Suitability and Evaluating Wind Speed Probability Distribution Models in a Hot Climate: Djibouti Case Study

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Received: 22.07.2019 Accepted:15.09.2019

Abstract- The paper investigates the most reliable numerical method for estimating the Weibull parameters to calculate the wind power density in urban and rural hot regions of the Republic of Djibouti. It is important to mention that no similar studies have been carried out and therefore this is the first study to evaluate and diagnosis the best Weibull distribution method for wind analysis and wind energy potential in the country. Five investigated numerical methods such as Graphical Method (GM), Empirical Method of Justus (EMJ), Energy Pattern Factor Method (EPFM), Standard Deviation Method (SDM) and Moment Method (MM) were adopted to estimate Weibull c and k parameters. Four statistical indicators including root mean square error, index of agreement, coefficient of determination and relative percentage error were used to precisely rank the methods. The study aims to identify the most accurate method to determine the wind power density in four stations which are University of Djibouti, International Airport of Djibouti, Ghoubet and Bara Wein. Then, to provide a complete analysis, the study is performed on monthly, yearly and seasonal scales. The results reveal that GM and EPFM are the most accurate methods for estimating the c and k parameters and are recommended in estimating the wind power density in Djibouti.

Keywords- wind speed, estimation methods, urban, rural, wind power density.

1. Introduction

The Republic of Djibouti (23,200 km², 948 249 inhabitants [1]), which is located in the East-Africa, has a large renewable energy potential including geothermal, wind and solar power. However, all electricity produced today by the Electricity of Djibouti (EDD) company, is of thermal origin using heavy fuel oil and gas oil. In addition to this, 70 % of hydroelectricity is imported from Ethiopia. This electricity which comes from the Nile basin is not secure because it is a source of conflict with three African neighboring countries which are Ethiopia, Egypt and Soudan.

Because of that, the government of Djibouti seeks to reduce production costs and dependence on Ethiopia, increase energy security in the country and increase access to energy for the Djiboutian population particularly in the rural areas. As Djibouti lacks natural resources such as water, petroleum and gold, the country heavily depends on international aid to balance its economic status and develop more revenue generating projects.

It is crucial to consider a long-term energy production from renewable energy. In this particular context, Djibouti is located in East Africa and subsequently it is abundant of solar [2], geothermal [3], and especially wind resources which is strongly considerable. In the future, wind power becomes a prominent resource of energy. The first step before using wind energy in urban or rural localities is to evaluate the potential and see the feasibility. In literature, various methods are used to determine Weibull parameters for modeling wind regimes [4-7].

Saleh et al. [8] recommended using the maximum likelihood method for determining the wind speed distribution in Zafarana region in Egypt.

Jiang et al. [9] compared the traditional numerical methods with metaheuristic optimization algorithms in wind energy resource assessments having low wind speed characters. In 2018, Kang et al. [10] made an investigation and then concluded that the moment method is more accurate for all topographical conditions.

In this paper, we used a 10-min time series wind speed data to collect at two different heights (10 m and 20 m) in four stations which are located at the University of Djibouti (UD), International Airport of Djibouti (IAD), Ghoubet and Bara Wein situated in the Republic of Djibouti. No similar statistical studies have been performed to diagnose important features of the wind speed distribution in rural and urban areas of the country. The aim of this study is to identify the appropriate numerical method for determining the wind potential with monthly, yearly and seasonal wind data collected from these stations.

2. Sites' presentation

The Republic of Djibouti has a hot desert maritime climate [11, 12]. The country has a cooler period from October to April with a temperature ranges from 20 °C to 34 °C, and a hot period from May to September with a temperature ranges from 36 °C to 47 °C. In this study, we selected four measurement stations which divided into urban and rural areas. Figure 1 illustrates the map of the Republic of Djibouti and shows the locations of the selected four stations.

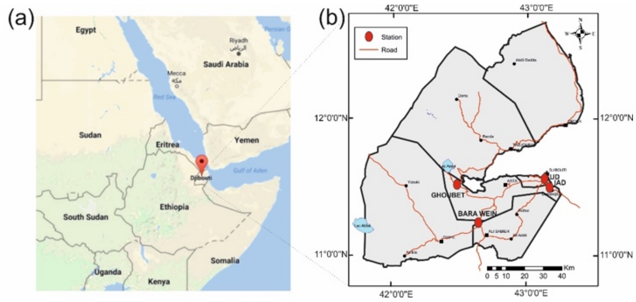

Fig. 1. (a) Geographical location of the Republic of Djibouti on the East Africa map showing surrounding countries (provided by Google Map) and (b) Locations of the selected four stations.

