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Wind Power Potential of Kaniga Region, Rwanda

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ABSTRACT

The purpose of this study was to investigate the potential of wind power in Kaniga, Rwanda. Wind speed and wind direction are the most important characteristics for assessing wind energy potential of a location using suitable probability density functions. In this study, a hybrid-Weibull probability density function was used to analyze data from Kaniga station. Kaniga is located in Gicumbi District, in the Northern Province of Rwanda. Onsite hourly wind speed and wind direction data for the year 2022 were analyzed using Computer programmes.

The research was conducted to reveal the wind power potential of Kaniga and other major wind stations in the country as an approach to address energy shortage problem in the country. It was found that the average annual wind speed for Kaniga, Nyarwambu, and Byumba were 4.5m/s, 3.7m/s and 4.1m/s respectively, while corresponding dominant wind directions for the stations were 320^0, 180^0 and 150^0 respectively. The average annual wind power density of Kaniga was found to be 1,285.4W/m^2, while the annual power densities for Nyarwambu and Byumba were determined as 689.4W/m^2 and 805.4W/m^2 respectively.

The other stations in Rwanda have the average annual power densities ranging from 6.99 W/m^2 to 138.2W/m^2. From these findings, it is clear that Kaniga has the greatest wind power potential among all other studied wind stations in the country.

Keywords: Wind power density, Wind speed, Wind direction, Probability density function, Weibul distribution, Kaniga, Rwanda.

INTRODUCTION

Currently, wind energy has been getting a lot of interest in Rwanda because of the focus on renewable energies. The effective use of wind energy requires having a detailed knowledge and developed understanding of its potential and its location.

Kaniga is one Sector of Gicumbi District located in Northern Province of Rwanda (Figure 1). It is a landlocked area, located a few degrees nearest to south of the Republic of Uganda, bordered by the Sectors of Rushaki in East, Cyumba in West and Mukarange in South. Total land area of Kaniga Sector is about 41.31 km^2 equivalent to 5% of the total area of Gicumbi District.

Figure 1: Map and geographic location of Kaniga

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Geographically, Kaniga Sector is in one of high mountains border of Rwanda-Uganda. It lies on the high land of North of Rwanda in the Northern bearing along Rukomo-Gatuna Road.

Figure 2: Map of Rwanda showing location of Kaniga. Source: NISR, 2014

Based on fifth Population and Housing Census survey, in 2022, Kaniga's population was 16,772. This comprises of 8,056 Male (48%) and 8,716 Female (52%) with density of 429 People per km², this makes it one of the most densely populated Northern Sectors in Rwanda. Kaniga's economy is primarily based on subsistence agriculture (30% of GDP) followed by Services (27%) and industry (10%), (NISR, 2022).

Kaniga has a tropical savanna climate typically with a pronounced dry season. It is warm every month with both a wet and dry season. The average annual temperature for Kaniga is 23°C and there is about 4178 mm of rain in a year. It is dry for 31 days a year with an average humidity of 80%.

The limited Wind data from Kaniga show a higher probability to generate sufficient wind energy (GLOBAL SUN WIND, 2015).

Reported annual wind power densities for Kigali, Gisenyi, and Kamembe are: 13.7 W/m^2, 18.4W/m^2 and 24.9W/m^2 respectively, from the yearly mean wind speeds of 2.36m/s, 2.95m/s and 2.97m/s (NKUNDA and NDENDA 2014).

Several researches have demonstrated the problem of persistence energy insufficiency in many regions of the country including Kaniga (NYANVUMBA, 2014). This problem has brought a number of negative effects on the development and to the environment like accelerated deforestation, pollution, absence of infrastructure and so on. The major part of the energy consumed in Rwanda today still comes from wood (80.4 per cent), (SAFARI, 2019).

The lack of knowledge on the wind energy potential of Kaniga is a problem and a gap to be filled and this has been accomplished by this study.

This research has addressed the following research question:

"What is the wind power potential of Kaniga region?"

MATERIALS AND METHODS

The following are the materials and methods used in this study

(a) Hybrid-Weibull distribution function calculation

Probability density functions (PDFs) are important in wind studies to estimate the power of a given wind speed which is then compared with the measured probabilities found by getting the ratio of the frequency of a given speed to the total frequency of speeds occurring in a location. The probability density function that has wide appeal as the standard function for wind speed modeling is the Weibull distribution (equation 1), but it is most appropriate for regions with negligible occurrence of null wind speeds. If one cannot ignore the presence of null wind speeds, then appropriate modifications to Weibull distribution is necessary (IOB, 2014).

One such modification is the Hybrid Weibull distribution given in (equation 2) with ϕ representing the distribution parameters k and c, while θo is the probability of null wind speeds. In this paper, the hybrid Weibull distribution was used for the analysis of wind power density. The three-parameter Weibull distribution was used in Kaniga to estimate the probability of null wind speed. The Weibull distribution was mostly used in reliability analysis and life data analysis because of its ability to adapt to different situations. Depending upon the parameter values, this distribution is used to model the variety of behaviour for a particular wind function. The parameters in the distribution control the shape, scale and location of the wind probability density function. The Weibull function provides a convenient representation of the wind speed data for wind energy calculation. The hybrid Weibull distribution is well defined (KABENDE, 2014). Generally, the Weibull probability density function of a random variable v is given in equation 1 where k is a shape parameter while c is a scale parameter. Both of these parameters are functions of mean wind speed and standard deviation as in equations 3 and 4 respectively.

$$f_{\omega}(v) = \left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{k-1} \exp^{\left[-\left(\frac{v}{c}\right)^{k}\right]} \qquad (1)$$

Where $f_{\omega}(v)$ is defined as the Weibull Probability Density function of a random variable

Hybrid Weibull distribution

$$h(v,\varphi,\theta_0) = \theta_0\delta(v) + (1-\theta_0)\, f_{\omega}(v,\varphi) \qquad (2)$$

$$where\ \delta\ (v) = \begin{cases} 1, & if\ v=0 \\ 0, & if\ v\neq 0 \end{cases}$$

$$k = \left(\frac{\sigma}{v_m}\right)^{-1.086} \quad (1 \le k \le 10) \qquad (3)$$

$$c = \frac{v_m}{\Gamma\left(1+\frac{1}{k}\right)} \qquad (4)$$

Where v_m the mean wind speed, is defined in equation 5 and σ is standard deviation as in equation 6. The symbol Γ () represents a gamma function of the bracketed term defined for n hours in equation 7.

$$\mathrm{v}_m = \frac{1}{n}\left[\sum_{i=1}^{n} \mathrm{v}_i\right] \qquad (5)$$

$$\sigma = \left[\frac{1}{n-1}\sum_{i=1}^{n}(\mathrm{v}_i - \mathrm{v}_m)^2\right]^{1/2} \qquad (6)$$

$$\Gamma(n) = \int_0^{\infty} x^{n-1}e^{-x}dx \qquad (7)$$

The hybrid Weibull cumulative distribution function in equation 9 is also defined from the Weibull cumulative distribution function of equation 8.

