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ARTICLE

Assessment of the Rural Water Supply Potential by Mechanical Wind Pumping Around the Floodplains of Lake Chad

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ABSTRACT

In the present work, an assessment of the rural water supply potential by mechanical wind pumping around the floodplains of Lake Chad has been considered. Inside the floodplains around Lake Chad, available surface water is largely contaminated and represents health hazards to populations. Access to underground and clean water has increasingly become rare. Moreover, clean water scarcity has led to conflict and territorial pressures, which are contributing factors to poverty in the considered area. Four localities, Baga, Baga-Sola, Makari and Nguigmi, respectively, in Nigeria, Chad, Cameroon and Niger have been selected inside the floodplains around Lake Chad, to evaluate the potential of wind power and prospects of windmills development to provide safe drinking-water supply, livestock watering and small-scale irrigation. Long-term satellite-derived data, obtained through the Prediction of Worldwide renewable Energy Resources have been considered suitable and viable alternative to missing site-specific data from ground stations. Windmill of Multi-blade driven piston pump is the preferred water pumping option for this study because of its higher overall system efficiency. The results of this study indicate that mean wind speeds, at 10 m height above ground level, are 4.64 m/s for Baga, 4.76 m/s for Baga-Sola, 4.32 m/s for Makari and 4.44 m/s for Nguigmi. In addition, wind speeds for Baga, for instance, are in the range of 2.5–10 m (working range of a wind pump), at 10, 15, 20 and 25 m height agl, for 79.64, 82.80, 84.79, and 86.19 per cent of the time. Corresponding values for Baga-Sola, Makari and Nguigmi are in the range of 80.50–87.76 per cent, 76.86–85, 58 per cent, 77.92–86.21 per cent, respectively. For a Windmill with a 2 m-blade, a 25 m-height tower and considering a total dynamic head of 30 m, average monthly discharges for the dry season are 1,330, 1,374, 1,200 and 1,199 m^3, respectively for Baga, Baga-Sola, Makari and Nguigmi. Furthermore, corresponding costs of water are 9.53, 9.23, 10.56 and 10.57 XAF/m^3, for Baga, Baga-Sola, Makari and Nguigmi, in that order.

KEYWORDS

Wind energy; windmill; water pumping; lake chad

Nomenclature

f(V)	Probability distribution function
F(V)	Cumulative distribution function
V	Wind speed (m/s)

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V_m	Mean wind speed (m/s)
C	Scale parameter (m/s)
Z	Elevation (m)
T	Temperature at the considered site (°K)
agl	Above ground level
V_{10}	Wind speed available at 10 m height agl
z_{10}	10 m height agl
n	Power law exponent
C_{10}	Scale parameter (m/s) at 10 m height agl
V_z	Wind speed at the height to be extrapolated
H	Pump head (m)
g	Acceleration due to gravity (m/s^2)
V_w	Volume of water (m^3)
E_H	Hydraulic energy
K_O	Pump constant
V_I	Cut-in wind speed (m/s)
C	Scale parameter (m/s)
C_0	Power coefficient of the rotor at the design point
C_P	Power coefficient of the rotor
P_V	Power developed by the system in pumping water
ρ_a	Air density at the site
A	Rotor area (m^2)
η	Pump and transmission efficiency
$C_P \cdot \eta$	Overall system (wind to water) efficiency
C_z	Scale parameter (m/s) at z m height agl
z	Desired height agl
ρ_w	Water density (kg/m^3)

1 Introduction

Wind energy is now widely seen as an environmentally friendly alternative energy for a sustainable development as well as for easing energy crisis [1], mainly in Sub-Saharan Africans countries. As such, a wind energy conversion system harnesses the power of wind and converts it into electrical or mechanical energy to improve access to electricity or water [2] for remote locations not connected to the grid. For locations where low wind speeds prevail, such as most Sub-Saharan African countries, low wind speed wind turbine technology, such as pumping applications for water supply, are the preferred option [3].

In Sub-Saharan Africa, around 40 per cent of people do not have access to clean and safe water, and more than 8 out 10 people in rural areas are without improved drinking water sources, where they continue to live largely through primitive subsistence farming [4]. The majority of people in rural areas inside the floodplains around Lake Chad, most of whom are low-income households, have limited access to affordable and reliable modern energy services. The lack of dissemination of modern energy services in the aforesaid areas offers prospects for the penetration of renewable energy such as wind energy. The potential for extensive use of wind pumping is significant as the average wind speeds, which are 4.64 m/s for Baga, 4.76 m/s for Baga-Sola, 4.32 m/s for Makari and 4.44 m/s for Nguigmi, are sufficient for water pumping [5]. Therefore, the use of mechanical wind driven systems for clean and safe water pumping in the aforementioned locations can provide a valuable prospect for meeting the greatest drinking water spending needs as well as improving health and increase the productive capacity of households [6].

The current contribution investigates wind energy using mechanical wind driven systems for water pumping, with an objective of evaluating the potential of mechanical wind pumping to improve rural water supplies around Lake Chad floodplains. The Rayleigh distribution, which is the Weibull distribution with a shape parameter $k = 2$, has been considered adequately accurate to model wind regimes at the selected locations. The power curve model of the considered windmills has been defined in a quadratic form [7,8]. The costs per cubic meter of water discharged using the Present Value of Costs (PVC) of energy produced over the lifetime of Windmills are explored for the selected localities. Windmills of different rotors sizes, ranging from 1.5 to 3 m are studied using TDH in the range of 10–30 m, in increments of 5 m. Long-term satellite-derived data, obtained through the POWER (Prediction of Worldwide renewable Energy Resources) [9], have been considered suitable and viable alternative to missing site-specific data from ground stations.

After a brief presentation of the selected study cases used in the current study, we provide the tools developed to elaborate the methodology for the modeling of the wind speed, the potentiality of mechanical wind pumping and of the cost of energy. Within these input data and modeling tools, we report and discuss the results obtained for the specific cases of the selected locations inside Lake Chad floodplains.

