.9148	0.8271	0.6739	0.6686	0.9091	0.8242	0.8376	0.8152	0.9046	0.9096	0.9046
Kurt.	0.4477	0.6280	0.5545	0.8054	0.8303	0.6259	0.2920	0.2858	0.8447	0.6068	0.6417	0.5664	0.8666	0.8276	0.8666
Ghoubet															
Max. speed (m/s)	17.5	18.4	17.7	15.2	15.0	12.3	10.9	13.1	13.8	15.1	15.0	14.2	18.4	15.0	18.4
Arithmetic mean	9.9461	12.5721	13.4810	9.5709	8.3966	5.8421	5.7844	6.3626	6.3615	3.8857	2.8772	8.5649	8.6683	6.5553	7.7826
Variance	12.7406	7.9922	4.3993	6.9728	9.5680	4.5233	4.7339	6.1356	7.7693	15.8640	13.3380	12.8517	24.4710	7.4663	18.4285
σ	3.5694	2.8271	2.0975	2.6406	3.0932	2.1268	2.1758	2.4770	2.7873	3.9830	3.6521	3.5849	4.9468	2.7325	4.2928
Skew.	-0.2500	-0.4133	-0.7220	-0.6563	-0.2838	0.2384	0.0150	-0.0106	0.1871	1.0760	1.7151	-0.9296	0.0325	0.2758	0.0325
Kurt.	-0.3974	0.0478	0.7655	0.4024	-0.2099	-0.0797	-0.6795	-0.7313	-0.5957	-0.0406	1.8559	-0.1772	-0.8478	-0.2468	-0.8478
Bara Wein															
Max. speed (m/s)	12.1	12.4	12.6	13.2	13.1	12.1	12.2	14.3	11.6	11.0	13.0	13.7	13.7	14.3	14.3
Arithmetic mean	7.0429	8.0596	8.6026	6.8776	5.4632	4.7787	5.2256	6.0069	4.2799	7.3183	7.0641	7.3534	7.4705	5.1590	6.5016
Variance	5.3937	3.9689	2.9258	3.6787	5.5002	5.6155	6.4796	7.8452	4.4100	2.8113	4.0776	3.7551	4.1326	6.3214	6.3505
σ	2.3224	1.9922	1.7105	1.9180	2.3453	2.3697	2.5455	2.8009	2.1000	1.6767	2.0193	1.9378	2.0329	2.5142	2.5200
Skew.	-0.0266	-0.2182	-0.3757	-0.2427	-0.0359	0.2594	0.1521	0.3134	0.3873	-0.4685	-0.1852	0.1648	-0.1900	0.3115	-0.1900
Kurt.	-0.6344	-0.4283	-0.0441	0.1663	-0.7191	-0.4669	-0.4840	-0.7016	-0.3129	0.2225	0.0546	0.1910	-0.4902	-0.4078	-0.4902

Table 4. Statistical properties of the selected probability density functions.

