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Research Paper

Assessment of wind energy potential for small scale water pumping systems in the north region of Cameroon

Dieudonné Kidmo Kaoga [1*], Noël Djongyang [1], Serges Yamigno Doka [2], Danwe Raidandi [3]

[1] *Department of Renewable Energy, Higher Institute of The Sahel, University of Maroua, PO Box 46 Maroua, Cameroon*
[2] *Department of Physics, Higher Teacher's Training College, University of Maroua, PO Box 46 Maroua, Cameroon*
[3] *Department of Mechanical Engineering, National Advanced Polytechnic School, University of Yaoundé I, PO Box 8390 Yaoundé Cameroon*
**Corresponding author E-mail: kidmokaoga@gmail.com*

Abstract

Based on the wind data recorded over a six year period (2007 to 2012) as observed in the main meteorological station of the Garoua International airport, an assessment of the wind potential has been performed by means of the Weibull Probability Density Function (PDF) with two parameters. The maximum likelihood estimation method (MLE) was used to estimate the dimensionless Weibull shape parameter k, and the Weibull scale parameter C. The maximum wind power density extracted by the blades as well as the useful average hydraulic power output and the daily water production of the hypothetic windmill were determined in order to forecast applications in the north region of Cameroon such as providing domestic water, watering farm animals and small scale irrigation.

Keywords: *Hydraulic Power Output, Power Density, Weibull Distribution, Weibull Parameters, Wind Speed.*

1. Introduction

With fast growing energy demand, in addition to rising environmental consciousness, it has become crucial to enhance energy supply with renewable sources of energy. This is particularly true for wind, an inexhaustible resource which has the potential to lower greenhouse gas emissions and local air pollutants coupled with the burning of fossil fuels.
In the north region of Cameroon, wind can be reasonably harnessed to provide significant quantities of energy to support rural areas' needs such as acquiring clean water, be it for domestic purposes, for livestock or for irrigation. Providing clean water is one of the best ways to improve health and increase the productive capacity of the population. Accessing to clean water is best achieved through pumping from underground water aquifers rather than using surface water sources, which are often polluted [1]. Given a good quality wind site and because of the moderately small quantities of water needed, wind pumping for community water supply and livestock watering could be cost-effective. However, irrigation pumping requires large quantities of water during the dry season. The seasonal variation in the north region of Cameroon is conventionally expressed by two climatic seasons, namely the dry season (mid-October to mid-July) and the rainy season (mid-July to mid-October). The months of July and October are the transition periods between the two seasons. The windiest months are observed between March and June. So far, studies on wind characteristics in the north region of Cameroon are limited.
A certain number of difficulties are related to the wind, as an energy source. One of these difficulties is wind speed variability. As a result, to forecast the energy output of a wind energy conversion system, the Weibull PDF with two parameters, the dimensionless Weibull shape parameter k, and the Weibull scale parameter C, is the model utilized. There are several methods which can be used to estimate the Weibull parameters C and k, depending on which wind statistics are available and what level of sophistication in data analysis one wishes to employ[5]. In this study, the MLE method has been chosen as a comprehensive understanding of wind characteristics required to assess the potential wind. Despite the wind categories suitable for the development of mechanical wind power for water pumping, there seems to be limited interests in wind energy as there are limited previous researches in this field. An attempt has been made by Tchinda *et al.* [2] to evaluate the wind energy potential with meteorological method using wind data from 1990 to 1999.

The aim of this study is to assess wind energy potential for water pumping windmills in the north region of Cameroon, provided that monthly wind data over a six year period (2007 to 2012) were supplied. It's then proceeded to the estimation of the daily water production of the hypothetic windmill, based on the total dynamic head, ranging from 10 to 30 meters for applications such as household use, small scale irrigation, and livestock.

2. Methods and materials

2.1. Data source

The data provided for the study are monthly mean wind speeds, recorded over six year period, from 2007 to 2012 at 10 m height above ground level (AGL). These data were obtained from the main meteorological station located in the Garoua International airport. The table 1 gives the geographical coordinates of the location.