2.1 Study Area

In this analysis, four selected locations inside Lake Chad floodplains are considered as seen (yellow color) in Fig. 1. The Lake is surrounded by Cameroon, Central African Republic (CAR), Chad, Niger and Nigeria, though its drainage basin, which covers around 8 per cent of the surface area of Africa, spreads over Algeria, Central African Republic (CAR), Libya and Sudan. The Saharan climate characterizes the Lake Chad Basin. The dry season usually lasts 8 months and is accompanied by Harmattan winds originated from the Sahara Desert. Lake Chad, a historically large and shallow, occupied first place among the endorheic lakes, up until 1960 [10]. Lake Chad is a vital source of fresh water to human, agriculture, livestock and wildlife and is a vast water lot surrounded by shoe string sand and floodplains [11]. The considered locations, Makari in Cameroon, Baga Sola in Chad, Baga in Nigeria and Nguigmi in Niger, were selected based on the potential of economic life as well as livelihood of rural communities residing on the lake shores. Makari is located on the East bank of a distributary of the Chari River in the delta just before it enters Lake Chad [12]. Baga is a city in the Northeastern Nigerian state of Borno, close to Lake Chad [10]. Baga and Baga Sola lie on the border of Lake Chad, are fishing centers as well as farming localities. Baga Sola is a locality on the shore of Lake Chad in western Chad. Nguigmi is a city in the easternmost part of Niger, on the shore of Lake Chad, whose primary economic activities are fishing and farming [13].

2.2 Wind Data Description and Source

Since ground-based measurement data are missing for the four selected locations, long-term satellite-derived data, obtained through the POWER, are considered suitable and viable alternative to site-specific data from ground stations [14–18]. These satellite-derived data are at daily level, at a 0.5×0.5-degree resolution. The time span of the presently used daily data is from January 2005 to January 2020. These data are obtained from the NASA Langley Research Center (LaRC) POWER Project funded through the NASA Earth Science/Applied Science Program [9]. Tab. 1 provides geographical coordinates of the selected locations, all of which are in the surroundings of the Lake's floodplains, in its four border countries.

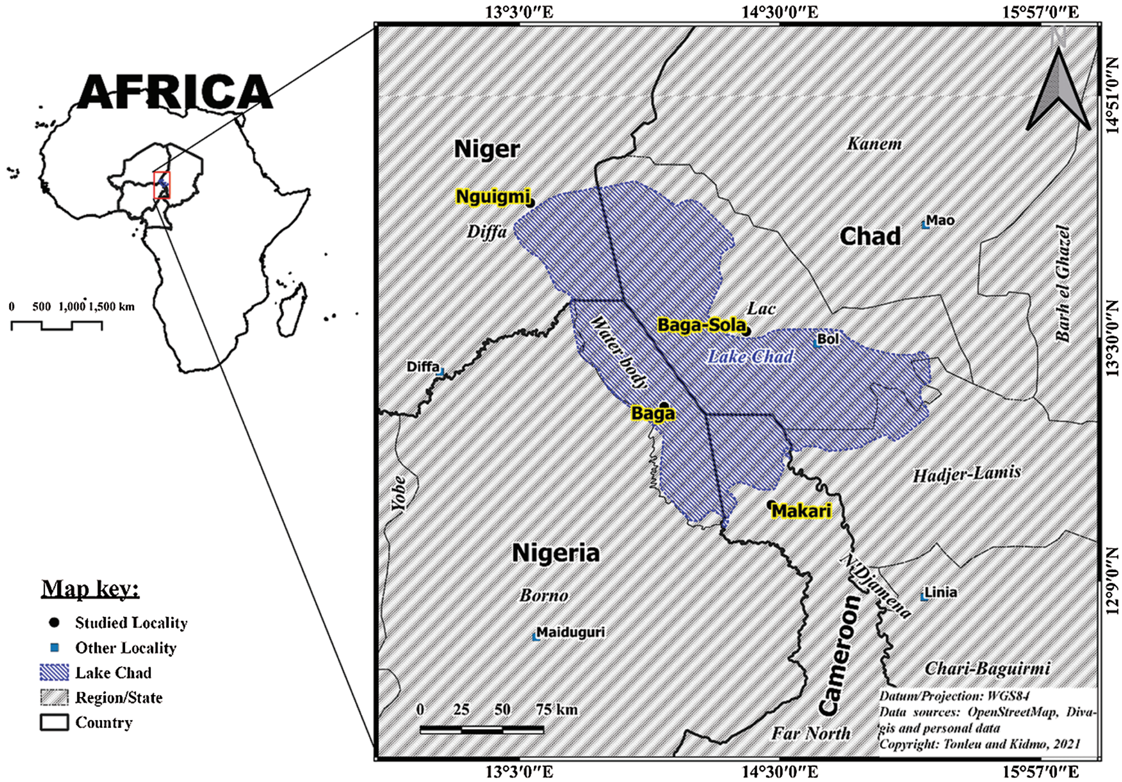

Figure 1: Map showing the four locations inside floodplains around Lake Chad

Table 1: Geographical data for the selected locations around Lake Chad

Location	Country	Latitude	Longitude	Altitude (m)	Time Period
Baga	Nigeria	13°7'7.7"N	13°51'23.7"E	299	Jan 2005–Jan 2020
Baga-Sola	Chad	13°32'18"N	14°18'46"E	299	Jan 2005–Jan 2020
Makari	Cameroon	12°34'27"N	14°27'14"E	300	Jan 2005–Jan 2020
Nguigmi	Niger	14°15'10"N	13°06'39"E	321	Jan 2005–Jan 2020

Fig. 2 provides monthly mean wind speed and standard deviation at 10 m height agl for Baga, Baga-Sola, Makari and Nguigmi. It is observed that higher mean wind speeds occur during the dry season (Jan-Jun and Nov-Dec), while lower values appeared in the rainy season (Jul-Oct). Average wind speeds, at 10 m height agl, are 4.64 m/s for Baga, 4.76 m/s for Baga-Sola, 4.32 m/s for Makari and 4.44 m/s for Nguigmi.

The monthly variation of mean temperature, at 2 m height agl, is shown in Fig. 3. It is observed that the four selected sites display similar values. Monthly mean temperatures, at 2 m height agl, are 29.67°C, 29.32°C, 29.38°C and 28.56°C, respectively for Baga, Baga-Sola, Makari and Nguigmi.

3 Methodology and Models

3.1 Rayleigh Probability Distribution Function

In this work, the considered approach for modeling wind speed data is based on the Rayleigh probability distribution function (PDF). The Rayleigh PDF, which is a special case of the Weibull PDF when the shape parameter is equal to 2, is defined by its PDF $f(V)$ and cumulative distribution function (CDF), $F(V)$, respectively as given by Eqs. (1) and (2) [19,20]:

$$f(V) = \frac{\pi}{2} \cdot \left(\frac{V}{V_m^2}\right) \cdot \exp\left[-\frac{\pi}{4}\left(\frac{V}{V_m}\right)^2\right] \tag{1}$$

$$F(V) = 1 - \exp\left[-\frac{\pi}{4}\left(\frac{V}{V_m}\right)^2\right] \tag{2}$$

where V = wind speed [m/s] and V_m = mean wind speed [m/s].