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$$F_{\omega} = 1 - \exp\left[-\left(\frac{v}{c}\right)^{k}\right] \quad (8)$$

Where F_{ω} is the Weibull Cumulative Distribution.

$$H(v,\varphi,\theta_0) = \begin{cases} \theta_0 + (1-\theta_0)F_{\omega}, & \text{if } v \geq 0 \\ 0, & \text{if } v < 0 \end{cases} \quad (9)$$

Where $H(\upsilon,\varphi,\theta_0)$ is the Hybrid Weibull Cumulative Distribution

Wind power density per unit area Pω was calculated from equation 10

$$P_{\omega} = \frac{1}{2}\rho\int_{0}^{\infty} v^{3} h(v,\varphi,\theta_0)dv \quad (10)$$

Where ρ is the density of the air for each station. By implementing this research method, the equations were used especially in studying 3 main wind stations (Kaniga and surrounding stations), the summarized and obtained findings are presented in the tables.

(b) Geographic parameters of site

The study region lies at: Latitude of 01° 57' 55.33" South, Longitude of 030° 8' 05.18" East, and

Elevation: 1,849 meters (Figure 1).

A large part of Kaniga region is a plateau rising gradually from some 950 meters in Murindi Swamp to 2,000 meters above sea level in the highlands north of Gicumbi District (METEO RWANDA, 2020).

(c) The Computer Program

The frequency distribution and associated statistics of the measured data such as the mean and standard deviation are the output of a statistical subroutine that uses Matlab's in-built mathematical functions. Resulting frequency distribution table from 'statistics' subroutine establishes the dominant direction of wind flow and the most frequent wind speeds.

Information generated from statistical calculations of the data are input into a 'parameters' subroutine that determines Weibull parameters and also calculates the probability density functions using equation 2. Finally, the power density estimates emerge from the 'power density' subroutine that outputs all the required graphical illustrations and comparisons given in the bar graphs with the help of equation 10.

(d) Performance Analysis

In studying wind power potential of Kaniga Performance Data analysis was used to reveal the available potentials. The three main factors that influence Wind power output in Kaniga were found to be wind speed, air density, and plant/wind instrument radius. Wind plant/instruments need to be in areas with a lot of wind on a regular basis, which is more important than having occasional high winds.

There are various methods used to analyze convergence between measured data and results that are due to a mathematical model. Performance analysis of results obtained from the Hybrid-Weibull distribution was done using the mean absolute percentage error (MAPE) given in equation11 (Onyango, 2014). The coefficient of correlation R between the measured and estimated data was also determined using equation 12.

$$MAPE = \frac{1}{n}\sum_{1}^{n} abs\left(\frac{y-y_n}{y_n}\right) * 100 \quad (11)$$

Where n is the total number of input and output pairs used for experiment; y is the forecast wind speed for one hour; and y_n (measured) is the actual wind speed for one hour.

$$R = \frac{\overline{m.e} - \bar{m}.\bar{e}}{\sqrt{\{\overline{m^2} - (\bar{m})^2\}.\{\overline{e^2 -} (\bar{e})^2\}}} \quad (12)$$

Where m the measured wind is speed; e is the estimated data; ē is the mean of estimated data; $\bar{m}$ is the mean of measured data; $\overline{m.e}$ is the mean of product of measured and estimated data.

RESULTS AND DISCUSSIONS

3.1. Computation of Estimated Wind Power Potential at stations studied

The wind power is described as power obtained by harnessing the energy of the wind. Based on the climate data Meteo Rwanda provides in different regions or stations in the country, it is possible to project, forecast and estimate the wind power potential the country should generate if the available resources were fully exploited.

For Wind energy and power calculations, the power in the wind is given by equation 13 in simplified form as:

$$\boldsymbol{P_w = \frac{1}{2} \times \rho \times A \times v^3} \quad (\mathbf{13})$$

1. $\boldsymbol{P_W}$: measured in Watts
2. ρ density of the air in kg/m^3
3. A cross-sectional area of the wind in m^2
4. v the velocity of the wind in m/s

The commonly used value of wind density is ρ =1.225 kg/m^3 corresponding to standard conditions (sea level, 15 ^{0}C). Thus, the power available at a given wind station is based on the density of the air (here we approximate it as 1.2 kg/m^3) and the velocity of the wind. The calculations summarized in table1for the projected or forecasted power available on the stations in the country are based on data provided by Meteo Rwanda in 2022.

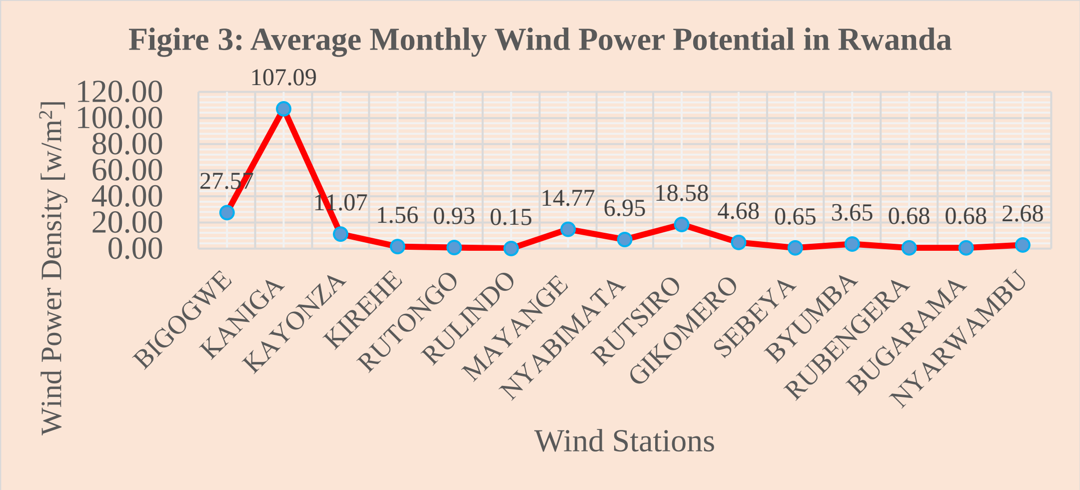
Table 1: Average Monthly Wind Power Potential on Stations studied