Table 1: Geographical coordinates of the study area

Variable	Value
Latitude	09°20' N
Longitude	13°23'E
Elevation	242 meters height AGL

2.2. Weibull distribution

The daily, monthly, seasonal, and yearly wind speed probability density distributions are modeled using the Weibull PDF. The Weibull PDF can be used with acceptable accuracy for prediction of wind energy output required for preliminary design and assessment of wind power plants [3]. The variation in wind speed are most often described by the Weibull PDF with two parameters, the dimensionless Weibull shape parameter k, and the Weibull scale parameter C which have reference values in the units of wind speed. The PDF function $f(V)$ is given by the following [4], [20]:

$$f(V) = (k/C).(V/C)^{k-1}.\exp(-(V/C)^k) \quad (1)$$

Where: $f(V)$ = probability of observing wind speed V
V = wind speed $[m/s]$
C = Weibull scale parameter $[m/s]$
k = Weibull shape parameter
The corresponding cumulative distribution function is given by [6], [20]:

$$F(V) = 1 - \exp(-(V/C)^k) \quad (2)$$

The mean wind speed $\bar{V}$ and the standard deviation σ of the observed data are determined using the following equations [8], [17], [20]:

$$\bar{V} = C\Gamma(1 + 1/k) \quad (3)$$

Where: $\bar{V}$ = mean wind speed $[m/s]$

$$\sigma = C[\Gamma(1 + 2/k) - \Gamma^2(1 + 1/k)]^{1/2} \quad (4)$$

Where the standard gamma function is given by:

$$\Gamma(x) = \int_0^{\infty} t^{x-1}\exp(-t)\,dt \quad (5)$$

The gamma function used by J.F. Manwell *et al.* [12] quoting Jamil [8] is given by:

$$\Gamma(x) = \left(\sqrt{2\pi x}\right)(x^{x-1})(e^{-x})\left(1 + \frac{1}{12x} + \frac{1}{288x^2} - \frac{139}{51840x^3} + \cdots\right) \quad (6)$$

2.3. Maximum likelihood method

The MLE method is a mathematical expression known as a likelihood function of the wind speed data in time series format. The MLE method was used by Deligiorgi *et al* [9] and Costa Rocha *et al* [17], quoting Stevens and Smulders [20] in their study for the estimation of parameters of the Weibull wind speed distribution for wind energy utilization purposes. The MLE method is solved through numerical iterations to determine the parameters of the Weibull distribution. The shape factor k and the scale factor c are estimated by the following equations:

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

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

Where: n = number of non-zero data values.
i = measurement interval.
V_i = wind speed measured at the interval i $[m/s]$.

2.4. Weibull parameters extrapolation

In a wide number of cases (Justus *et al.*[23]; Hennessey [24]), the Weibull seems to give a reasonable fit to observed distributions, and with Weibull C and k values known at one height, a consistent methodology can be used to adjust these parameters to another desired height**.** The Weibull distribution values C_{10} and k_{10} determined at 10 meters height AGL ($z_{10} = 10$ meters) are adjusted to any desired height z by the relation [5]:

$$C_z = C_{10} * (z/z_{10})^n \quad (9)$$

Where: C_z = adjusted Weibull scale parameter to a desired height z $[m/s]$.
C_{10} = Weibull scale parameter at 10 meters height above ground level $[m/s]$.
z_{10} = 10 meters height above ground level $[m]$.
z = desired height above ground level $[m]$.

$$k_z = k_{10}[1 - 0.00881\, ln(z_{10}/10)]/[1 - 0.00881\, ln(z/10)] \quad (10)$$

Where: k_z = adjusted Weibull shape parameter to a desired height z.
k_{10} = Weibull shape parameter at 10 meters height above ground level.
Where the power law exponent n is given by:

$$n = [0.37 - 0.088\, ln(C_{10})]/[1 - 0.088\, ln(z_{10}/10)] \quad (11)$$

2.5. Site specific wind speeds

There are two wind speeds that are very useful to wind energy investors and assessors. These are called the most probable (V_{mp}) and maximum energy carrying (V_{Emax}) wind speeds. They are given in terms of the Weibull 2-parameters as [6]:

$$V_{mp} = C[(k-1)/k]^{1/k} \quad (12)$$

Where: V_{mp} = the most probable wind speeds $[m/s]$.

$$V_{Emax} = C[(k+2)/k]^{1/k} \quad (13)$$

Where: V_{Emax} = the maximum energy carrying wind speeds $[m/s]$.