Table 1 presents the names and coordinates of the four selected sites: UD and IAD for the urban areas; Ghoubet and Bara Wein for the rural areas. For UD and IAD, a series of data that were collected every hour and every 10-min at 10 m hub 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, a similar set of wind speed data was collected at 20 m hub height for one-year period from January 2015 to December 2015.

3. Numerical methods and statistical analysis

In literature, the probability density distribution of the wind speed represents the major characters of wind resources [14-22]. The wind speed can be expressed by two functions which are the probability density function and the cumulative distribution function [9, 21]. The 2-parameter Weibull probability density function and Weibull cumulative distribution function are expressed as follows:

$$f(V)=\left(\frac{k}{c}\right)\left(\frac{V}{c}\right)^{k-1}\exp\left[-\left(\frac{V}{c}\right)^{k}\right] \tag{1}$$

$$F(V)=1-\exp\left[-\left(\frac{V}{c}\right)^{k}\right] \tag{2}$$

Where V is the wind speed (m/s), k is the shape factor (dimensionless) and c is the scale parameter (m/s).

In this study, five numerical methods are selected to determine c and k parameters to provide a better curve fit to the wind speed distribution.

Table 1. Geographical information (name, location and period) for four studied stations.

Site	Location	Latitue	Longitude	Elevation (m)	Wind data period
A	UD (urban)	11.5946° N	43.1500° E	7	Jan 2014 - Jan 2018
B	IAD (urban)	11.5504° N	43.1537° E	8	Jan 2005 - Jan 2014
C	Ghoubet (rural)	11.5615° N	42.6036° E	160	Jan 2015 - Dec 2015
D	Bara Wein (rural)	11.2439° N	42.6017° E	539	Jan 2015 - Dec 2015

3.1 Measured mean wind speed, standard deviation and turbulence intensity

The analysis of the wind quality and wind potential analysis for a given site require the knowledge of the mean wind speed, the standard deviation and the turbulence intensity at the different heights. The mean wind speed and standard deviation are expressed as:

$$V_{mean} = \frac{1}{n}\sum_{i=1}^{n}(V_i) \tag{3}$$

$$\sigma = \sqrt{\frac{\left[\sum_{i=1}^{n}(V_i - V_{mean})^2\right]}{n-1}} \tag{4}$$

Where V_{mean} and σ are respectively the mean and the standard deviation of the wind speed, V_i is the i[th] data of the wind speed data; while *n* represents the number of the observed wind.

The turbulence intensity (TI) for each site is the criterion which describes the uncertainty of wind speed over the considered period and is defined as the ratio between σ and V_{mean} [22, 23]. The correlation coefficient is given by:

$$TI(\%) = \frac{\sigma}{V_{mean}} \times 100 \tag{5}$$

3.2 Moment Method (MM)

The method of moment is used to estimate Weibull c and k parameters [24]. These are determined by the following equations:

$$c = \frac{V_{mean}}{\Gamma\left(1+\frac{1}{k}\right)} \tag{6}$$

$$k = \left(\frac{0{,}9874}{\frac{\sigma}{V_{mean}}}\right)^{1{,}0983} \tag{7}$$

Where Γ(x) is the Gamma function.

3.3 Standard Deviation Method (SDM)

The standard deviation method [25] is also used to estimate k and c parameters and expressed as:

$$k = \left(\frac{\sigma}{V_{mean}}\right)^{-1{,}086} \tag{8}$$

$$c = \frac{V_{mean}k^{2{,}6674}}{0{,}184 + 0{,}816k^{2{,}73855}} \tag{9}$$

3.4 Graphic Method (GM)

The graphic method is attained by using cumulative distribution function [6, 26]. By taking a double logarithmic transformation of Eq. (2), a new equation of a linear regression is derived as:

$$\ln[-\ln[1-F(V)]] = k\ln V - k\ln c \tag{10}$$

To determine the two parameters c and k, we plot the $\ln[-\ln[1-F(V)]]$ as y axis versus $\ln V$ as x axis. We obtain $y = ax + b$ form; then *k* is the slope of the straight line and c is obtained the y-intercept of the straight line. After solving the linear equation, we obtain coefficients *a* and *b*.