With regards to the Rayleigh PDF, the scale parameter C is given by the equation:

$$C = 2\frac{V_m}{\sqrt{\pi}} \tag{3}$$

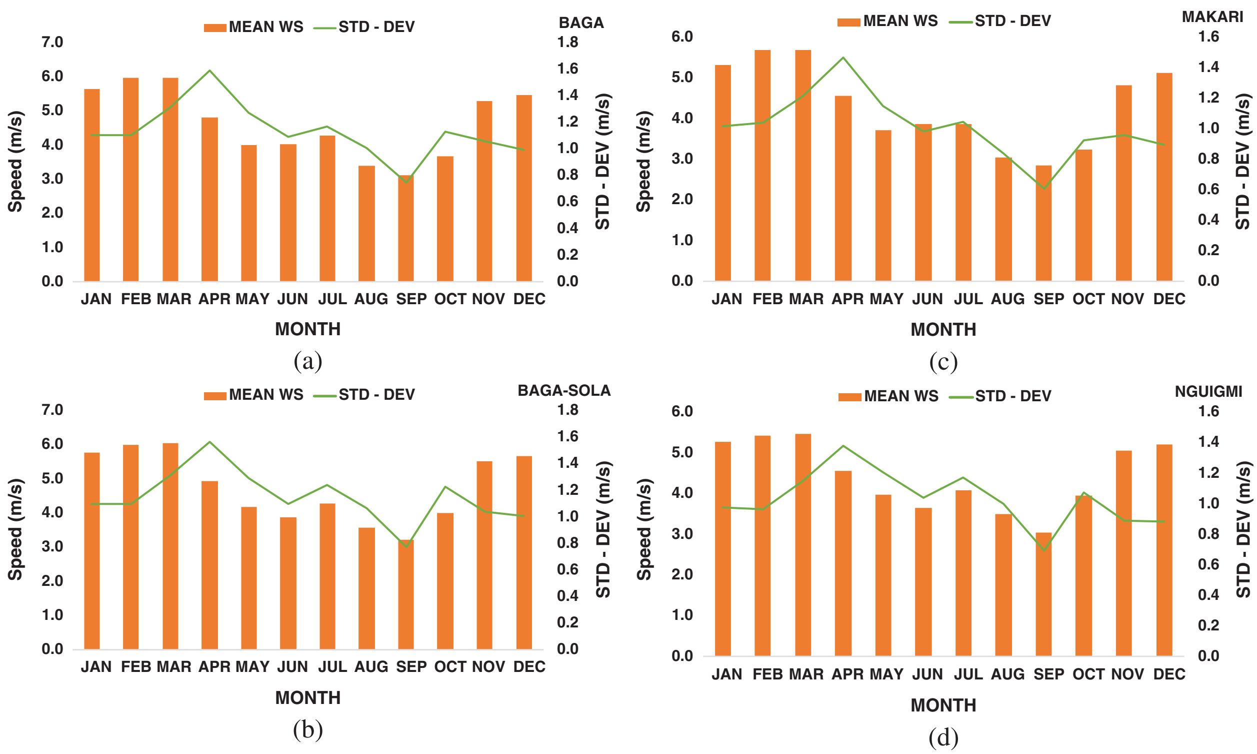

Figure 2: Monthly mean wind speeds at 10 m height agl and standard deviation for (a) Baga (b) Baga-Sola (c) Makari (d) Nguigmi

3.2 Extrapolation of Wind Speeds at Different Hub Heights

Wind speed increases with elevation agl. In this study, windmills hub heights of interest range from 10 m to a maximum of 25 m. Since the available wind speed data are at 10 m height agl, wind speeds need to be adjusted to relevant windmills hub heights. In the scientific literature, several studies with reference to vertical wind profiles are acknowledged and the approaches for wind height extrapolation include the power law and logarithmic law [21,22]. The power law is recognized to give a better approach for wind profiles and is, for this reason, preferred in the present case study. It can be expressed as given [23]:

$$V_z = V_{10} * \left(\frac{z}{z_{10}}\right)^n \tag{4}$$

where V_{10} = wind speed available at 10 m height agl, z_{10} = 10 m height agl, and V_z = wind speed at the height to be extrapolated; z_z = the desired height agl.

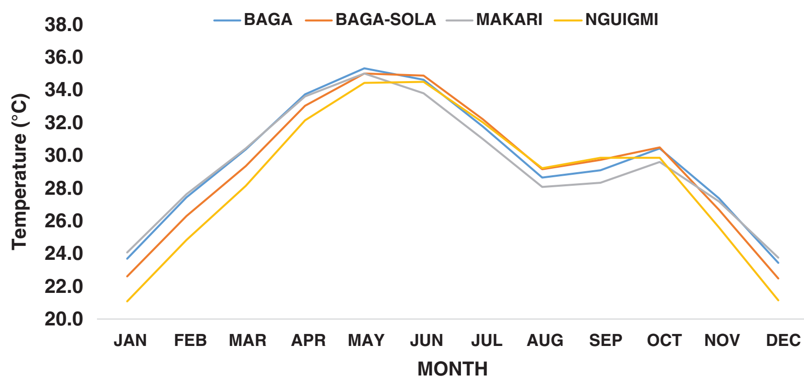

Figure 3: Monthly mean temperatures at 2 meters height AGL for Baga, Baga-Sola, Makari and Nguigmi