	W	**G**	**R**	**Gu**
PDF	$f(v)=\frac{kv^{k-1}}{C^k}e^{-(\frac{v}{C})^k}$	$f(v)=\frac{v^{\alpha-1}}{\beta^\alpha\Gamma(\alpha)}e^{-(\frac{v}{\beta})}$	$f(v)=\frac{v}{\sigma^2}e^{-0.5(\frac{v}{\sigma})^2}$	$f(v)=\frac{1}{\beta}exp\left[-\exp\left(-\frac{v-\mu}{\beta}\right)\right]exp\left(-\frac{v-\mu}{\beta}\right), v\in\mathbb{R},\beta>,\mu\in\mathbb{R}$
CDF	$F(v)=1-e^{-(\frac{v}{C})^k}$	$F(v)=\frac{\Gamma_{v/\beta(\alpha)}}{\Gamma(\alpha)}$	$F(v)=1-e^{-\frac{1}{2}(\frac{v}{\sigma})^2}$	$f(v)=exp\left[-\exp\left(-\frac{v-\mu}{\beta}\right)\right]$
Mean	$c\Gamma(1+\frac{1}{k})$	$\beta\alpha$	$\sigma\sqrt{\frac{\pi}{2}}=1.253\sigma$	$\mu+\gamma\beta$, with $\gamma=0.5772$
Variance	$c^2\left[\Gamma\left(1+\frac{2}{k}\right)-\Gamma^2(1+\frac{1}{k})\right]$	$\alpha\beta^2$	$\sigma^2(2-\frac{\pi}{2})\approx 0.429\sigma^2$	$\frac{\pi^2}{6}\beta^2$
	LN	**IG**	**Nak**	**Exp**
PDF	$f(v)=\frac{1}{v\sigma\sqrt{2\pi}}e^{-\frac{1}{2}(\frac{\ln(v)-\mu}{\sigma})^2}$	$f(v)=\frac{\lambda}{2\pi v^3}e^{-\left[\frac{\lambda(v-\mu)^2}{2\mu^2 v}\right]}$	$f(v,m,\Omega)=\frac{2m^m}{\Gamma(m)\Omega^m}v^{2m-1}e^{(-\frac{m}{\Omega}v^2)}$	$f(v,\lambda)=\begin{cases}\lambda e^{-\lambda v} & v\geq 0\\ 0 & v<0\end{cases}$
CDF	$F(v)=\phi(\frac{\ln(v)-\mu}{\sigma})$	$F(v)=\phi\left[\sqrt{\frac{\lambda}{v}}(\frac{v}{\mu}-1)\right]+e^{\frac{2\lambda}{\mu}}\phi\left[\sqrt{\frac{\lambda}{v}}(\frac{v}{\mu}+1)\right]$	$F(v)=1-\frac{\gamma\left(m,\frac{m}{\Omega}v^2\right)}{\Gamma(m)}$	$F(v,\lambda)=\begin{cases}1-e^{-\lambda v} & v\geq 0\\ 0 & v<0\end{cases}$
Mean	$e^{\mu+\frac{\sigma^2}{2}}$	λ	$(\frac{m}{\Omega})^{0.5}\frac{\Gamma\left(m+\frac{1}{2}\right)}{\Gamma(m)}$	$\frac{1}{\lambda}$
Variance	$e^{2\mu}\omega(\omega-1)$; $\omega\equiv e^{\sigma^2}$	$\frac{\mu^3}{\lambda}$	$\Omega\left\{1-\frac{1}{m}\left[\frac{\Gamma(m+\frac{1}{2})}{\Gamma(m)}\right]^2\right\}$	$\frac{1}{\lambda^2}$

.

1.8. Exponential distribution (Exp)

The exponential distribution is determined by the PDF and CDF functions given in Table 4. λ is the scale parameter of the Exp distribution. This parameter can be obtained by reverse of mean speed. The Exp distribution is also used in several studies [4-9].

2. Parameters Determination

In this section, we calculate the monthly, seasonal and annual wind speed data to determine the scale and shape parameters for all the probability distribution functions described above. These parameters of each distribution are used to fit the wind speed frequencies and to rank them for all sites. For precise ranking, the goodness-of-fit indicators are used and detailed in the following section.

3. Goodness-of-Fit Indicators of the Distributions

The suitability of each distribution based on goodness-of-fits statistical indicators is investigated to examine the distribution of wind speed for all the stations over the considered periods. In this study, the fitting accuracies based on the root mean square error (RMSE), the coefficient of determination (R^2) and the index of agreement (IA) were applied to determine the suitability between the predicted and the collected data distributions.

The definition of these tests are given in Table 5, where f_i is the frequency of wind speed data or i^{th} calculated value from measured wind data; y_i is the frequency of observation or i^{th} calculated value from the eight selected distributions functions and n is the number of data; $\overline{f_i}$ the mean of measured wind data. The ranking of the eight used distributions functions in terms of RMSE, R^2 and IA tests are reported in the Table 6 and 7 over the considered periods.

Table 5. Goodness-of-fit tests and references.

Goodness-of-fit	Definition	References
RMSE	$\sqrt{\left(\frac{1}{n}\sum_{i=1}^{n}(y_i - f_i)^2\right)}$	[9,38,39]
R^2	$1 - \frac{\sum_{i=1}^{n}(y_i - f_i)^2}{\sum_{i=1}^{n}(y_i - \overline{f_i})^2}$	[9,38,39]
IA	$1 - \frac{\sum_{i=1}^{n}\lvert y_i - f_i\rvert}{\sum_{i=1}^{n}(\lvert y_i - \overline{f_i}\rvert + \lvert y_i - \overline{f_i}\rvert)}$	[36-40]

4. Results and Discussions

The accuracy of eight different distribution functions based on the goodness-of-fit is studied to describe the best fitting with the measured wind speed frequencies distribution for four stations in the Republic of Djibouti. Depending on monthly, seasonal and yearly analysis, the shape and scale parameters are calculated by solving the statistical properties of the distributions presented in Tables 4. To better understand the quality of the wind speed fitting distributions for all stations, Table 6 provides the ranking of each distribution function in terms of goodness-of-fit for the RMSE, R^2 and IA tests reported in Table 5. The ranking position 1 identifies the best fitting distribution, whereas the ranking position 8 identifies the worst one. In Table 6, for each location, the top four accurate distribution functions are highlighted in bold.