2.6. Wind shear characterization wind speeds

Since the observed wind speed data were measured at 10 meters height AGL and the desired anemometer level is most often at a different height, there is a need characterize the wind shear, variation of wind speed with elevation. The most commonly used methods of estimating wind shear are known as the log law and the power law [10]. Given that wind speed in general increases with elevation, and that wind turbines are designed to operate at different hub heights when compared to the available measured wind data, the observed wind speed height ($z_{10} = 10$ meters AGL) can be extrapolated to the turbine hub height through the power law expression given as [11]:

$$V(z_2) = V(z_{10})(z_2/z_{10})^{\alpha_1} \quad (14)$$

Where: $V(z_2)$ = wind speed at the wind turbine hub height z_2 $[m/s]$
$V(z_{10})$ = wind speed at original height $z_{10} = 10\ meters$ AGL $[m/s]$
α_1 = power law exponent proposed by [12]:

$$\alpha_1 = [0.37 - 0.088\, ln(v_{10})]/[1 - 0.088\, ln(z_{10}/10)] \quad (15)$$

2.7. Wind power density estimation

To calculate the mean power on a long time T (a month, a season, a year. . ..), Tchinda *et al*. [2], quoting Petersen *et al.*[22], proposed the use of $f(\bar{V})$**,** the statistical distribution of the mean speed corresponding to the interval of time T. therefore wind power density is given by [2]:

$$\bar{P} = (1/2) * \rho * (1 + 3I^2) \int_0^\infty f(\bar{V}) \cdot \bar{V}^3 \quad (16)$$

Where: $\bar{P}$ = wind power density $[watts/m^2]$.
$f(\bar{V})$ = Statistical distribution of the mean speed $\bar{V}$.
The wind power density can be estimated from the Weibull parameters as [5], [20]:

$$\bar{P} = (1/2) * \rho * (1 + 3I^2) C^3 (1 + 3/k) \quad (17)$$

Where:I : turbulence factor, $I = \frac{\sigma_v}{\bar{V}}$;
σ_v : The standard deviation of the twelve month wind speed $[m/s]$
$\bar{V}$: mean wind speed $[m/s]$
ρ = air density at the site, is often written in a simple form [4]:

$$\rho = \rho_0 - 1.194 * 10^{-4} * H_m \quad (18)$$

Where: H_m = site elevation in meters
The air density value at sea level is $\rho_0 = 1.225\ kg/m^3$.
The site elevation is 242 meters, and based on the equation 18, the air density value is $\rho = 1.196\ kg/m^3$.

2.8. Extractable wind energy estimation

The daily extractable wind energy is given by:
$\bar{E}_d = (24/1000) * \bar{P}$ (19)
Where: $\bar{E}_d$ = daily extractable wind energy $[kWh/m^2.day]$.
Therefore the daily extractable wind energy can be estimated from the Weibull parameters as:
$\bar{E}_d = 14.35 * 10^{-3} * \rho * (1 + 3I^2)C^3(1 + 3/k)$ (20)
The monthly extractable wind energy can be estimated from the Weibull parameters as:
$\bar{E}_m = 14.35 * 10^{-3} * d_j * \rho * (1 + 3I^2)C^3(1 + 3/k)$ (21)
Where: $\bar{E}_m$ = monthly extractable wind energy $[kWh/m^2.month]$.
d_d = number of days in the month considered.
The annual extractable mean energy $\bar{E}_{an}$ is the sum of the monthly extractable wind energies. $\bar{E}_{an}$ Can be formulated as follows [2], [14], [18]:
$\bar{E}_{an} = \sum_{m=1}^{n=12} \bar{E}_m$ (22)
Where: $\bar{E}_{an}$ = annual extractable energy $[kWh/m^2.an]$.