The power law exponent n is given by:

$$n = [0.37 - 0.088\ ln(V_{10})]/[1 - 0.00881 ln(z/10)] \tag{5}$$

Alternatively, the Weibull PDF can be used to extrapolate wind profiles at different desired windmills hub heights. The Weibull parameters C_{10} and k_{10} determined at 10 m height agl are adjusted to any desired height z by the following relations [24,25]:

$$C_z = C_{10} * \left(\frac{z}{z_{10}}\right)^n \tag{6}$$

$$k_z = \frac{k_{10}}{1 - 0.00881\ \ln(z/10)} \tag{7}$$

It is worth mentioning here that for the Rayleigh PDF, the shape parameter k_z is equal 2, where z and z_{10} are in meters, and the power law exponent n is given by:

$$n = [0.37 - 0.088 ln(C_{10})]/[1 - 0.00881 ln(z/10)] \tag{8}$$

3.3 Power Curve Model and Expected Wind Pump Discharges

The considered windmills are mechanically coupled to a piston pump with neither power regulation nor controllability. Accordingly, the windmill power curve can be modeled as a function of cut-in wind speed (V_I), cut-out wind speed (V_O) and maximum reached power (P_O) [26,27]. As a general rule, variations in rotor power with the wind speed can be matched by different polynomial expressions [28]. In the literature, a variety of models using linear, quadratic, cubic and higher powers of wind speed or their combinations are utilized [8]. In the present study, it is assumed that windmills rotors utilized for water pumping show a quadratic wind speed-power relationship and the instantaneous power output (P_V) at wind speed V, is given as follows [26]:

$$P_V = P_O \frac{V^2 - V_I^2}{V_O^2 - V_I^2} \tag{9}$$

The maximum reached power (P_O) takes into consideration the rotor, pump and wind regime characteristics. It can be written as expressed [28]:

$$P_O = \frac{1}{2}\rho_a A V_O^3 (C_P \cdot \eta_0) \tag{10}$$

And the overall system (wind to water) efficiency ($C_P \cdot \eta_0$) can be modelled as [26]:

$$C_P \cdot \eta_0 = 4C_0 \cdot \eta_0 \left[1 - K_O\left(\frac{V_I}{V_O}\right)^2\right] K_O\left(\frac{V_I}{V_O}\right)^2 \tag{11}$$

where A is the rotor area (m^2), C_P and C_0 are the Power coefficient of the rotor and its value at the design point, η_0 and K_O are the combined transmission with the pump efficiency and the pump constant, respectively.

From Eqs. (9) and (10), P_O can further be simplified as:

$$P_O = 2\rho_a A V_O^3 (C_0 \cdot \eta_0)\left[1 - K_O\left(\frac{V_I}{V_O}\right)^2\right] K_O\left(\frac{V_I}{V_O}\right)^2 \tag{12}$$

The air density at the site is often written in a simple form [29]:

$$\rho_a = \frac{353.049}{T} e^{\left(-0.034\frac{Z}{T}\right)} \tag{13}$$

where Z is the elevation in meters and T is the temperature at the considered site (°K).

The energy produced by the windmill in a given time period (T) can be expressed as [26]:

$$E = T\int_{V_I}^{V_O} P_V \cdot f(V)dV \tag{14}$$

After further substitutions, integrations and simplification, Eq. (13) yields:

$$E = \left\{[2\rho_a A V_O^3 T (C_0 \cdot \eta_0)\left[1 - K_O\left(\frac{V_I}{V_O}\right)^2\right] K_O\left(\frac{V_I}{V_O}\right)^2\right\}\left\{\frac{4V_m^2}{\pi(V_O^2 - V_I^2)}\left(e^{-\frac{\pi}{4}\left(\frac{V_I}{V_m}\right)^2} - e^{-\frac{\pi}{4}\left(\frac{V_O}{V_m}\right)^2}\right) - e^{-\frac{\pi}{4}\left(\frac{V_O}{V_m}\right)^2}\right\} \tag{15}$$

The hydraulic energy (E_H) needed by the pump for delivering a volume of water $V_w(m^3)$, can be given as [30]:

$$E_H = \rho_w \cdot g \cdot V_w \cdot H \tag{16}$$

Equating Eqs. (14) and (15), the volume of water $V_w(m^3)$ expected from the wind driven piston pump, installed at a given site, can be estimated, over a given time period T, using the following expression [28]:

$$V_W = \left\{2T(C_0 \cdot \eta_0) \cdot \frac{\rho_a}{\rho_w}\frac{A \cdot V_O^3}{g \cdot h}\left[1 - K_O\left(\frac{V_I}{V_O}\right)^2\right] K_O\left(\frac{V_I}{V_O}\right)^2\right\}\left\{\frac{4V_m^2}{\pi(V_O^2 - V_I^2)}\left(e^{-\frac{\pi}{4}\left(\frac{V_I}{V_m}\right)^2} - e^{-\frac{\pi}{4}\left(\frac{V_O}{V_m}\right)^2}\right) - e^{-\frac{\pi}{4}\left(\frac{V_O}{V_m}\right)^2}\right\} \tag{17}$$

where ρ_w is the water density (kg/m^3), g is the acceleration due to gravity (m/s^2), and H is the pump head (m).

3.4 Cost of Water

The economic evaluation of the wind-generated water is assessed using the present value of costs (PVC) of energy produced during the entire lifetime of the Windmill [31]:

$$PVC = I + C_{om}\left(\frac{1+i}{r-i}\right) * \left(1 - \left(\frac{1+i}{1+r}\right)^n\right) - S\left(\frac{1+i}{1+r}\right)^n \tag{18}$$

where the following assumptions are made to estimate the cost of energy produced by the windmill:

- I is the investment cost, which includes the windmill price in addition to 10 per cent for civil works and other connections;
- The windmill price is assumed to be US$ 250 (XAF 150,000) per m^2 swept area of the rotor;
- **n** is the useful lifetime of WT in years (20 years);
- $\mathbf{i_o}$ is the nominal interest rate (16 per cent);
- $\mathbf{C_{om}}$ is the operation and maintenance costs (5 per cent of the investment cost);
- **S** is the scrap value (10 per cent of the windmill price);
- **i** is the inflation rate (3.6 per cent);

The discount rate (***r***) is determined using the following expression [31]:

$$\boldsymbol{r} = \frac{\boldsymbol{i}_0 - \boldsymbol{i}}{1 + \boldsymbol{i}} \tag{19}$$

The annual volume of water V_y (m^3/year) produced by the windmill is determined from:

$$V_y = \left(\frac{8760}{T}\right)V_w \tag{20}$$

The Cost of water (XAF/m^3), *COW* using the PVC method can be estimated using the following expression:

$$COW = \frac{PVC}{V_y} \tag{21}$$

4 Results and Discussion

The Rayleigh PDF allows to model wind characteristics for Baga, Baga Sola, Makari and Nguigmi, located inside Lake Chad floodplains. These locations are low wind speed resource areas, as wind power class 2 areas, which are thus considered as marginal for wind power development in the wind power scheme proposed by Battelle—Pacific Northwest Labs (PNL) [32]. These marginal areas for wind power development necessitate low wind speed wind turbine technology, such as windmills. By investigating wind energy option for wind power development in the considered locations, it is expected to raise awareness on forgotten wind water pumping niches which could help alleviating clean and safe water access, mainly in rural areas. The findings of this study are provided in the next sections.