Regarding Table 6, Wei, R, G and Gu distributions are identified as the most appropriate and same distribution functions for UD and IAD stations. However, for Ghoubet and Bada Wein stations, the Nak distribution provides the best fit to the measured wind speed data for the yearly analysis; it ranks 1st (RMSE=0.0023, R^2=0.9999 and IA= 0.9738) and 3rd RMSE=0.0221, R^2=0.9916 and IA= 0.8122) respectively as reported in Figs. 2,3 and 4. The analyze of the used distribution functions indicate clearly the supremacy of Wei distribution followed by G and R distributions at the studied locations, while the least accurate one is obtained for the Exp distribution.

Table 6. The ranking position of the distributions functions for all stations in terms of goodness-of-fit tests indicators; yearly and seasonal periods.

		W	G	R	LN	IG	Gu	Nak	Exp
Yearly	UD	**1**	**3**	**2**	8	5	**4**	6	7
	IAD	**1**	**2**	**4**	8	6	**3**	5	7
	Ghoubet	**4**	5	**2**	7	6	**3**	**1**	8
	Bada Wein	**1**	**2**	6	5	7	**4**	**3**	8
May-Sep. (Hot season)	UD	**1**	**3**	**2**	8	5	**4**	6	7
	IAD	**1**	**2**	**4**	7	5	**3**	8	6
	Ghoubet	**1**	**2**	**3**	5	7	**4**	6	8
	Bada Wein	**1**	**3**	**2**	6	7	**4**	5	8
Oct.-Apr. (Cold season)	UD	**2**	**4**	**1**	8	5	**3**	6	7
	IAD	**2**	**1**	**4**	8	5	**3**	6	7
	Ghoubet	**2**	**3**	**1**	7	6	**4**	5	8
	Bada Wein	**2**	**4**	**3**	6	8	5	**1**	7

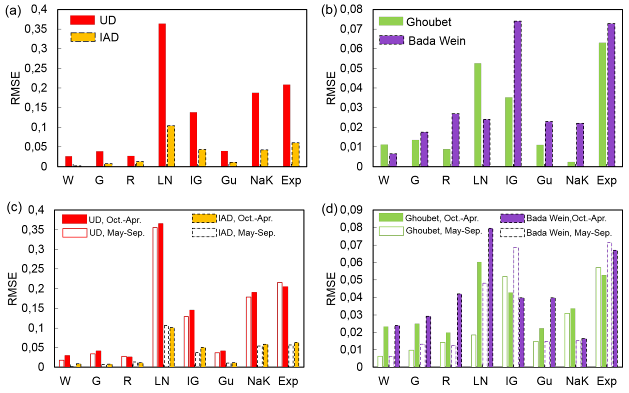

Fig. 2. Histograms with the eight fitted distributions regarding RMSE test indicator for all stations: (a, b) yearly and (c, d) seasonal analysis.

Another finding shows that for hot season, the top four ranked distributions are Wei, G, R and Gu and are similar among stations. Furthermore, the Nak distribution provides the best fit in Bada Wein station for cold season in terms of statistical indicators (with RMSE=0.0165, R^2=0.9953 and IA= 0.8411) so that it ranked 1st. Table 7 shows the ranking of the eight distributions for all studied locations based on the monthly analysis. It is observed that the monthly ranking analysis for all stations gives similar results for yearly ranking analysis except for the cold and hot season reported in Table 6. In addition, Figure 5 shows the histograms fitted by the top four ranked distributions for the four stations, in the purpose to illustrate how these distributions can describe the measured wind speed data based on the yearly scale.

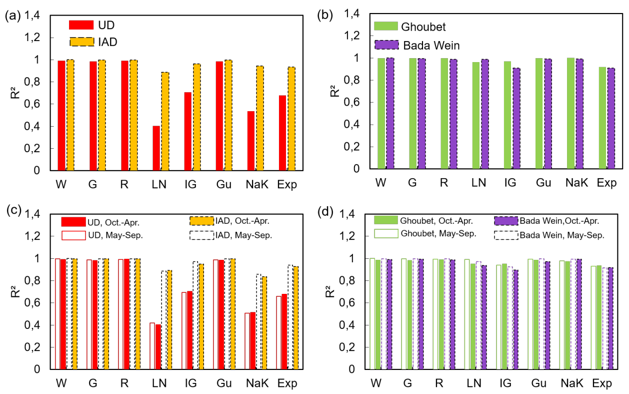

Fig. 3. Histograms with the eight fitted distributions regarding R^2 test indicator for all stations: (a, b) yearly and (c, d) seasonal analysis.