Hence

$$k = a \tag{11}$$

$$c = \exp\left(\frac{-b}{a}\right) \tag{12}$$

3.5. Empirical Method of Justus (EMJ)

The empirical method of Justus [17, 27] is seen as a special case of the moment method, where the Weibull parameters k and c are given by Eq. (13) and (14) as:

$$k = \left(\frac{\sigma}{V_{mean}}\right)^{-1{,}086} \tag{13}$$

$$c = \frac{V_{mean}}{\Gamma\left(1+\frac{1}{k}\right)} \tag{14}$$

3.6. Energy Pattern Factor Method (EPFM)

The energy pattern factor method is defined as the ratio between the mean of wind speed cubes and the cube of the mean wind speed [8,24] which is defined by:

$$E_{pf} = \frac{\frac{1}{n}\sum_{i=1}^{n}V_i^2}{\left(\frac{1}{n}\sum_{i=1}^{n}V_i\right)^2} \tag{15}$$

Afterwards, the parameters k and c can be estimated respectively, as follows:

$$k = 1 + \frac{3{,}69}{E_{pf}^2} \tag{16}$$

$$c = \frac{V_{mean}}{V_i\left(1+\frac{1}{k}\right)} \tag{17}$$

4. Numerical Statistical indicators

To make a fair and complete comparison of these above-mentioned estimation numerical methods, four accuracy tests RMSE (root-mean-square error), R^2 (coefficient of determination or analysis of variance), IA (index of agreement) and RPE (relative percentage error) are used to find and rank the best method for the analysis [22-24]. To reach this goal, the distribution pattern of wind speed data is often needed to evaluate wind speed analysis in each station. They are described below.

4.1 Distribution pattern

Statistical characteristics of wind speed are computed using skewness and kurtosis [28]. The coefficient of skewness and kurtosis are a measure for the degree of symmetry and the degree of tailedness in the variable distribution (wind speed data sequence), respectively. For a normal distribution, the skewness is zero which means that the distribution is symmetric. For Kurt=0, the distribution of the observed wind speed data exactly matches the normal distribution. They are expressed by the following equations:

$$Skew = \frac{1}{n-1}\sum_{i=1}^{n}\frac{(V_i - V_{mean})^3}{\sigma^3} \tag{18}$$

$$Kurt = \frac{1}{n-1}\sum_{i=1}^{n}\frac{(V_i - V_{mean})^4}{\sigma^4} - 3 \tag{19}$$

Where V_{mean} and σ are given by Eq. (3) and (4), respectively.

4.2 Assessment of the method accuracy

To analyze the efficiency of each estimation method, the following tests including IA, RMSE, R^2, and RPE are used and are calculated as follows:

(a) Index of agreement

$$IA = 1 - \frac{\sum_{i=1}^{n}\left|V_{i,w} - V_{i,m}\right|}{\sum_{i=1}^{n}\left(\left|V_{i,w} - V_{mean,m}\right| + \left|V_{i,m} - V_{mean,m}\right|\right)} \tag{20}$$

(b) Root-mean-square error

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(V_{i,w} - V_{i,m}\right)^2} \tag{21}$$

(c) Coefficient of determination

$$R^2 = 1 - \frac{\sum_{i=1}^{n}\left(V_{i,w} - V_{i,m}\right)^2}{\sum_{i=1}^{n}\left(V_{i,w} - V_{mean,m}\right)^2} \tag{22}$$

(d) Relative percentage error

$$RPE = \left(\frac{P_W - P_m}{P_m}\right) \times 100 \tag{23}$$

Where $V_{i,m}$ is the frequency of wind speed data or i^{th} calculated value from measured wind data; $V_{i,w}$ is the frequency of observation or i^{th} calculated value from the Weibull distribution; $V_{mean,m}$ the mean of measured wind data. RPE is the percentage deviation between the values of power density obtained with the Weibull distribution (Pw) and the values of power density obtained with the measured data (Pm) [7, 29-32].