No	Station Name	Latitude	Longitude	Elevation (m)	Months of year	Wind speed (m/s)	P density of air kg/m3	A area of the wind in m^2	V^3 velocity	Wind Power Potential (Watts)	An Average Wind Power Density (W/m^2)
1	Bigogwe	-1.63	29.42	2392	1-12	8.2	1.2	52.22	551.37	17,275.46	27.57
2	Kaniga	-1.55	30.24	1503	1-12	12.89	1.2	56.4	2141.70	72,475.15	107.09
3	Kayonza	-1.90	30.51	1575	1-12	6.05	1.2	161.42	221.445	21,447.40	11.07
4	Kirehe	-2.28	30.67	1576	1-12	3.15	1.2	99.34	31.255	1,862.98	1.56
5	Rutongo	-1.82	30.06	1865	1-12	2.65	1.2	28.69	18.6096	320.35	0.93
6	Rulindo	-1.72	29.92	1800	1-12	1.45	1.2	33.37	3.048	61.04	0.15

7	Mayange	-2.20	30.12	1433	1-12	6.66	1.2	146.8	295.408	26,019.56	14.77
8	Nyabimata	-2.69	29.44	2134	1-12	5.18	1.2	119.5	138.991	9,965.71	6.95
9	Rutsiro	-1.96	29.39	1970	1-12	7.19	1.2	89.16	371.694	19,884.19	18.58
10	Gikomero	-1.89	30.22	1877	1-12	4.54	1.2	34.8	93.5766	1,953.88	4.68

Source: Primary Data, 2022

The results in table 1, which are illustrated in Figure 3 show that Kaniga Station has the highest wind power potential among all the studied stations.



Source: Primary Data, 2022

The findings and results are detailed in table 2 which shows the forecasted and estimated average annual wind power for the studied regions.

Table 2: Estimated Average Annual Wind Power Potential in Rwanda

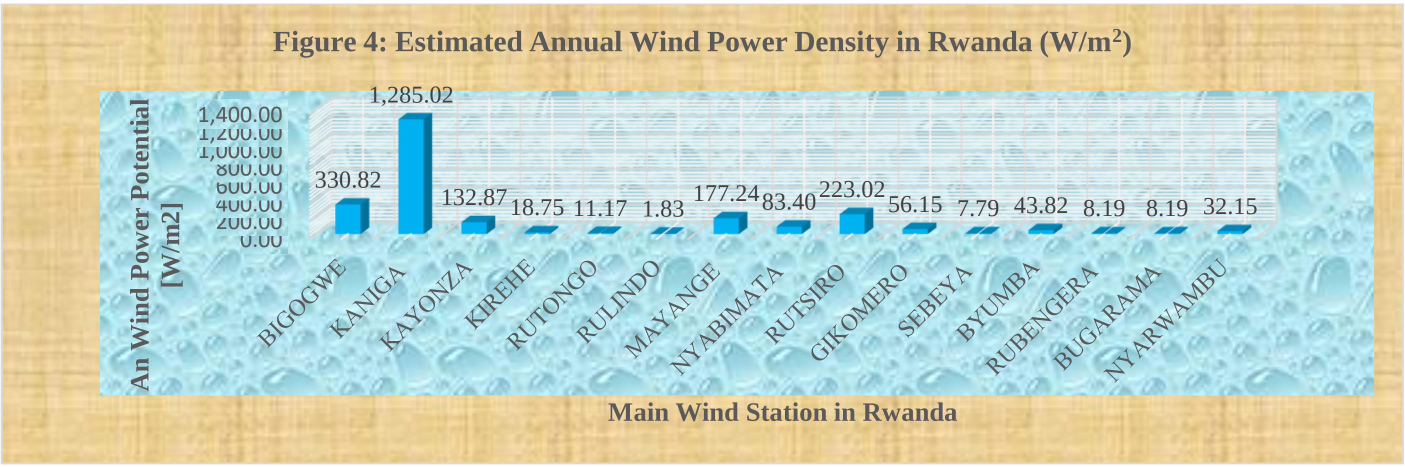
№	**Station Name**	**Month**	**Wind speed (m/s)**	**P density of air (kg/m^3)**	**Area of the wind A (m^2)**	**Velocity (V^3)**	**Annual Wind power density (W/m^2)**
1	Bigogwe (Nyabihu)	1-12	8.2	1.2	52.22	551.37	330.82
2	Kaniga (Gicumbi)	1-12	12.89	1.2	56.4	2141.70	1,285.02
3	Kayonza	1-12	6.05	1.2	161.42	221.45	132.87
4	Kirehe	1-12	3.15	1.2	99.34	31.26	18.75
5	Rutongo (Kigali)	1-12	2.65	1.2	28.69	18.61	11.17
6	Rulindo	1-12	1.45	1.2	33.37	3.05	1.83
7	Mayange (Bugesera)	1-12	6.66	1.2	146.8	295.41	177.24
8	Nyabimata	1-12	5.18	1.2	119.5	138.99	83.40
9	Rutsiro	1-12	7.19	1.2	89.16	371.69	223.02
10	Gikomero (Gasabo)	1-12	4.54	1.2	34.8	93.58	56.15
11	Sebeya (Rubavu)	1-12	2.35	1.2	52.16	12.98	7.79
12	Byumba	1-12	4.65	1.2	107.52	73.035	43.8

13	Rubengera (Karongi)	1-12	2.39	1.2	47	13.65	8.19
14	Bugarama (Rusizi)	1-12	2.39	1.2	307	13.65	8.19
15	Nyarwambu	1-12	3.79	1.2	128.78	53.582	32.15
	Total Expected Wind Power						**2,420**

Source: Primary Data, 2022

The results of table 2 are illustrated graphically in Figure 3.

Figure 4: Graphical representation of Forecasted Annual Wind Power Densities of the Stations in Rwanda including Kaniga.