2.9. Maximum extractable wind energy (Betz theory)

The power extracted by the blades is customarily expressed as a fraction of the upstream wind power and the theoretical maximum value is given as follows [3]:
$\bar{P}_{max} = (16/27) * \bar{P} = C_p * \bar{P}$ (23)
Where: $\bar{P}_{max}$ = maximum extractable wind power density $[watts/m^2]$
C_p = Rotor efficiency.
For a given upstream wind speed, the power coefficient of the rotor or the rotor efficiency C_p has a theoretical maximum value of $16/27$ or 0.59, known as the Betz limit. When considering the Betz limit and for the given site, the air mean specific mass, the maximum wind power density extracted by the blades is given by:
$\bar{P}_{max} = (16/27) * (1/2) * \bar{P}$ (24)
Therefore the maximum power extracted is given as followed:
$\bar{P}_{max} = 0.354 * (1 + 3I^2)C^3(1 + 3/k)$ (25)
The maximum daily energy extracted by the blades is given by:
$\bar{E}_{max,d} = 24 * 10^{-3} . \bar{P}_{max}$ (26)
Where: $\bar{E}_{max,d}$ = maximum daily extractable wind energy $[kWh/m^2.day]$
As a result:
$\bar{E}_{max,d} = 8.50 * 10^{-3} * (1 + 3I^2)C^3(1 + 3/k)$ (28)
The maximum monthly energy extracted by the blades, estimated from the Weibull parameters is given:
$\bar{E}_{max,m} = 8.50 * 10^{-3} * d_j * (1 + 3I^2)C^3(1 + 3/k)$ (29)
Where: $\bar{E}_{max,m}$ = maximum monthly extractable wind energy $[kWh/m^2.month]$.
The maximum yearly energy extracted by the blades is given by:
$\bar{E}_{max,an} = \sum_{m=1}^{n=12} \bar{E}_{max,m} \quad (kWh/m^2.year)$ (30)
Where: $\bar{E}_{max,an}$ = maximum yearly extractable wind energy $[kWh/m^2.year]$.

3. Results and discussions

In this study, wind speed data analyses were done using Microsoft Excel®. The dimensionless Weibull shape parameter k and the Weibull scale parameter C were estimated using the MLE method. In addition, Weibull mean wind speed $\bar{\boldsymbol{V}}$, standard deviation, most probable (V_{mp}), maximum energy carrying (V_{Emax}) wind speeds and power density are summarized in table 2.
It can be seen from the table 2 that the highest monthly wind speeds occur in March ($2.11\ m/s$), April ($2.71\ m/s$), May ($2.52\ m/s$), June ($2.34\ m/s$) and July ($2.34\ m/s$) while the minimum monthly wind speeds occur in November ($1.40\ m/s$) and December ($1.24\ m/s$). The overall yearly mean wind speed in Garoua is found to be $1.91\ m/s$. Moreover, the knowledge of the most probable (V_{mp}) and maximum energy carrying (V_{Emax}) wind speeds help to establish whether or not this particular location is suitable for wind turbine. The results of the most probable (V_{mp}) and maximum energy carrying (V_{Emax}) wind speeds analyses are presented in the table 2. It showed that the values of V_{mp} and V_{Emax} from January to December range from *1.22* to *2.81* m/s and *1.63* to *3.21* m/s respectively. The Weibull shape and scale parameters (k and C) show that k varies from *2.76* (October) to *6.40* (March), while C is between *1.39* (December) and *2.97* m/s (April). In addition, it can be observed that the power density range from 3.15 W/m^2 in December to 25.83 W/m^2 in March. Therefore, this location falls under wind energy class 1 ($< 100\ W/m^2$) [12],

adequate for mechanical applications such as small scale water pumping. The tables 12 and 13 summarize the maximum extractable daily and monthly wind energy.

Table 2: Some of the results of Weibull Analysis

Month	$V_{weibull}$ (m/s)	$\sigma_{weibull}$ (m/s)	$C_{weibull}$ (m/s)	$k_{weibull}$	V_{mp} (m/s)	V_{Emax} (m/s)	$p(v)$ (W/m^2)
Jan.	1.59	0.51	1.77	3.47	1.60	2.02	6.18
Feb.	1.59	0.54	1.78	3.26	1.59	2.06	6.46
Mar.	2.11	0.38	2.26	6.40	2.20	2.36	10.19
Apr.	2.71	0.67	2.97	4.60	2.81	3.21	25.83
May	2.52	0.56	2.73	5.16	2.62	2.91	19.34
June	2.49	0.65	2.74	4.31	2.58	2.99	20.81
July	2.34	0.73	2.60	3.58	2.37	2.94	19.26
Aug.	1.84	0.58	2.05	3.50	1.86	2.33	9.54
Sep.	1.60	0.50	1.78	3.59	1.62	2.01	6.18
Oct.	1.59	0.59	1.78	2.93	1.54	2.12	6.81
Nov.	1.40	0.55	1.57	2.76	1.34	1.92	4.85
Dec.	1.24	0.44	1.39	3.08	1.22	1.63	3.15

The figure 1 illustrates monthly frequencies distribution of wind speed. The plots were drawn using the values of scale and shape parameters obtained with equations (3) and (4). The corresponding monthly cumulative frequencies distributions are shown in figures 2.