4.3 Wind power density estimation

$$P_m = \frac{1}{2n}\rho\sum_{i=1}^{n}V^3 = \frac{1}{2}\rho\overline{V^3}\left(\frac{W}{m^2}\right) \tag{24}$$

$$P_W = \int_0^\infty \frac{1}{2}\rho V^3 f(V)dV = \frac{1}{2}\rho c^3\Gamma\left(1+\frac{3}{k}\right)\left(\frac{W}{m^2}\right) \tag{25}$$

Where ρ is the air density and is assumed to be equal to 1.225 kg/m^3; $\overline{V^3}$ is the mean of wind speed cubes. The *c* and *k* parameters are obtained from the Weibull distribution.

5. Results and discussions

Table 2 presents the yearly statistical quantities including maximum, arithmetic mean, variance, standard deviation, skewness and kurtosis of the measured wind speed data for all stations. The coefficient of skewness and kurtosis are a measure for the degree of symmetry and peakedness in the wind speed distribution, respectively. As seen in Table 2, the site C has excellent wind energy potential with the highest mean wind speed value of 7.78 m/s while site A has the lowest mean wind speed with the value of 1.76 m/s. The value of skewness is positive for all stations, except for site D which mean that the distribution is skewed to the left in this case. Furthermore, the coefficient of Kurtosis is negative for all stations except for B.

The negative values of the coefficient of kurtosis indicate a light tailed distribution. For C and D, it can be shown that the annual mean wind speed is 7.78 m/s. The standard deviation value for all sites is greater than 1.17 m/s.

For a precise diagnosis, the monthly mean wind speed and turbulence intensity at 10 m and 20 m heights are presented in Fig. 2. We show that site A presents a uniform mean wind speed during all the year comparing to other sites, as shown in Fig.2a. In the Fig.2b, the TI of all sites varies from 15.8 % to 90.4 %. It is low for the cool season and increases during the hot season. It can be clearly seen that the turbulence intensity is comparatively low for the high altitude.

Table 2. Descriptive statistics of the selected sites.

Site	Max. (m/s)	Mean (m/s)	Variance (m/s)	St. deviation (m/s)	Skewness	Kurtosis
A	6.3	1.768	1.388	1.178	0.208	-0.624
B	18	4.286	6.889	2.624	0.904	0.866
C	18.4	7.782	18.428	4.292	0.032	-0.847
D	14.3	6.501	6.350	2.520	-0.190	-0.490

Fig. 2. Comparisons of monthly variation of (a) mean wind speed and (b) mean turbulence intensity (TI) for the selected sites.

To make accurate comparison of the five methods, monthly, yearly and seasonal wind speed data are used to offer a complete analysis in all selected sites.

5.1. Comparisons of Weibull distributions parameter values based on monthly analysis

Figures 3 and 4 present the monthly mean values of Weibull parameters for urban and rural sites. From Fig. 3, the values of c parameter are totally close for both sites and minor differences are observed for the GM method. For site A, the values of c and k parameters are respectively in the range of 1.29-2.37 m/s and 1.09-1.96. For site B, it is found that the shape and scale parameter are respectively in the range of 3.93-6.43 m/s and 1.58-1.96. The values of parameters c and k are high for the cooler season for site A and are also high during the hot season for site B.

Fig.3. Comparisons of monthly values of c (m/s) and k (-) for the urban sites (A and B).

Figure 4 shows the different values of the shape and scale parameter from the five methods for site C and D. Specifically, it can be noted that for both sites C and D, the maximum values of c parameter are obtained for EPFM method during the cooler season and are respectively for all the months in the range of 2.05-14.83 m/s and 4.75-9.50 m/s.

We can therefore argue that the monthly analysis cannot be used exclusively to consider the precision level of the numerical method for determining the Weibull parameters for the selected sites. In the next section, the statistics of goodness-of-fit is employed to evaluate the performance of the five numerical methods based on yearly analysis.