4.1 Rayleigh Probability Distribution Function

From the results obtained, the monthly PDF and CDF at 10–30 m agl, as shown, respectively, in Figs. 4 and 5, are obtained from long-term satellite-derived wind speeds data, for Baga, Baga-Sola, Makari and Nguigmi. It is found that monthly Weibull scale parameters, C, at 10–30 m agl are in the range of 5.24–6.70, 5.37–6.85, 4.87–6.28 and 5.00–6.43 m/s, with their corresponding monthly mean wind speeds in the range of 5.65–7.09, 5.77–7.23, 5.33–6.73 and 5.28–6.67 m/s, respectively, for Baga, Baga-Sola, Makari and Nguigmi. In addition, it is observed that the most probable wind speeds, range from 3.70 m/s at 10 m agl to 4.78 m/s at 30 m agl for Baga, from 3.80 m/s at 10 m agl to 4.88 m/s at 30 m agl for Baga-Sola, from 3.45 m/s at 10 m agl to 4.48 m/s at 30 m agl for Makari and from 3.54 m/s at 10 m agl to 4.58 m/s at 30 m agl for Nguigmi. Furthermore, the maximum energy carrying wind speeds at 10–30 m agl are in the range of 7.41–9.43, 7.59–9.63, 6.89–8.83 and 7.08–9.04 m/s, for Baga, Baga-Sola, Makari and Nguigmi, in that order.

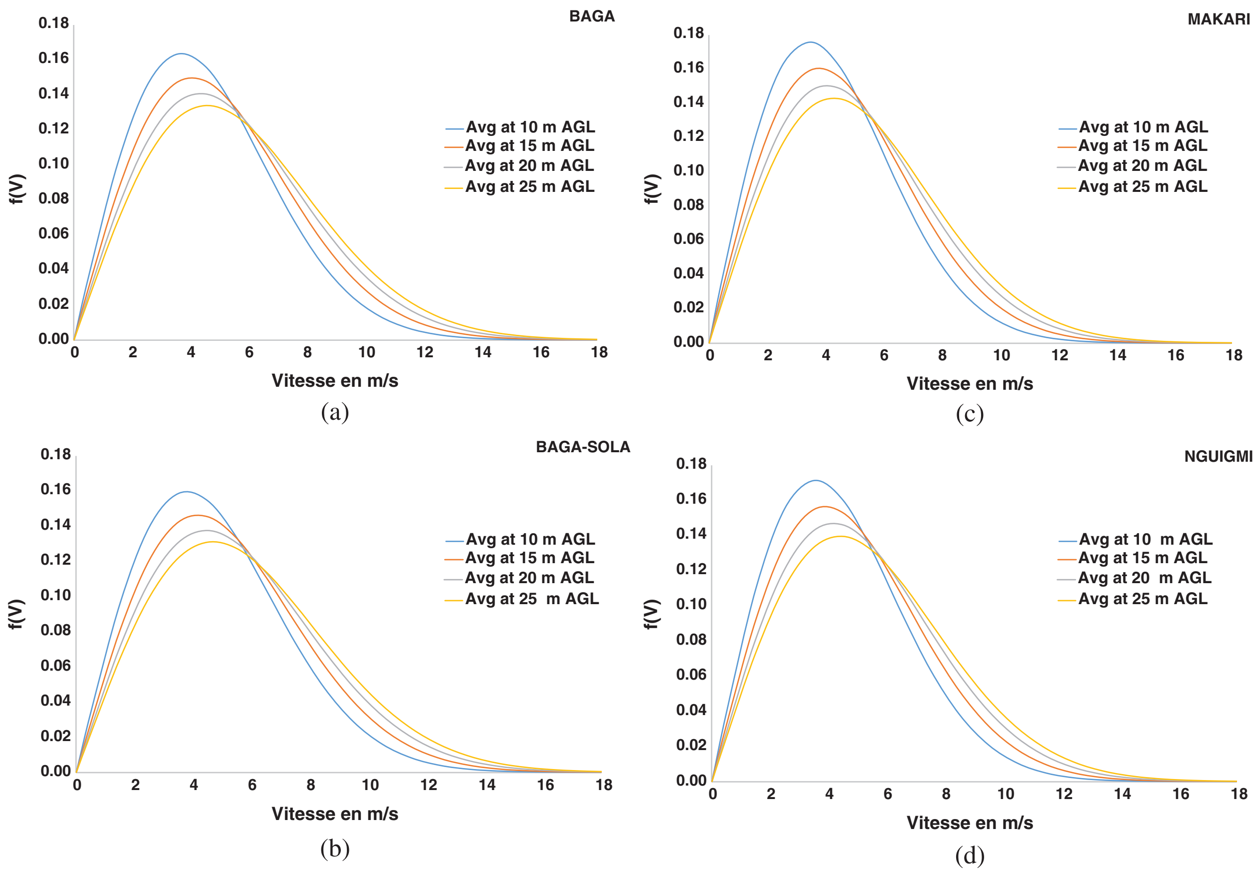

Figure 4: PDF at 10–30 m height agl for (a) Baga (b) Baga-Sola (c) Makari (d) Nguigmi

The monthly CDF calculated from the satellite-derived wind speeds at 10, 15, 20, and 25 m agl for Baga, Baga-Sola, Makari and Nguigmi, in that order, are shown in Fig. 5. For Baga, it can be seen that, the wind speed is in the range of 2.5–10 m (working range of a wind pump), at 10, 15, 20, 25 and 30 m agl, for 79.64, 82.80, 84.79, 86.19 and 87.25 per cent of the time. Corresponding values for Baga-Sola, Makari and Nguigmi are in the range of 80.50–87.76 per cent, 76.86–85, 58 per cent, 77.92–86.21 per cent, respectively.

4.2 Windmills Characteristics

When considering mechanical wind pumps with mechanical transmission, numerous types of pumps are available, such as centrifugal pump, compressor pump, piston pump and screw pump [24,31]. Windmills of Multi-blade driven piston pump are the preferred water pumping option for this study because of its higher overall system efficiency (the volumetric efficiency is higher than 90 per cent), in addition to acceptable performance and efficiency at lower range wind speeds and with an interesting performance/price ratio. Fig. 6 shows a typical water pumping windmill. The considered applications range from community water supply to cattle watering and small-scale irrigation. Rotor sizes ranging from 1.5 to 3 m are chosen for estimating power output and hydraulic power delivered by the piston pump. Total dynamic heads in the range of 15–30 m are considered, reflecting head range nearby floodplains around Baga, Baga-Sola, Makari and Nguigmi.