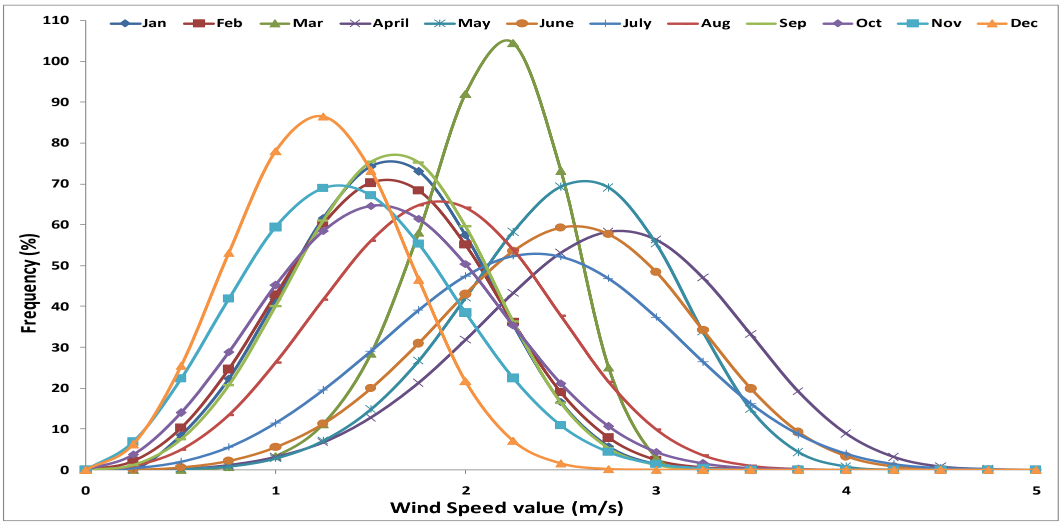

Fig. 1: Plot of monthly frequency distribution (%) of wind speed, at 10 m height AGL.

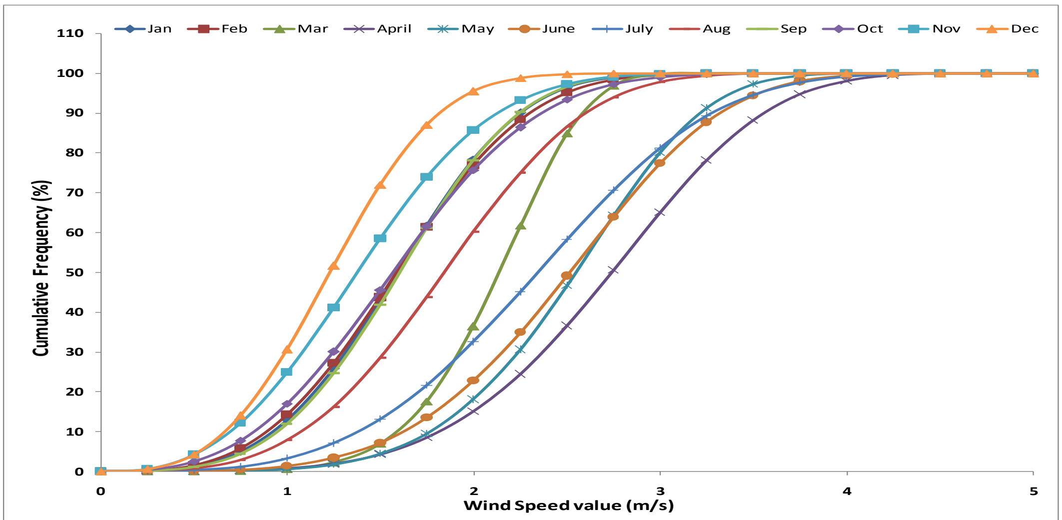

Fig. 2: Plot of monthly cumulative frequency distribution (%) of wind speed, at 10 m height AGL

3.1. Application to water pumping

The average hydraulic power output $\bar{P}_{hyd}$ of a wind pump (at sea level) is given by [19]:

$$\bar{P}_{hyd} = B * \bar{V}^3 * A_{rotor} \quad (31)$$

Where: $\bar{V}$ = average wind speed at the site $[m/s]$
A_{rotor} = swept rotor area $[m^2]$.
B = quality factor expressing the effectiveness with which wind power is converted to net hydraulic power. Normal values of B range from 0.05 to 0.15, the first being acceptable, the second value being excellent. The value B = 0.1 can be regarded as an average value for a well-designed wind pump. Therefore the useful average hydraulic power output $\bar{P}_{hyd}$ can be estimated is given by [24]:

$$\bar{P}_{hyd} = 0.1 * \bar{V}^3 * A_{rotor} \quad (32)$$

Where $\bar{P}_{hyd}$ is a function of the pump head, the required water flow rate, the density of water, and the acceleration due to gravity. Otherwise, the hydraulic power output is given:

$$\bar{P}_{hyd} = \rho_w q g H \quad (32)$$

Where: $\bar{P}_{hyd}$ = average hydraulic power output$[w/m^2]$.
ρ_w = density of water $[kg/m^3]$.
q = average water flow rate $[m^3/day]$.
g = acceleration of gravity $[m^2/s]$.
H = total pumping head $[m]$.
To estimate the daily water production of the hypothetic windmill based on the total dynamic head, for small scale water pumping applications, the table 3 [19] has been used as a guideline. Weibull parameters C_{10} and k_{10} determined at *10* meters height AGL, were extrapolated to *15* and *20* meters AGL (Table 7 and 8) in order to evaluate the wind shear (table 9), then to estimate the most probable (V_{mp}) and maximum energy carrying (V_{Emax}) wind speeds (Table 10 and 11).
For community water supply in the north region, a total pump head of *30* meters has been utilized for a windmill that is *20* meters height AGL. The Weibull distribution parameters determined at *10* meters height AGL were extrapolated to 20 meters height AGL using the equations (9) and (10). The results are presented in the table 4. On average, a hypothetic windmill with *2.5* to *5* meters blade's diameter could produce less that than *20* m^3/day . For a rotor diameter above 5 meters, the daily water production could be sufficient for a community of 500 persons approximately.

Table 3: Rough indication of water depths, required daily volume of water and typical size of the rotor for various applications [19].

Application	Head very low $< 3\,m$	low $3-10\,m$	medium $10-30\,m$	deep $> 30\,m$	Daily volume (m^3/day)	Typical rotor diameter (m)
Community water supply			*	*	20 (500 persons)	2.5 to 7.0
Domestic water supply			*	*	1 - 3 (small farm)	1.5 to 2.5
Cattle watering			*	*	20 (500 head)	1.5 to 4.5
Irrigation	*	*			40 – 100 (≈ 1 hectare)	2.5 to 5.5
Drainage	*				100	2.5 to 3.5

Table 4: Daily flow rate (m^3/day) based on the blade diameter at 20 m Height AGL

Typical rotor diameter (m)	2.50	3.00	3.50	4.00	4.50	5.00	5.50	6.00	6.50	7.00
Jan.	2.82	4.06	5.52	7.21	9.13	11.27	13.64	16.23	19.05	22.09
Feb.	2.94	4.24	5.76	7.53	9.53	11.76	14.23	16.94	19.88	23.06
Mar.	2.94	4.24	5.76	7.53	9.53	11.76	14.23	16.94	19.88	23.06
Apr.	10.75	15.49	21.08	27.53	34.84	43.02	52.05	61.94	72.70	84.31
May	8.15	11.74	15.98	20.87	26.42	32.61	39.46	46.96	55.12	63.92
June	8.80	12.68	17.25	22.54	28.52	35.21	42.61	50.71	59.51	69.02
July	8.21	11.82	16.09	21.01	26.60	32.83	39.73	47.28	55.49	64.36
Aug.	4.21	6.07	8.26	10.78	13.65	16.85	20.39	24.26	28.48	33.03
Sep.	2.82	4.06	5.52	7.21	9.12	11.26	13.63	16.22	19.04	22.08
Oct.	3.09	4.46	6.06	7.92	10.02	12.38	14.98	17.82	20.92	24.26
Nov.	2.26	3.26	4.43	5.79	7.33	9.04	10.94	13.02	15.28	17.73
Dec.	1.50	2.17	2.95	3.85	4.88	6.02	7.28	8.67	10.17	11.80
Average	4.88	7.02	9.56	12.48	15.80	19.50	23.60	28.08	32.96	38.23

For domestic water supply in the north region, a total pump head of 15 meters has been utilized for a hypothetic windmill that is *20* meters height AGL. On average, a hypothetic windmill with *1.5* to *2.5* meters blade's diameter could produce between *3.51* and *9.75*m^3/day. The results are presented in the table 5.

For cattle watering, a total pump head of *15* meters has been utilized. On average, a hypothetic windmill with *1.5* to *4.5* meters blade's diameter could produce from *3.51* to *31.59*m^3/day. The results are as well presented in the table 5.