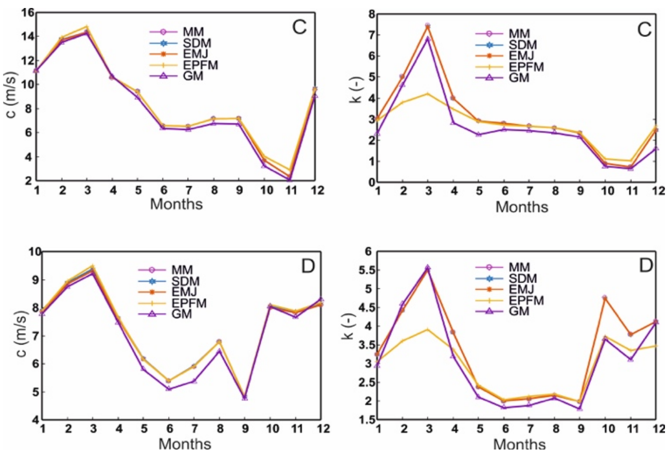

Fig.4. Comparisons of monthly values of c (m/s) and k (-) for the rural sites (C and D).

5.2. *Comparisons of Weibull distributions parameter values based on yearly analysis*

Table 3 summarizes the efficiency of the numerical methods based on yearly analysis which derive from the histograms not shown here between the yearly Weibull probability density distributions with observed yearly probability density distributions of the wind speed. Additionally, the estimates of the Weibull parameters c and k, the ranking of the methods and the goodness-of-fit tests are also illustrated in the table. In each site, the efficient numerical method is highlighted in bold.

Compared to all other methods, the GM method seems to have the best performance for the urban sites in terms of statistical indicators. Simultaneously, the IA values for the sites A and B obtained using the GM method, are respectively equal to 0.9555 and 0.9996 which means the good agreement between distribution and observations. The second-best method is EPFM in terms of RMSE and R^2.

For the rural stations, EPFM method gives acceptable results according to the RMSE, R^2 and IA analyses. RMSE values for sites C and D obtained for the first best method which is EPFM are respectively 0.0096 and 0.0071. The GM method is more appropriate for wind data assessment at the lower height (10 m) and it is the worst for the higher height (20 m). We also concluded that the EPFM is the efficient numerical method based on the goodness-of-fit indicators.

It can be stated that the EPFM method is applicable and show better performance than other methods regardless of the hub height and site location.

Table 3. Yearly performance analysis of the numerical methods for all the sites.

Site	Parameters	Methods				
		MM	**GM**	**SDM**	**EMJ**	**EPFM**
A	k (-)	1.2923	**1.5340**	1.3065	1.3065	1.3932
	c (m/s)	1.7480	**1.7863**	1.7534	1.7518	1.7721
	IA	0.9420	**0.9555**	0.9452	0.9451	0.9519
	RMSE	0.0244	**0.0150**	0.0235	0.0236	0.0189
	R^2	0.9921	**0.9972**	0.9927	0.9926	0.9954
	Rank	5	**1**	3	4	2
B	k (-)	1.6902	**1.6588**	1.7036	1.7036	1.6843
	c (m/s)	4.8025	**4.7517**	4.8060	4.8051	4.8013
	IA	0.9908	**0.9996**	0.9877	0.9878	0.9918
	RMSE	0.0016	**0.0005**	0.0020	0.0021	0.0014
	R^2	0.9998	**0.9999**	0.9986	0.9987	0.9998
	Rank	3	**1**	4	5	2
C	k (-)	1.8548	1.5755	1.8676	1.8676	**1.9737**
	c (m/s)	8.7631	7.7101	8.7657	8.7654	**8.7795**
	IA	0.8423	0.7039	0.8468	0.8465	**0.8797**
	RMSE	0.0124	0.0243	0.0120	0.0121	**0.0096**
	R^2	0.9966	0.9867	0.9967	0.9967	**0.9980**
	Rank	4	5	2	3	**1**
D	k (-)	2.6853	2.3469	2.6926	2.6926	**2.7030**
	c (m/s)	7.3124	6.7104	7.3159	7.3117	**7.3107**
	IA	0.9480	0.8600	0.9492	0.9491	**0.9506**
	RMSE	0.0074	0.0201	0.0072	0.0073	**0.0071**
	R^2	0.9988	0.9911	0.9987	0.9988	**0.9989**
	Rank	4	5	2	3	**1**

5.3. Comparisons of Weibull distributions parameter values based on seasonal analysis

The rank of the methods based on averaged seasonal wind speed either in the urban and rural sites' data is given in Table 4. Similar to the yearly analysis, it is found for the seasonal analysis the same results for the three sites A, C and D except the cooler period of site B.