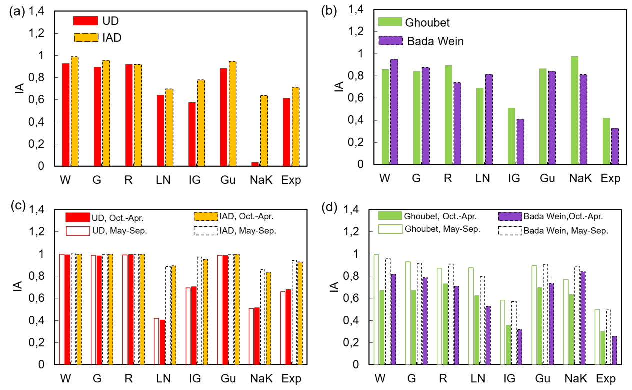

Fig. 4. Histograms with the eight fitted distributions regarding IA test indicator for all stations: (a, b) yearly and (c, d) seasonal analysis.

For the site UD (Fig. 5-a), it is noticed a difference between the distributions in the range of wind speed from 0 to 2 m/s. For the IAD station illustrated in Fig. 5-b, the result show that the four distributions are superimposed and clearly confirm the results based on goodness-of-fit as reported in Table 6. Regarding the site of Ghoubet (Fig. 5-c), it is obtained a tiny difference between the two first best distributions Nak and R and relative one between the 3rd and 4th distributions which are Wei and G. Moreover, in Fig. 5-d, for the Bada Wein site, Wei distribution is the more appropriated distribution function to describe wind speed at different ranges. The three other distributions show the difference in the range of wind speed from 0 to 8 m/s. The results indicate that Wei, G, R and Gu distributions are more appropriate as they can give good performance for all stations. The Nak distribution is also identified as best fits for high wind speed obtained in Ghoubet and Bada Wein stations.

Table 7. The ranking position of the distributions functions for all stations in terms of goodness-of-fit tests indicators; monthly periods.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
UD												
W	1	2	2	1	2	1	1	1	2	2	2	2
G	3	4	4	3	4	3	2	2	3	3	3	3
R	2	1	1	2	1	2	3	3	1	1	1	1
LN	8	8	8	8	8	8	8	8	8	7	8	8
IG	5	6	5	5	5	5	5	6	5	6	5	5
Gu	4	3	3	4	3	4	4	4	4	4	6	6
Nak	6	7	6	6	6	6	6	5	6	5	4	4
Exp	7	5	7	7	7	7	7	7	7	8	7	7
IAD												
W	1	1	1	1	1	1	3	1	1	1	1	1
G	3	2	3	2	2	2	4	4	3	3	3	2
R	2	3	2	4	4	4	1	3	4	5	5	4
LN	8	8	8	8	8	8	8	8	8	8	8	8
IG	5	5	5	5	5	5	6	6	5	6	6	5
Gu	4	4	4	3	3	3	5	5	3	4	4	3
Nak	6	6	7	6	6	7	2	2	2	2	2	6
Exp	7	7	6	7	7	6	7	7	7	7	7	7
Ghoubet												
W	1	2	5	1	1	1	1	1	1	5	3	1
G	2	3	4	3	2	2	2	3	3	4	4	3
R	5	1	1	2	5	3	5	6	2	1	1	2
LN	4	4	2	5	4	5	4	4	5	8	8	5
IG	6	6	7	8	6	7	8	7	6	3	2	7
Gu	3	5	8	4	3	4	6	5	4	2	5	4
Nak	7	8	6	6	8	8	3	2	8	7	7	6
Exp	8	7	3	7	7	6	7	8	7	6	6	8
Bada Wein												
W	1	1	1	1	1	1	8	1	1	1	2	1
G	3	2	3	2	2	2	3	4	3	3	3	2
R	2	3	2	4	4	3	1	3	5	5	5	4
LN	8	8	8	8	8	8	7	8	8	8	8	8
IG	5	5	5	5	5	5	5	6	6	6	6	5
Gu	4	4	4	3	3	4	4	5	4	4	4	3
Nak	6	6	7	7	6	7	2	2	2	2	1	6
Exp	7	7	6	6	7	6	6	7	7	7	7	7