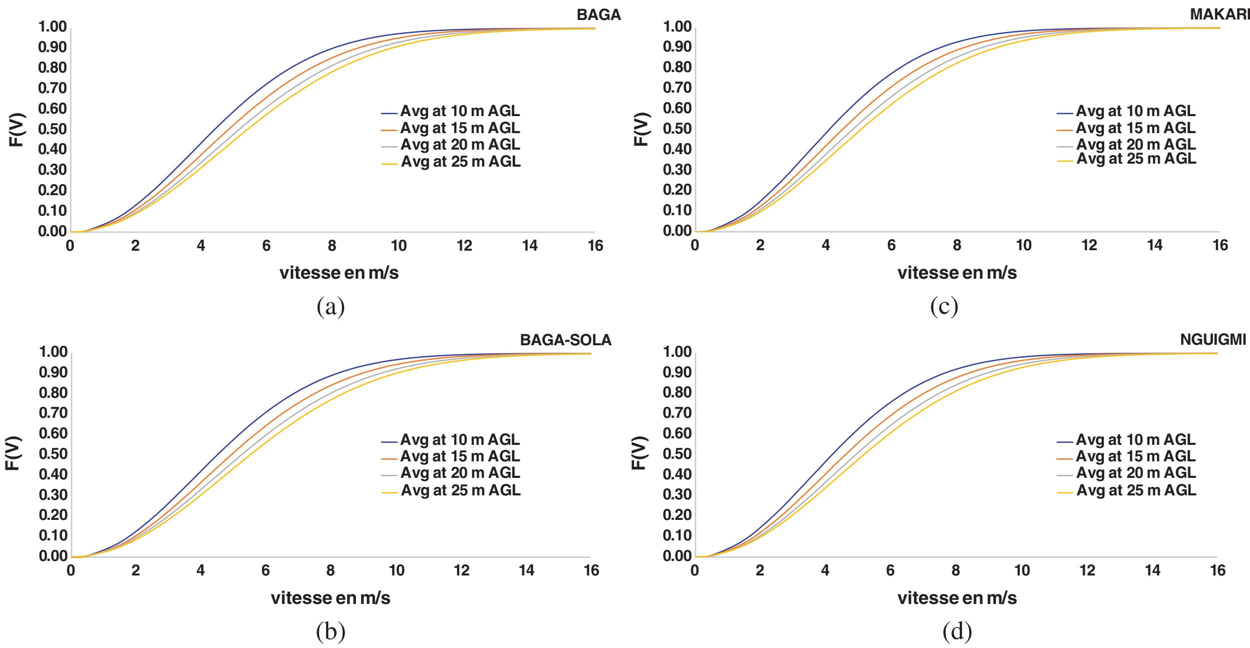

Figure 5: CDF at 10 m height agl for (a) Baga (b) Baga-Sola (c) Makari (d) Nguigmi

4.3 Wind Pump Discharges at Different Heads

The expected wind pump discharges are computed considering a total pumping head (TDH) of 30 m, a 2 m-blade and hub heights of 10, 15, 20 and 25 m agl. To estimate the discharge volume of water $V_w(m^3)$ over a year, the design power coefficient C_0 is set to 0.3, the combined transmission and pump efficiency $\eta_0 =$ 0.95 and $K_O = 0.25$. Fig. 7 illustrates monthly discharges at the studied sites using a 2 m-blade, 25 m-height tower and 30 m-dynamic head and at the aforementioned hub heights. When looking at TDH, it's seen that pump discharges values decreases by one-third from 15 to 20 m TDH, while their values are reduced by 25 and 20 per cent, respectively from 20 to 25 m and from 25 to 30 m TDH. Shallower TDH provides substantial opportunities for larger water pumping volume. When upgrading a 1 m-blade to a 1.5 m-blade, a 125 per cent volume increase is observed, while an upgrade of a 1.5 m-blade to a 2 m-blade, provide a 78 per cent volume increase. Furthermore, 56 and 44 per cent volume increases are noticed, when upgrading, respectively from a 2 m-blade to a 2.5 m-blade and from a 2.5 m-blade to a 3 m-blade. The highest monthly volumes are observed from January to April and from November to December, corresponding to the dry season, while the lowest monthly volumes are seen in august, September and October, which corresponds to the rainy season. For a 2 m-blade, a 25 m-height tower and at a TDH of 30 m, average monthly dry season discharges are 1,330.05, 1,374.19, 1,200.74 and 1,199.47 m^3, respectively for Baga, Baga-Sola, Makari and Nguigmi. These discharges values during the rainy season are reduced to 629.55 m^3 for Baga, 697.77 m^3 for Baga-Sola, 463.31 m^3 for Makari and 640,51 m^3 for

Nguigmi. There is, on average, a volume gain in the range of 19–22 per cent, when using a 15 m-height tower in comparison to a 10 m-height tower, while a volume gain in the range of 12–14 per cent is seen when switching from a 15 m-height tower to a 20 m-height tower. Furthermore, when replacing a 20 m-height tower by a 25 m-height tower it is seen an 8.46 per cent volume gain for Baga, an 8.08 per cent volume gain for Baga-Sola, a 9.64 per cent volume gain for Makari and a 9.19 per cent volume gain for Nguigmi.