Firstly, the GM method showed the best performance for the cooler and hot season at site A among the statistical indicators. Next, for the two seasons at site A, the EPFM method had the second-best accuracy method.

The comparison of the results for site B shows that the EPFM and GM methods are the best method in cooler and hot seasons respectively.

While for sites C and D, the good results are observed using the EPFM method for every period. The EPFM method seems to have the best and efficient performance for all seasons in terms of the statistical indicators. In the majority of seasons of the sites, GM and EPFM are the most efficient methods to estimate Weibull parameters. These two numerical methods have been used to calculate the monthly, annual and seasonal mean available power density and to compare with the measured data

6. Wind power density estimation and error analysis

In order to calculate the monthly, annual and seasonal mean wind power density and its error (RPE), the GM and EPFM methods were only used in this section. The Weibull c and k parameters for GM and EPFM are derived from monthly values for urban and rural sites obtained in section 5.1.

6.1. Monthly wind power density estimation and error analysis

Figure 5 presents the monthly mean values of the available wind power density for the stations (A, B, C and D). The Pm and Pw values and RPE were obtained respectively using Equations (23), (24) and (25).

The results obtained for site A show that the values of power density using GM method and measured data are respectively in the range 3.62-10.78 W/m² and 4.35-13.39 W/m². The wind power density using GM method obtained varies from 3.62 W/m² in May to 10.78 W/m² in February while the annual value is 6.70 W/m².

From Table 5, it is seen that for site A, the RPE does not in the acceptable range between -10 % and +10 % for all the months, except for April (-9.93 %), August (-9.81 %) and October (-1.26 %) [7, 17, 23]. From site B, the monthly results show that the power density using GM was above 66.58 W/m². It is also observed from the RPE indicator that the values of power density obtained are very close to each other. For site C, the maximum values of power density are respectively 1531.98 W/m² and 1398.8 W/m² which are recorded in February (with RPE= 9.51 %). For site D, the monthly variation of mean wind power density using EPFM is between 92.17 W/m² (September) and 485.25 W/m² (March) with the RPE is in the acceptable range.

6.2. Seasonal wind power density estimation and error analysis

The wind power density estimation and its error of seasonal approach have been represented in Fig.6. Furthermore, it is possible to verify how estimation power density obtained using GM and EPFM comparing to measured data, change between the cooler and hot season.

Table 4. Obtained rank based on seasonal analysis for each site.

Period	Methods	A	B	C	D
		Rank	Rank	Rank	Rank
Oct.-Apr.	MM	5	2	5	4
	GM	**1**	5	2	5
	SDM	4	3	3	2
	EMJ	3	4	4	3
	EPFM	2	**1**	**1**	**1**
May-Sep.	MM	3	3	4	4
	GM	**1**	**1**	5	5
	SDM	4	5	2	3
	EMJ	5	4	3	2
	EPFM	2	2	**1**	**1**

Fig.5. Monthly variation of the power density values calculated from measured data (Pm) and using best estimation methods (Pw): GM for the urban sites A and B; and EPFM for the rural sites C and D.

See the results given for site A, according to the obtained RPE values, the GM performance in estimating the wind power density was the worst one and its values for cool and hot seasons are -24.83 % and -11.46 %, respectively. The estimation power density using GM is 6.30 W/m² for the cooler period and 6.62 W/m² for the hot season. For site B, because of obtained results in section 5.3, it can be seen that, in cooler and hot periods, EPFM and GM methods are used to calculate the estimated power density in the same site. The error for the selected methods was -0.23 % in the cool season while it was -1.50 % in the hot season.

For site C, the values of wind power density using EPFM method have been observed in cool and hot season with the values of 766.39 W/m² and 274.08 W/m². On the other hand, for site D, it can be seen similar behavior, the values of wind power density have been observed in cool and hot season with the values of 335.19 W/m² and 154.45 W/m².

Table 5. Monthly variation of the RPE obtained for each site.