Source: Primary Data, 2022

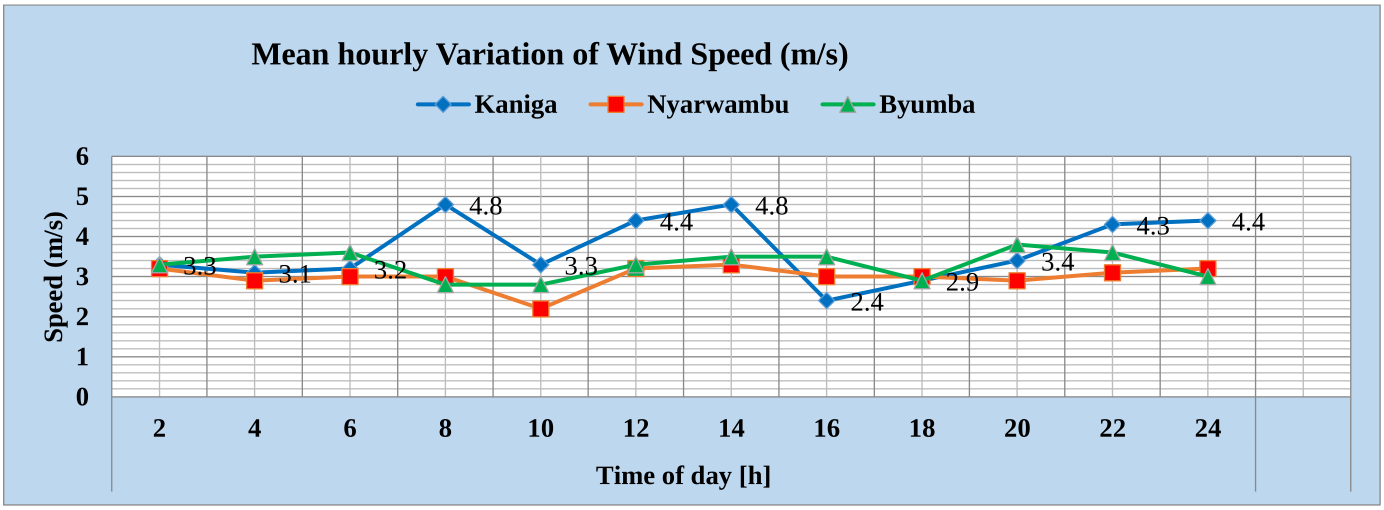
In Figure 4 it is observed that Kaniga region has the highest wind power density of 1,285 W/m^2.

3.2. Data analysis

The value of the shape factor k determines the width of the wind speed distribution around the average. With the results obtained it has been determined that Kaniga region has highest scale factor c, i.e it has highest variability and modality of the wind power potentials compared to Nyarwambu and Byumba Stations.

Figure 5 shows the mean hourly variation of wind speeds

Figure 5: Mean hourly Variation of Wind Speed



Source: Primary data, 2022

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3.3. Probability Density Functions

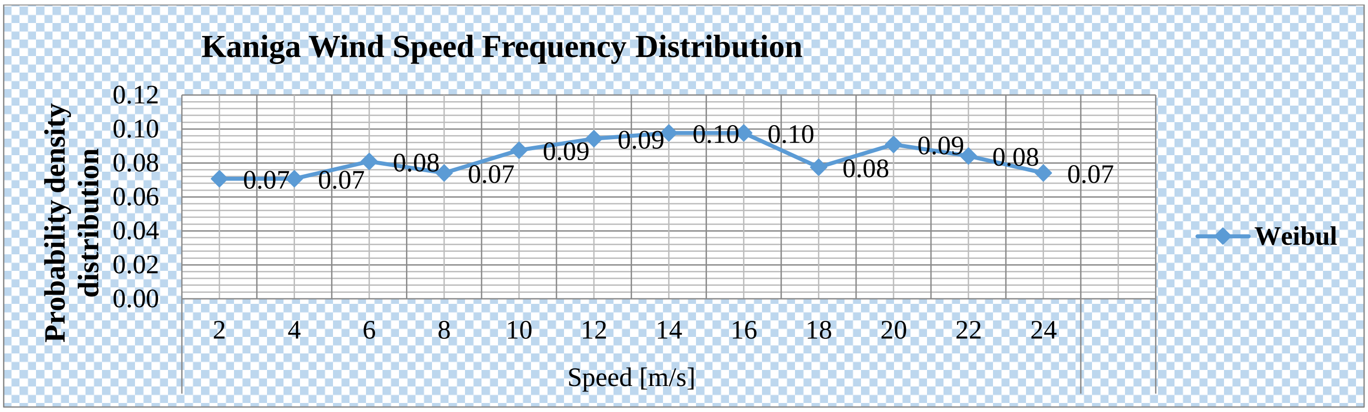
The probability density distributions for wind speed are given in figures 6-8 while cumulative probability distribution for the stations are in figure 9. A probability density distribution of wind speeds in a given site is important in predicting the daily energy generating capacity of a wind turbine in that the period for which a power plant would be in and out of production is foretold.

From the distribution curves, we see that the duration of the most frequent wind speeds according to the hybrid Weibul distribution model is approximately the same across all stations at about 24% of the time even though the speed level varies.

It is clear from the curves that the model exaggerates the duration of the most frequent wind speeds in Kaniga and underestimates the same in Nyarwambu and Byumba stations probably due to high frequencies of null wind speeds. Otherwise, the measured distribution puts almost at par the duration of occurrence of nonzero most frequent wind speeds in Nyarwambu and Byumba stations.

In figure 5, it is apparent that hourly wind speeds are higher in Kaniga followed by Byumba with Nyarwambu having the lowest hourly wind speeds of them all. Kaniga therefore offers better prospects for wind energy generation.

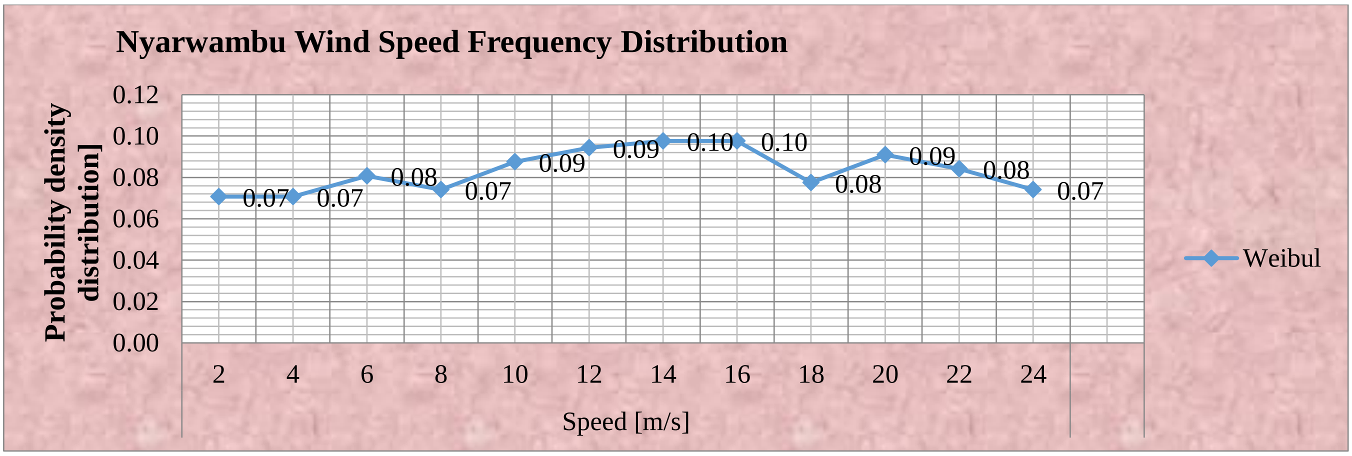
Figure 6: Wind speed frequency distribution for Kaniga station