Table 5: Daily flow rate (m^3/day) based on the blade diameter at 15 m Height AGL

Typical rotor diameter (m)	1.5	2	2.5	3.00	3.50	4.00	4.50
Jan.	2.03	3.61	5.64	8.12	11.05	14.43	18.26
Feb.	2.12	3.76	5.88	8.47	11.53	15.06	19.06
Mar.	2.12	3.76	5.88	8.47	11.53	15.06	19.06
Apr.	7.74	13.77	21.51	30.97	42.16	55.06	69.69
May	5.87	10.44	16.31	23.48	31.96	41.75	52.83
June	6.34	11.27	17.61	25.35	34.51	45.07	57.04
July	5.91	10.51	16.42	23.64	32.18	42.03	53.19
Aug.	3.03	5.39	8.42	12.13	16.51	21.57	27.30
Sep.	2.03	3.60	5.63	8.11	11.04	14.42	18.25
Oct.	2.23	3.96	6.19	8.91	12.13	15.84	20.05
Nov.	1.63	2.89	4.52	6.51	8.86	11.58	14.65
Dec.	1.08	1.93	3.01	4.33	5.90	7.70	9.75
Average	3.51	6.24	9.75	14.04	19.11	24.96	31.59

For farm irrigation, a total pump head of *10* meters has been utilized for a windmill that is *20* meters height AGL. The results are presented in the table 6. On average, it could be attractive to choose a hypothetic windmill with blade's diameter of more than *4* meters to produce more than *40* m^3/day. For rotor diameter of *5.5* meters, the windmill will produce more than *40* m^3/day from January to October. Additionally, the windmill could produce a maximum of *156* m^3/day in April, more than *100* m^3/day from April to July which correspond to the dry season when the need is in rise.

Table 6: Daily flow rate (m^3/day) based on the blade diameter at 10 m Height AGL

Rotor diameter (m)	2.50	3.00	3.50	4.00	4.50	5.00	5.50	6.00	6.50	7.00
Jan.	8.45	12.17	16.57	21.64	27.39	33.81	40.92	48.69	57.15	66.28
Feb.	8.82	12.71	17.29	22.59	28.59	35.29	42.70	50.82	59.64	69.17
Mar.	8.82	12.71	17.29	22.59	28.59	35.29	42.70	50.82	59.64	69.17
Apr.	32.26	46.46	63.24	82.59	104.53	129.05	156.15	185.83	218.10	252.94
May	24.46	35.22	47.94	62.62	79.25	97.84	118.39	140.89	165.35	191.77
June	26.41	38.03	51.76	67.61	85.57	105.64	127.82	152.12	178.52	207.05
July	24.63	35.46	48.27	63.04	79.79	98.50	119.19	141.84	166.47	193.07
Aug.	12.64	18.20	24.77	32.35	40.95	50.55	61.16	72.79	85.43	99.08
Sep.	8.45	12.17	16.56	21.63	27.37	33.79	40.89	48.66	57.11	66.23
Oct.	9.28	13.37	18.19	23.76	30.07	37.13	44.93	53.46	62.75	72.77
Nov.	6.78	9.77	13.29	17.36	21.98	27.13	32.83	39.07	45.85	53.18
Dec.	4.51	6.50	8.85	11.56	14.63	18.06	21.85	26.00	30.52	35.39
Average	14.63	21.06	28.67	37.44	47.39	58.51	70.79	84.25	98.88	114.68

Table 7: Weibull scale parameter C extrapolation to 15 and 20 m AGL

Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
10 m HAGL	1.77	1.78	2.26	2.97	2.73	2.74	2.60	2.05	1.78	1.78	1.57	1.39
15 m HAGL	2.01	2.02	2.55	3.32	3.07	3.07	2.92	2.32	2.02	2.02	1.80	1.59
20 m HAGL	2.21	2.22	2.78	3.59	3.32	3.33	3.17	2.53	2.22	2.22	1.98	1.76

Table 8: Weibull shape parameter extrapolation to 15 and 20 m AGL

Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
10 m HAGL	3.47	3.26	6.40	4.60	5.16	4.31	3.58	3.50	3.59	2.93	2.76	3.08
15 m HAGL	3.60	3.38	6.64	4.77	5.35	4.47	3.71	3.63	3.72	3.04	2.86	3.19
20 m HAGL	3.70	3.47	6.82	4.90	5.50	4.59	3.81	3.73	3.82	3.12	2.94	3.28