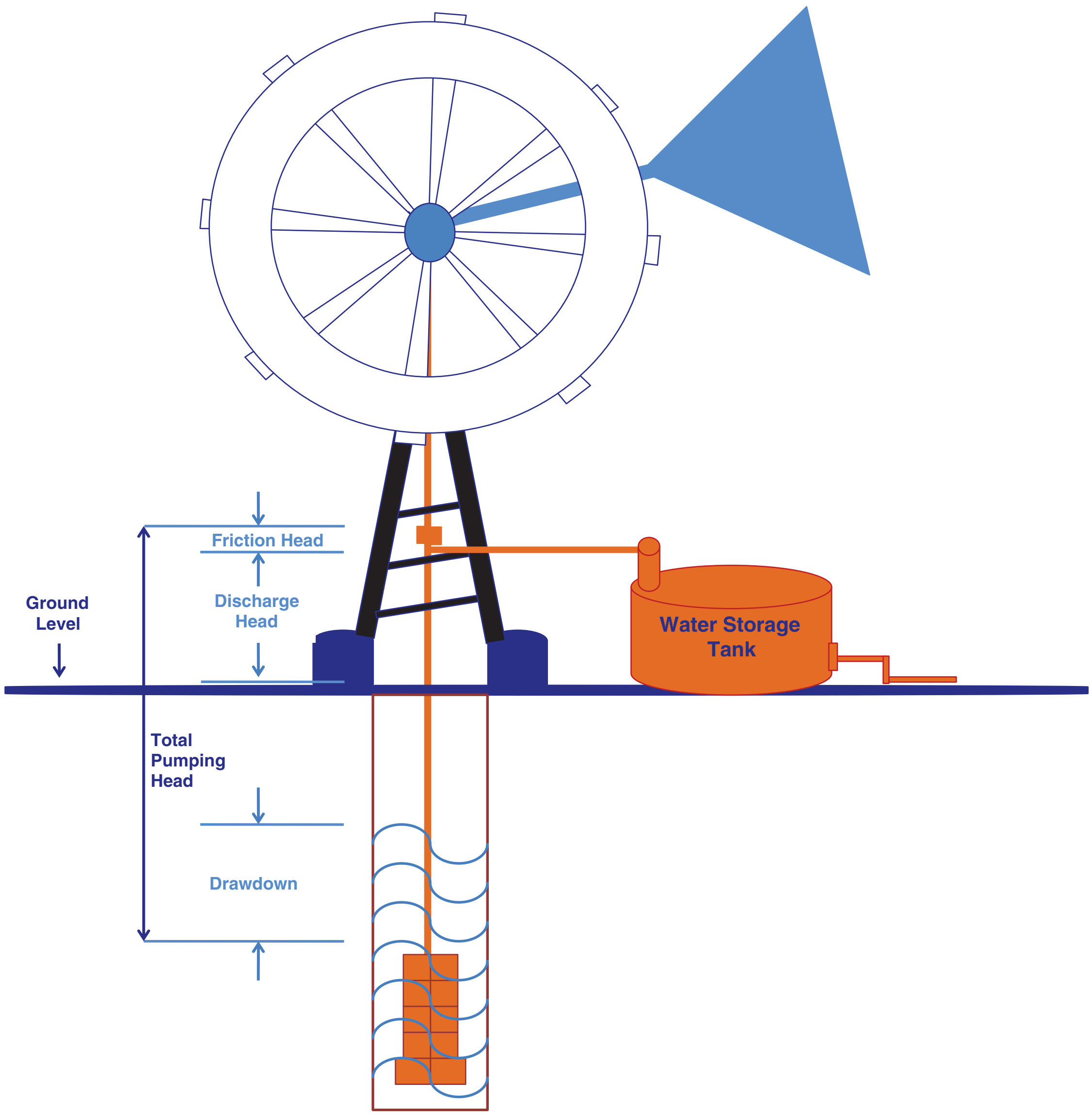

Figure 6: Typical windmill for pumping systems

4.4 Cost of Water

The economic evaluation of the multi-blade driven piston pump for water pumping has been assessed using the present value of costs (PVC) of water produced during the entire lifetime of the Windmill. Fig. 8 presents the cost of water using a 2 m-blade, a 25 m-height tower and a 30 m-dynamic head at hub heights of 10, 15, 20 and 25 m agl for the four selected localities. Average costs of water (COW) at 10–25 m agl, are in the range of 11.43–16.59 XAF/m^3 for Baga, 10.91–16.60 XAF/m^3 for Baga-Sola, 13.19–20.08 XAF/m^3 for Makari and 12.46–18.63 XAF/m^3 for Nguigmi, with the lowest costs observed at 25 m height agl, while the highest costs are seen at 10 m height agl. For a 2 m-blade, a 25 m-height tower and at a TDH of 30 m, average COWs in the dry season are 9.53, 9.23, 10.56 and 10.57 XAF/m^3, respectively for Baga, Baga-Sola, Makari and Nguigmi. These COWs soar during the rainy season to 20.14 XAF/m^3 for Baga, 18.17 XAF/m^3 for Baga-Sola, 27.36 XAF/m^3 for Makari and 19.79 XAF/m^3 for Nguigmi.