	RPE (%)			
	A	**B**	**C**	**D**
Jan.	-21,2	-2,54	2,99	3,73
Feb.	-19,54	-0,03	9,51	7,94
Mar.	-16,47	-5,93	13,09	10,51
Apr.	-9,93	-2,03	6,93	6,13
May	-16,82	-0,9	2,6	0,25
Jun.	-20,01	-1,04	1,67	-0,57
Jul.	-12,67	-1,22	1,33	-0,5
Aug.	-9,81	-0,12	1,02	-0,42
Sep.	-14,93	-3,05	0,11	-0,58
Oct.	-1,26	0,4	-20,6	8,91
Nov.	-52,48	-2,37	-46,58	5,86
Dec.	-13,84	-0,99	1,39	6,81
Annual	-15,4	-1,38	1,56	-0,57

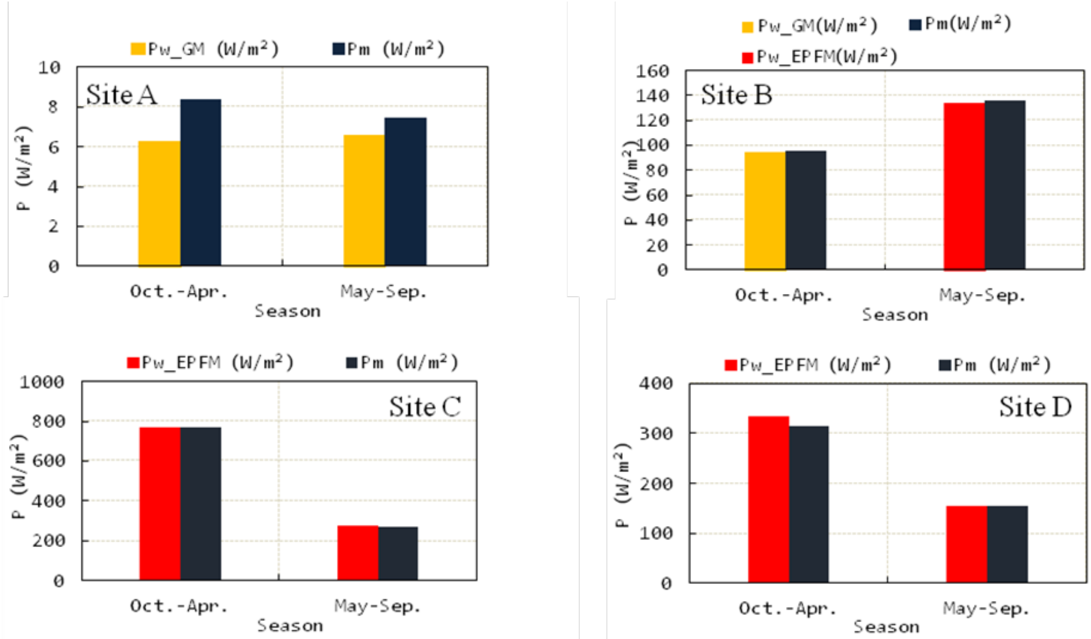

Fig. 6. Seasonal variation of the power density values calculated from measured data and using best estimation methods: GM for the urban sites A and B; and EPFM for the rural sites C and D.

7. Conclusions

Djibouti is part of Sub-Saharan Africa and has an enormous potential of solar, geothermal, and wind energy. Consequently, series of initiatives were launched to develop the wind energy sector to meet the strong demand for energy and consolidate our energy production. Indeed, the accessibility of the majority of populations to energy is a major challenge for the improvement of living conditions and modernization of both rural and urban areas. Therefore, this paper contributes to the development of wind power applications.

To fulfill the objective of the country, the first evaluation and statistical diagnosis of the five numerical methods including GM, MM, EMJ, EPFM and SDM were assessed for estimating the Weibull parameters and to determine wind power density in the selected stations. The accuracy of methods was evaluated using four statistical indicators and these indicators are reliable to rank the methods. The availability of wind speed data in urban and rural areas permits the evaluation of wind energy density and determination of appropriateness of the location for wind energy systems. Depend on averaged monthly, yearly, seasonal cases and statistical tools, the results illustrate that GM and EPFM are the most efficient methods with less error and are applicable to calculate the wind power density at any height and locations. Cool season has more wind potential than the hot season for both urban and rural sites.

These results provide further support for the finding that wind energy applications are an alternative and promising energy sources for the future of the Republic of Djibouti to reduce its dependence on non-renewable and imported energy.

Therefore, it can be finally concluded these analyses can extended to the Sub-Saharan countries with same climate and wind characteristics.

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