Source: Primary data 2022

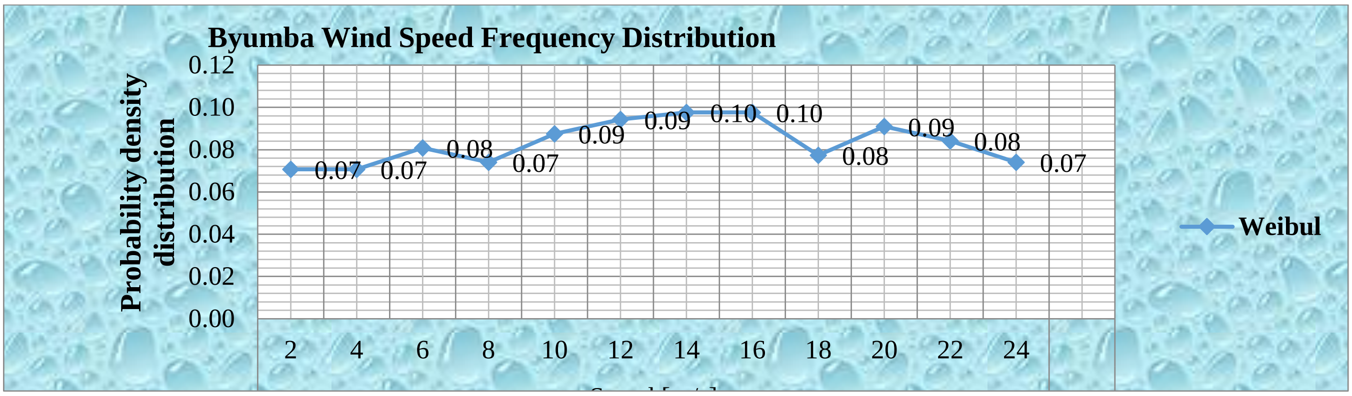
The Probability Density is the output of the produced energy per unit measured area and range from 0 to 1). The energy process with a high *W* is necessary to find a possible potential for a scale-up of the possibility to maximize energy production. The capacity of the energy production is required based on the specific energy related parameters. The results were obtained by measuring the expected power density per unit area.

Figure 7: Wind speed frequency distribution for Nyarwambu station



Source: Primary Data., 2022

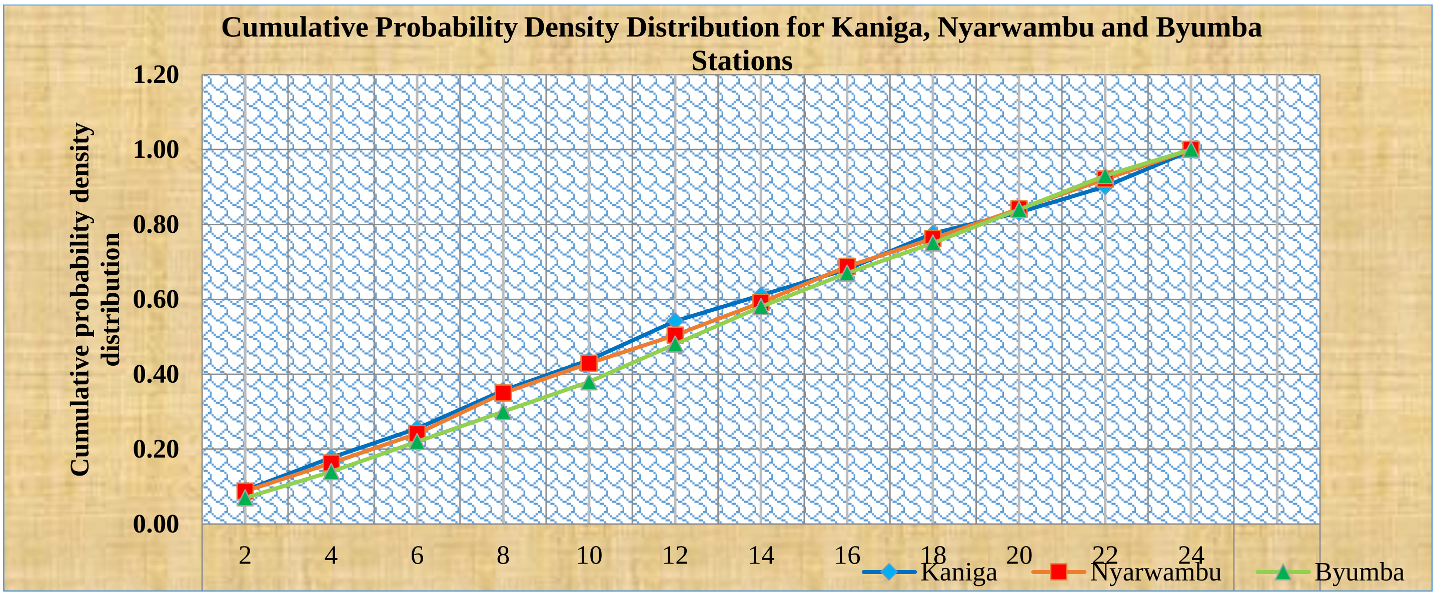
Figure 8: Wind speed frequency distribution for Byumba station



Source: Primary Data., 2022

Figure 9 shows the variation, comparison and relationship in terms of cumulative probability density distribution between Kaniga, Nyarwambu and Byumba. The output of density distribution presented in the diagram was measured for different wind speed levels.

Figure 9: Cumulative Probability Density Distribution for Kaniga, Nyarwambu and Byumba Stations



Source: Primary Data., 2022

3.4. Power Density Distributions

The bar graphs in figure 10-13 were prepared from Weibull and measured data. They present monthly and annual power density variations in each station and clearly reveal that the hybrid-Weibull model overestimates the actual power densities. It is clear that Kaniga has the highest power densities throughout the year except in the first and third quarters of the year where on average Byumba has better prospects.