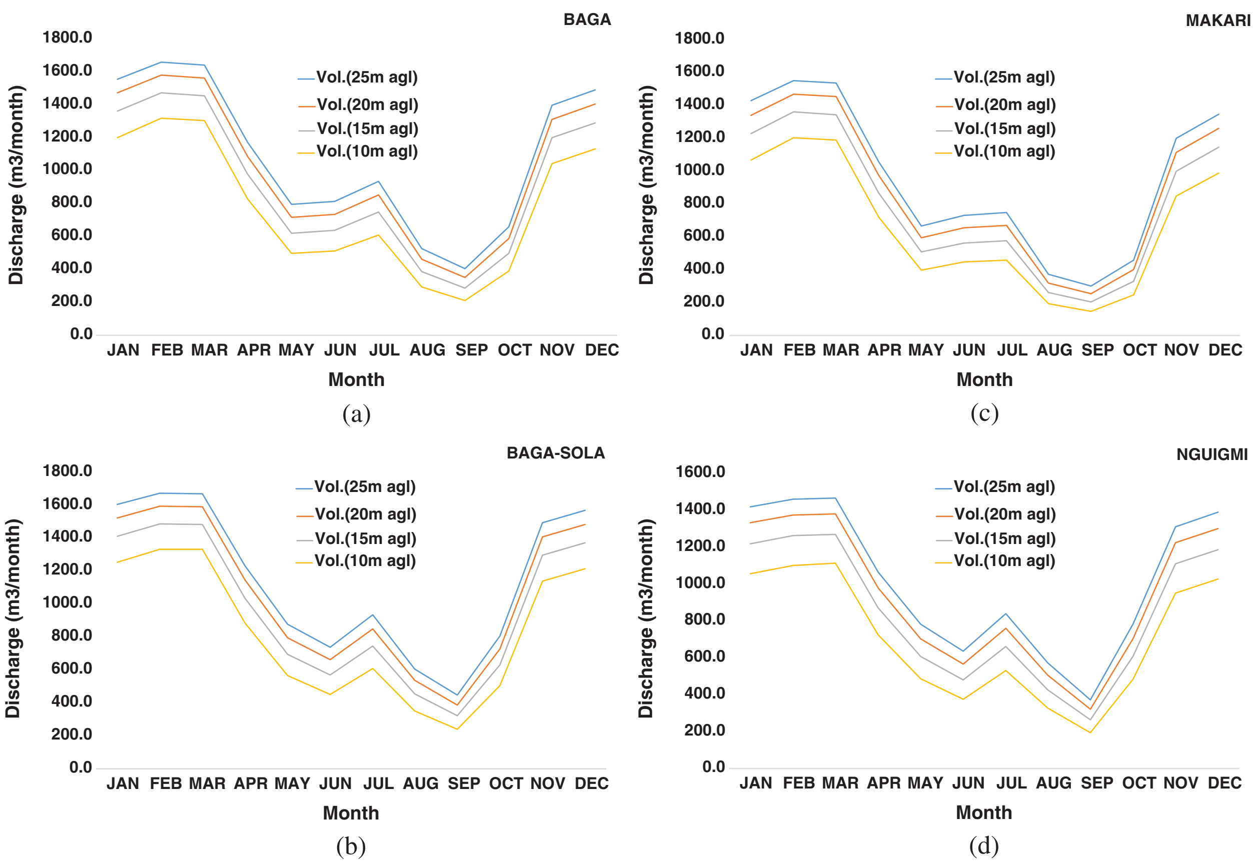

Figure 7: Monthly discharge and required energy using a 2 m-blade, 25 m-height tower and 30 m-dynamic head for (a) Baga (b) Baga-Sola (c) Makari (d) Nguigmi

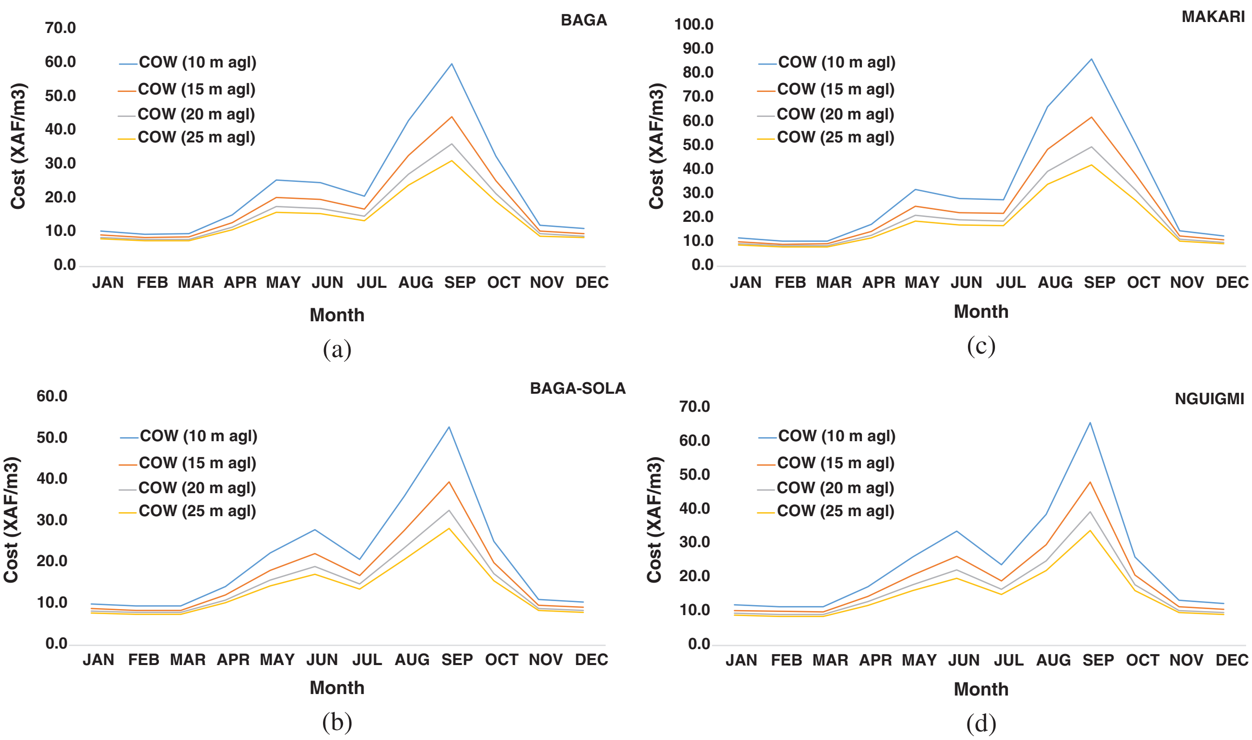

Figure 8: Cost of water using a 2 m-blade, 25 m-height tower and 30 m-dynamic head for (a) Baga (b) Baga-Sola (c) Makari (d) Nguigmi

5 Conclusion

Clean water scarcity is acknowledged as a major regional threat to security and stability around the shrinking Lake Chad. Moreover, the surface water poses significant health hazards to populations inside the floodplains around Lake Chad. To develop sustainable solutions to overcome water and health related crisis, mechanical wind pumping system has been explored to raise stakeholders' awareness for the option of using windmills driven piston pump for improving access to clean and safe drinking water. This study outlines the following:

- No ground measurements are available and wind data utilized for this study are provided by NASA-SSE, satellite measurements;
- Lake Chad floodplains are considered low wind speed resource areas and per se, necessitate low wind speed wind turbine technology, such as windmills;
- Mean wind speeds, at 10 m height above agl, range from 4.64 m/s in Baga, 4.76 m/s in Baga-Sola, 4.32 m/s in Makari to 4.44 m/s in Nguigmi;
- Wind speeds are in the range of 2.5–10 m (working range of a wind pump), at 10, 15, 20 and 25 m height agl, for 79.64, 82.80, 84.79, and 86.19 per cent of the time;
- For Windmill with a 2 m-blade, a 25 m-height tower and considering a TDH of 30 m during the dry season:
  - average monthly discharges are 1,330, 1,374, 1,200 and 1,199 m^3, respectively for Baga, Baga-Sola, Makari and Nguigmi;
  - Average COWs are 9.53, 9.23, 10.56 and 10.57 XAF/m^3, respectively for Baga, Baga-Sola, Makari and Nguigmi.

- The expected wind pump discharges have the potential to improve clean and safe water access;
- Inside floodplains of Lake Chad, average wind speed values are higher during the dry season and wind water pumping for farming during that season can be a sustainable manner to diversify agriculture and enhance food productivity;
- Larger rotor sizes yield better windmill pumping capacity.

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