Table 9: Mean wind speed extrapolation to 15 and 20 meters AGL

Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
10 m HAGL	1.59	1.59	2.09	2.71	2.51	2.49	2.33	1.84	1.60	1.58	1.40	1.24
15 m HAGL	1.81	1.82	2.37	3.04	2.82	2.80	2.63	2.09	1.83	1.81	1.60	1.43
20 m HAGL	1.99	2.00	2.59	3.30	3.07	3.05	2.86	2.29	2.01	1.99	1.77	1.58

Table 10: Most probable wind speed extrapolation to 15 and 20 m AGL

Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
10 m HAGL	1.60	1.59	2.20	2.81	2.62	2.58	2.37	1.86	1.62	1.54	1.34	1.22
15 m HAGL	1.84	1.82	2.49	3.16	2.95	2.90	2.68	2.12	1.86	1.77	1.55	1.42
20 m HAGL	2.03	2.01	2.72	3.43	3.20	3.15	2.92	2.33	2.05	1.96	1.72	1.57

Table 11: Maximum energy carrying wind speeds (V_{Emax}) extrapolation to 15 and 20 m AGL

Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
10 m HAGL	2.02	2.06	2.36	3.21	2.91	2.99	2.94	2.33	2.01	2.12	1.92	1.63
15 m HAGL	2.28	2.32	2.66	3.57	3.25	3.33	3.28	2.62	2.27	2.39	2.16	1.85
20 m HAGL	2.48	2.53	2.89	3.85	3.52	3.60	3.54	2.84	2.48	2.60	2.36	2.03

Table 12: Extractable daily, monthly wind energy

Period	$\bar{P}(w/m^2)$	$\bar{E}_d(kWh/m^2.day)$	$\bar{E}_m(kWh/m^2.month)$
Jan.	8.06	0.19	5.99
Feb.	8.67	0.21	5.82
Mar.	11.21	0.27	8.34
Apr.	30.57	0.73	22.01
May	22.21	0.53	16.52
June	25.09	0.60	18.06
July	24.82	0.60	18.46
Aug.	12.39	0.30	9.22
Sep.	7.96	0.19	5.73
Oct.	9.62	0.23	7.16
Nov.	7.08	0.17	5.10
Dec.	4.34	0.10	3.23

Table 13: Maximum Extractable daily, monthly and yearly wind energy

Period	$\bar{P}_{max}(w/m^2)$	$\bar{E}_{max.\ d}(kWh/m^2.day)$	$\bar{E}_{max.\ m}(kWh/m^2.month)$
Jan.	4.77	0.11	3.55
Feb.	5.14	0.12	3.45
Mar.	6.64	0.16	4.94
Apr.	18.11	0.43	13.04
May	13.16	0.32	9.79
June	14.87	0.36	10.70
July	14.71	0.35	10.94
Aug.	7.34	0.18	5.46
Sep.	4.72	0.11	3.40
Oct.	5.70	0.14	4.24
Nov.	4.20	0.10	3.02
Dec.	2.57	0.06	1.91

4. Conclusion

The main goal of this study was to assess the wind energy for small scale water pumping in the north region of Cameroon. The following observation can be done throughout this study:

- Weibull distribution proved to be a useful tool to predict the wind regime relevant to wind power generating systems.
- Wind energy potential in the north region of Cameroon is not fitted for generating electricity. Furthermore, based on the foreseen applications, the following could be concluded.
- For community water supply, a hypothetic windmill with a rotor diameter bigger than *5* meters could produce on average more than $20m^3/day$, given total pump head of *30* meters.
- For domestic water supply, a hypothetic windmill with a rotor diameter of *1.5* meters could produce *3.51* m^3/day while a rotor diameter of *2.5* meters could produce 9.75 m^3/day on average, given a total pump head of *15* meters.
- For cattle watering, a hypothetic windmill with a rotor diameter of *4.5* meters could produce *3.51* m^3/day while a rotor diameter of *4.5* meters could produce *31.59* m^3/day on average, given a total pump head of *15* meters.
- For farm irrigation, a hypothetic windmill with a rotor diameter of *5.5* meters could produce on average, more than *40* m^3/day from January to October, given a total pump head of *10* meters.

Although the results of this study encourages the utilization of water pumping windmills in rural areas to help easing difficulties accessing to clean water for household use, small scale irrigation, and livestock, further wind characterization studies at different height above ground level are required.

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