Table 3 represents the variation and comparison between power potentials of the stations in terms of results found using Weibull model compared to the actual data measurement. The findings show that most of the time Weibull model give more power potentials than actual data.

Table 3: Comparison of monthly and annual power density variation between the stations

Stations	**Density (W/m^2)**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**An Mean**
Kaniga	Weibull Model	123.3	98.9	93.9	115.9	100.9	109.9	105.8	75.6	84.9	106.8	138.2	131.4	107.1

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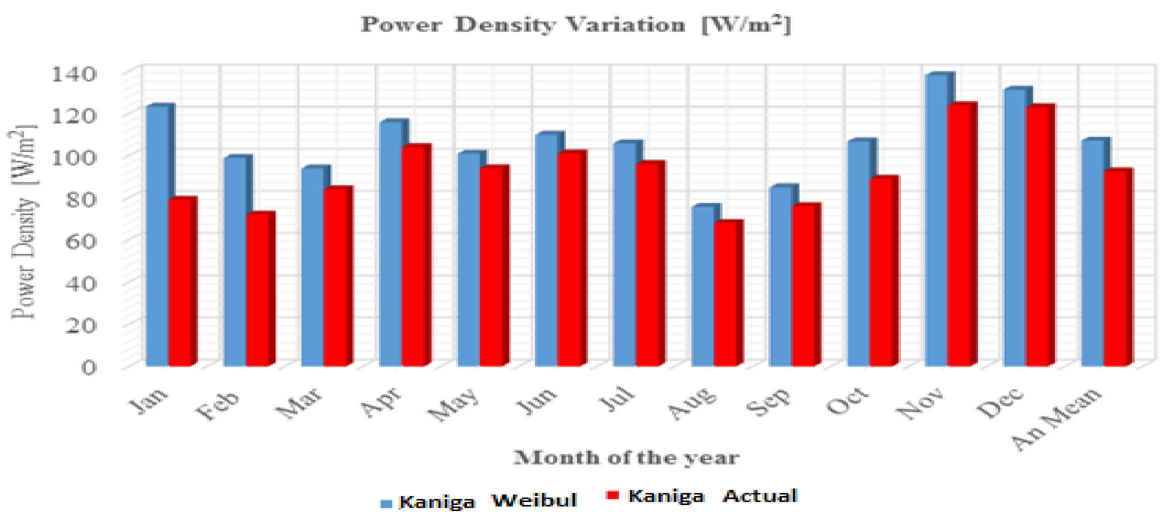
	Actual data	79	72	84	104	94	101	96	68	76	89	124	123	92.50
	Lowest Wind Speed (m/s)	4.7	4.4	4.3	4.9	4.4	4.7	3.9	4.1	3.9	4.6	4.8	5.2	4.51
	Highest Wind Speed (m/s)	12.8	11.8	10.9	13.1	11.6	12.9	12.3	12.5	12.8	13.9	14.3	14.7	12.8
Nyarwambu	Weibull Model	52.07	74.65	46.59	41.33	56.94	64.98	52.24	69.04	58.68	89.63	78.84	70.48	62.96
	Actual data	46	53	41	34	48	56	45	53	49	71	67	65	52.33
	Lowest Wind Speed (m/s)	3.8	3.6	3.5	3.1	4.2	4.1	3.8	3.9	3.7	3.6	3.4	4.7	3.78
	Highest Wind Speed (m/s)	3.8	3.6	3.5	3.1	4.2	4.1	3.8	3.9	3.7	3.6	3.5	4.7	3.79
Byumba	Weibul l Model	43.28	36.87	48.92	68.87	77.91	84.94	74.83	79.57	93.89	54.74	88.21	73.37	68.78
	Actual data	34	31	33	54	65	71	63	69	86	42	68	50	55.50
	Lowest Wind Speed (m/s)	4.7	3.7	4.3	4.2	4.4	4.1	3.9	4.1	3.9	3.6	3.8	4.8	4.12
	Highest Wind Speed (m/s)	4.9	4.9	4.6	4.7	4.8	4.9	4.3	4.4	4.5	4.2	4.7	4.9	4.65

Source: Primary data 2022

Interestingly, Kaniga has higher power densities in the 4 quarters of the year than Nyarwambu and Byumba (figure 13), for most of the months it presents superior wind speeds than Nyarwambu station. However, Kaniga station records the highest power density of 131.1W/m^2 in the month of November, while the lowest power density found to be 33.93W/m^2 occurs in Byumba in the month of February. The highest power in Kaniga corresponds to a monthly speed of 5.2 m/s available only in 22% of the one-year period. In overall, Kaniga has the greatest wind power potential than the other sites as given by its annual power density of about 99.8W/m^2.

Figure 10 shows the monthly and annual variation of the power density and statistical presentation of the variability in the graph of Kaniga station. It also compares power density obtained by using Weibul model and actual data as a wind power potential computation method.

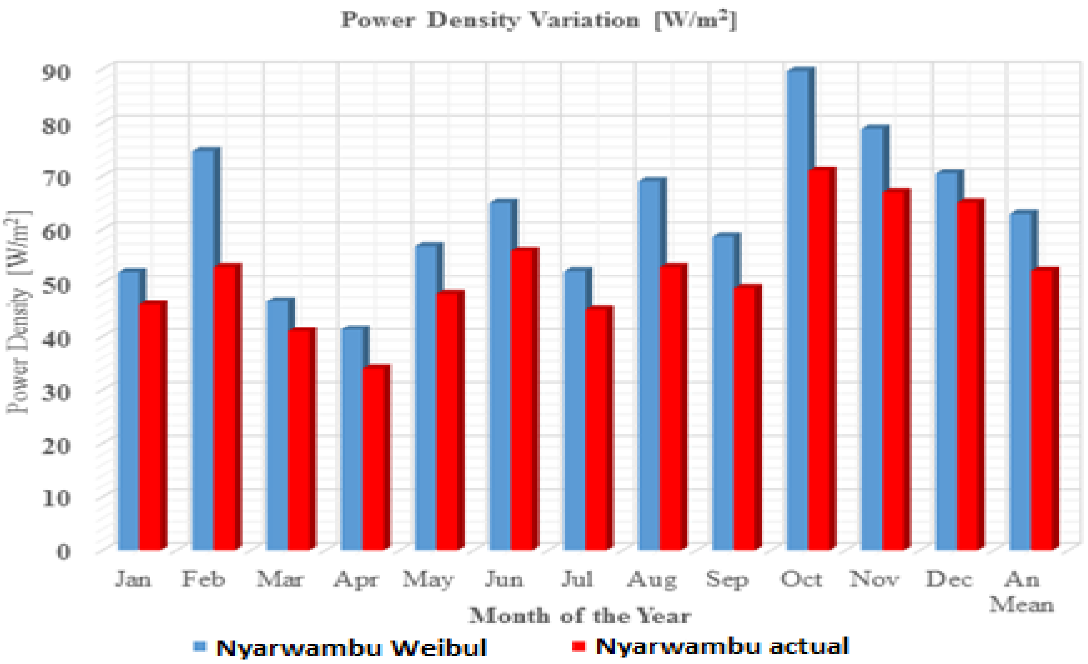
Figure 10: Monthly and annual power density variation for Kaniga station