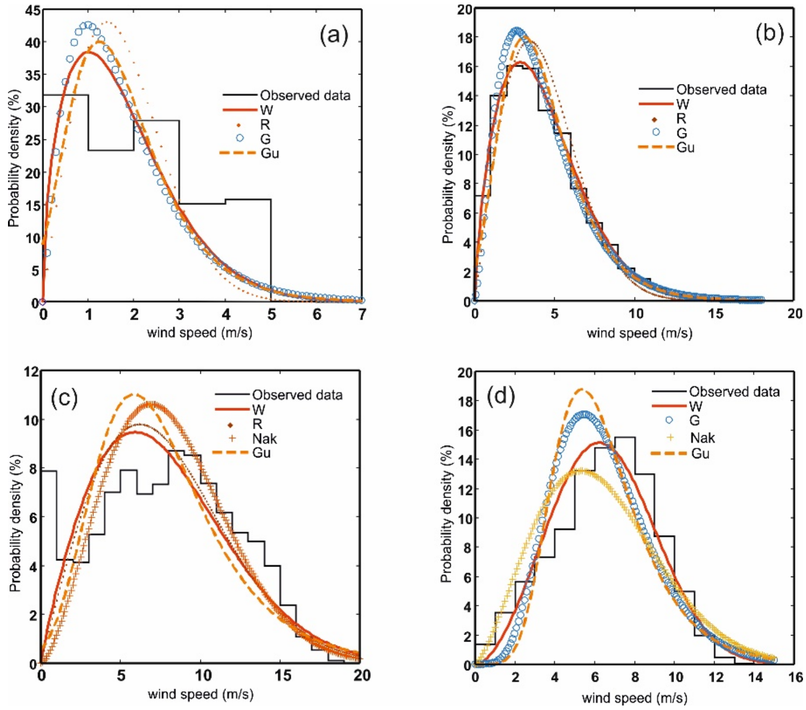

Fig. 5. Histograms with the top four fitted distributions and observed data for yearly analysis: (a) UD, (b) IAD, (c) Ghoubet, and (d) Bada Wein.

7. Conclusion

The wind energy development has not been harnessed or used yet in Djibouti. To make a detailed diagnosis of the wind characteristics, the distribution of wind speed is one of the most crucial step in wind resource assessment for the selected location. In the presents study, the suitability of eight distributions for modeling the wind speed distributions in the urban and rural regions of Djibouti was evaluated for the first time. For all stations, for each season and period, the scale and shape parameter were calculated and can be used for others applications on wind energy. Finally, each probability density function is ranked using the statistical indicators of root mean square error (RMSE), coefficient of determination (R^2) and index of agreement (IA). Based on yearly, monthly and seasonal analysis, the results show that W, R, G and Gu are the top four ranked distributions functions which provide the best fits for all stations. Moreover, for the rural station, the Nak distribution function is ranked 1st for Ghoubet and 3rd for Bada Wein. It is important to indicate that the Nak distribution should be conducted and evaluated for more rural sites which have high wind speed.

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Nomenclature	
$f(v)$	Weibull, Probability density function
$F(v)$	Cumulative distribution function (%)
f_i	Frequency of wind speed data (%)
y_i	Frequency of observation
v	Wind speed (m/s)
v_i	Wind speed measured at the interval
$\bar{v}$	Arithmetic mean (m/s)
n	Number of data
k	Shape parameter of Weibull distribution
c	Scale parameter of Weibull distribution
Γ	Gamma function
σ	Standard deviation (m/s)
σ^2	Variance
$\Gamma_{v/\beta}$	Incomplete Gamma Function.
α	Shape parameter
λ	Shape parameter
β	Scale parameter (m/s)
μ	Location or scale parameter (m/s)
γ	Euler's constant
ϕ	Error Function
m	Shape parameters
Ω	Scale parameters (m/s)
UD	University of Djibouti
IAD	International Airport of Djibouti
PDF	Probability distribution function
CDF	Cumulative distribution function
RMSE	Root Mean Square Error
R^2	Coefficient of determination
IA	Index of Agreement
W	Weibull
G	Gamma
R	Rayleigh
Gu	Gumbel
LN	Lognormal
Nak	Nakagami
IG	Inverse Gaussian
Exp	Exponential
Skew	Skewness
Kurt	Kurtosis