Source: Primary data 2022

Figure 11 shows the monthly and annual variation of the power density and statistical presentation of the variability in the graph of Nyarwambu station. It compares power density obtained by using Weibul model and actual.

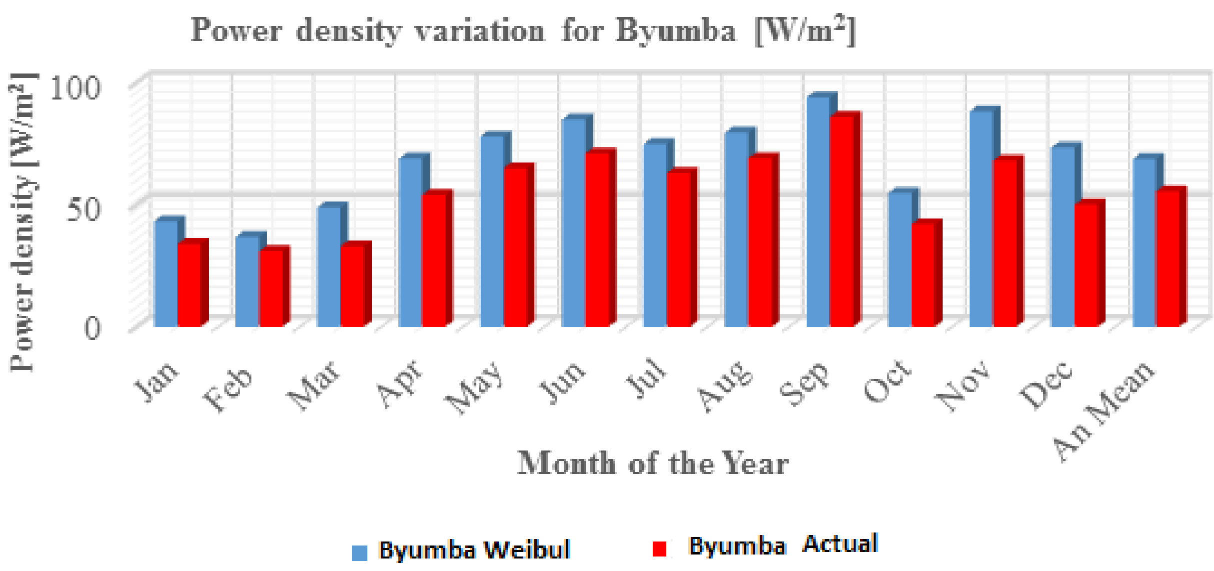
Figure 11: Monthly and annual power density variation for Nyarwambu station



Source: Primary data 2022

Figure 12 shows the monthly and annual variation of the power density and statistical presentation of the variability in the graph of Byumba station. It compares power density obtained by using Weibul model and actual.

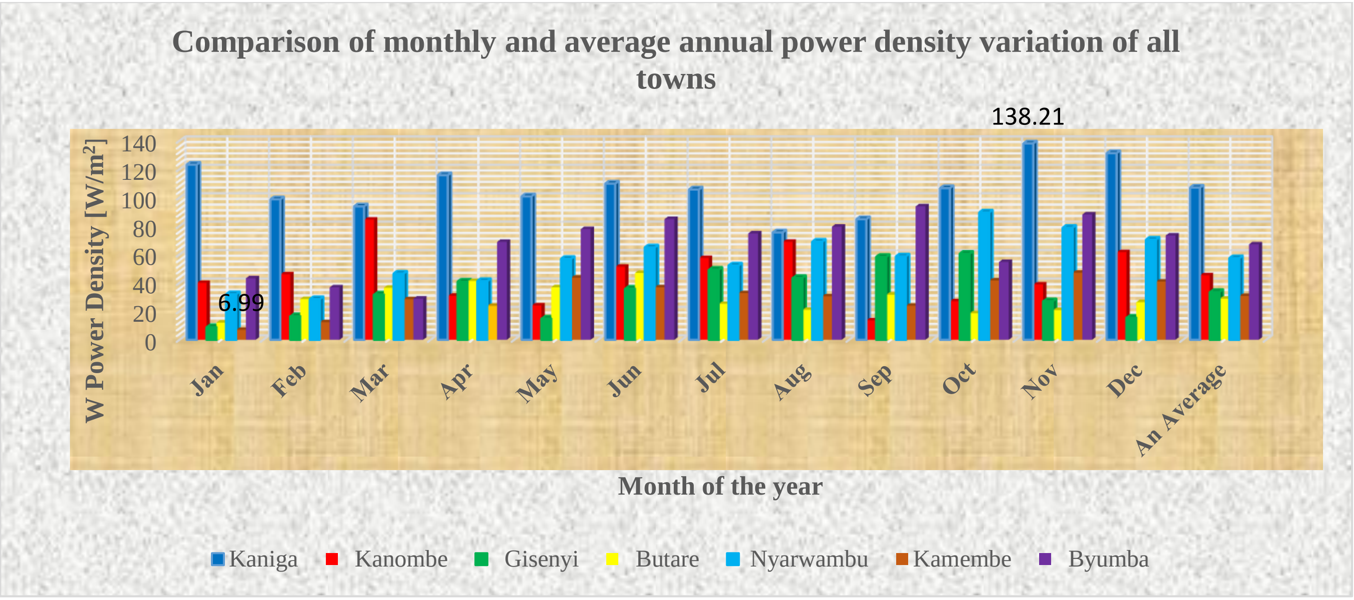
Figure 12: Monthly and annual power density variation for Byumba station



Source: Primary data 2022

Figure 13 shows the monthly and annual variation of the power density and statistical presentation of the variability in the graph of both Kaniga, Kanombe, Gisenyi, Butare, Nyarwambu, Kamembe and Byumba Stations.

Figure 13: Comparison of monthly and average annual power density variation between Kaniga and Other Towns of Rwanda



Source: Primary data 2022

By using Performance values of the hybrid Weibull model using Mean Absolute Percentage Error (MAPE) and coefficient of correlation R different results were correctly calculated and interpreted.

The mean absolute percentage error (MAPE) is a statistical measure of how accurate a forecast system is. It measures this accuracy as a percentage. The MAPE indicates the accuracy in fitting time series values in statistics, in particular, trending. The wind speed prediction accuracy is established by MAPE, which characteristically presents accuracy as a percentage, and is defined by the formula equation 11

A MAPE < 10% indicates high prediction accuracy 10%≤MAPE≤20% indicates good prediction, 20%≤MAPE≤50% implies acceptable prediction, and MAPE≥50% implies inaccurate prediction.

Based on our data, the MAPE were calculated as follow:

$$MAPE\ for\ Kaniga = \frac{1}{12}\sum_{1}^{12}\frac{35.17-31.67}{31.67}*100 = 0.92$$

$$MAPE\ for\ Nyarwambu = \frac{1}{12}\sum_{1}^{12}\frac{30.42-27.5}{27.5}*100 = 0.88$$

$$MAPE\ for\ Byumba = \frac{1}{12}\sum_{1}^{12}\frac{31.08-26.17}{26.17}*100 = 0.57$$

It is observed that the values differ across the stations with the best value determined in Kaniga station, which also gives the best coefficient of correlation at 0.33. From the performance results, it is necessary to test other models since the Weibull hybrid model appears not to yield best coefficient of correlation values. In statistics, the correlation coefficient R measures the strength and direction of a linear relationship between two variables (Weibull model and Actual data) on a scatterplot. In general, the results show a moderate uphill (positive) relationship between data.

Table 4 summarizes the mean absolute percentage error (MAPE) and the coefficient of correlation on different studied stations. The results presented in the table were calculated and obtained by the application of equation (11) and equation (12). With the MAPE of Kaniga of 0.92 it means that the study predictions are more accurate and findings are reliable.

Table 4: Performance Values

Station	MAPE	Coefficient of Correlation, R
Kaniga	0.92	0.33
Nyarwambu	0.88	0.23
Byumba	0.57	0.05

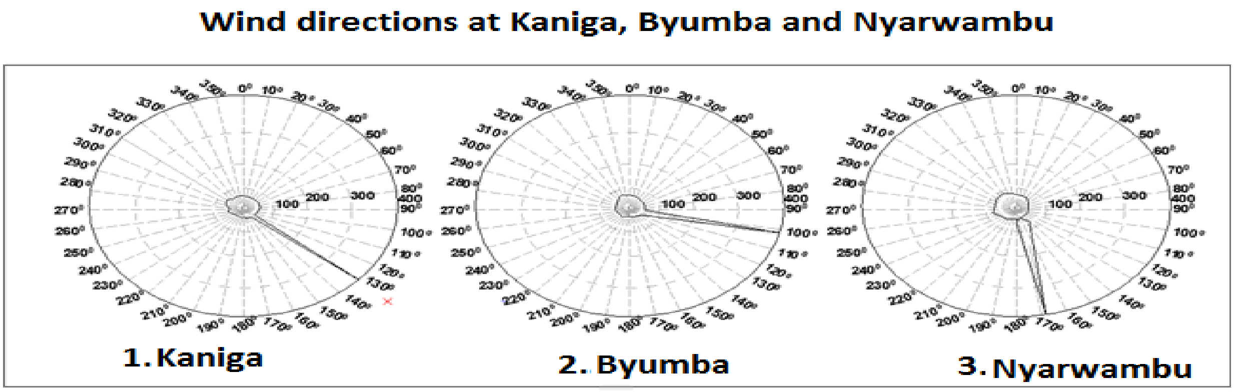
Source: Primary Data., 2022

Wind Directions of Representative Wind Data Stations in Rwanda

From the results and findings, the wind direction at Kaniga, Nyarwambu and Byumba were 320^0, 180^0 and 150^0 respectively, although on average the prevalent wind direction are the same in all stations.

Figure 14 represent the wind direction of the representative wind data stations in Rwanda. Based on the data provided by Meteo Rwanda., 2022, the diagrams briefly show the wind directions in Rwanda by sampling the area with high wind potentials.

Figure 14: Variation of Wind Directions for Kaniga, Byumba and Nyarwambu



Source: Meteo Rwanda, 2022

Table 5: Monthly and Annual Weibull Parameters (Shape k, and scale c) for the studied Stations

Station	Parameters	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Kaniga	*k*	3.2	3.5	3.0	3.7	3.4	3.7	3.8	3.3	3.0	3.2	3.7	3.1	3.4
	c(m/s)	3.9	4.8	4.6	4.1	4.8	4.6	4.7	3.9	4.3	4.9	4.0	3.9	4.5
Nyarwambu	*k*	3.8	3.6	3.5	3.8	3.3	3.3	3.8	3.4	3.7	3.6	3.3	3.7	3.6
	c(m/s)	3.6	3.3	3.4	3.3	3.3	3.0	3.2	3.3	3.3	3.3	3.0	3.4	3.7
Byumba	*k*	3.2	3.3	3.1	3.0	3.4	2.1	3.4	2.9	3.1	3.2	3.2	2.9	3.2
	c(m/s)	3.8	3.8	4.0	4.1	4.2	3.9	4.2	4.1	4.3	4.2	4.1	4.0	4.1

Source: Primary Data, 2022

CONCLUSION

A study was made on the wind power potential of Kaniga region. It was found that the average annual wind power densities for Kaniga and its 2 surrounding stations of Nyarwambu, and Byumba have been correctly determined, summarized and tabulated. Results obtained revealed that the annual wind power density of Kaniga is 1,285W/m^2, while the annual power densities for Nyarwambu and Byumba are 689.4W/$m^2$and 805.4W/m^2 respectively.

The other stations in Rwanda have the monthly average power densities ranging from 7.99 W/m^2 to 138.2 W/m^2. From these findings and results, it is clear that Kaniga has the greatest wind power potential among all other studied wind stations in the country, hence it might be a promising site for installing wind devices and wind instruments like wind farms in addressing energy shortage through the appropriate exploitation of available wind resources.

RECOMMENDATIONS

From this study, the following recommendations are made:

(i) Government should construct wind farms to increase household accessibility to electricity by electrifying the rural areas and reducing (subsidizing) the connection costs of wind power.

(ii) The Government should promote the wind energy for household cooking and heating.

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