Journal of Industrial Technology, 2018, 3 (1): 23- 32
Journal Homepage: www.erjournals.com
ISSN Online: 0184-7937

WEIBULL AND CAUCHY DISTRIBUTION ANALYSES OF WIND PARAMETERS IN THE EASTERN PART OF ANAMBRA STATE, NIGERIA

Kingsley Ejikeme Madu

Department of Mechanical Engineering, Chukwuemeka Odumegwu Ojukwu University, Uli, Anambra, Nigeria.
E-mail: kingsleyblack2@gmail.com

ABSTRACT

This paper presents the analyses of wind parameters in the Eastern part of Anambra State, Nigeria. The wind characteristics of three locations (Ugwu-Osu, Okegbe, and Ogba-Ukwu) have been fitted to two distribution functions (Weibull and Cauchy). The interaction between the dependent variable (Wind Speed) and independent variables (Mean Temperature and Relative Humidity), measured at an altitude of 10 m, was studied. Wind speed was found to have a linear correlation with ambient temperature; and inversely proportional to relative humidity. The analyses revealed a mean density value of wind speed to be 0.609816 for Weilbull distribution, and 0.009304 for Cauchy distribution. It follows that these models can be used, reliably, for predicting wind energy output needed for design assessment of wind turbines for the locations.

Keywords: Weibull, Cauchy Distribution, Wind Parameters, and Mean Density Value

Citation: Madu, K. E. (2018). Weibull and Cauchy Distribution Analyses of Wind Parameters in the Eastern Part of Anambra State, Nigeria. *Journal of Industrial Technology*, 3 (1): 23-32

1. INTRODUCTION

Wind is merely air in motion. It is an effect caused as a result of pressure differences over regions and heights in the atmosphere, resulting in bulk motion of air masses. Wind is produced by uneven heating of the Earth surface by energy from the Sun. Since the Earth's surface is made up of different types of land and water, it absorbs the Sun's radiant energy at different rates. Much of this energy is converted into heat as it is absorbed by land areas, bodies of water, and the air over these formations. Air has mass, though its density is low, and when this mass has velocity, the resulting wind has kinetic energy which is proportional to $\frac{1}{2}$ [mass x $(\text{velocity})^2$]. The mass of air passing in unit time is ρAV, and the kinetic energy passing through the area in unit time (power available in the wind) is:

$$P_W = \frac{1}{2}\rho AVV^2 = \frac{1}{2}\rho AV^3 \qquad (1)$$

Where ρ is the air density (approx. $1.225 kg/m^3$ at the sea level), V is the velocity of wind (m/s), and A is the area through which wind passes normally (m^2). The force carried by the moving air mass (wind) can be harnessed for useful purposes such as grinding grain (in windmills) and generating electricity (in wind turbine generators). It is estimated that between 1.5 and 2.5% of the global solar radiation received on the surface of the earth is converted to wind (Vosburgh, 1983). Hence, wind energy, which contributes very little or no pollution, and few greenhouse gases to the environment, is a valuable alternative to the non-renewable and environmentally hazardous fossil fuels (Taylor, 1983). Equation (1) gives the total power available in the wind (approx. 3.6×10^{12} kW). However, only a fraction of this power can actually be extracted. The power extracted by a wind turbine can, therefore, be given as:

$$P = k\,\frac{1}{2}\,\rho A V^3$$

$$k = C_p N_g N_b \qquad (2)$$

C_p is the coefficient of performance or power coefficient, N_g is the generator efficiency, and N_b is the gearbox/bearing efficiency. The torque generated by the wind turbine is:

$$T_s = \frac{P}{\omega_s} \qquad (3)$$

Where T_s is the mechanical torque at the turbine side, P is the power output of the turbine and ω_s is the rotor speed of the wind turbine. The power coefficient, C_p, is the percentage of power in the wind that can be converted into mechanical power; and the ratio of the blade tip speed in the wind is referred to as the tip-speed ratio (TSR).

$$TSR = \frac{\omega_s R}{V} \qquad (4)$$

Wind turbine operation is limited by its TSR; a larger wind turbine operates at a lower frequency (Muljadi, E., et al, 2002). Basically, rotor movement is a balance between the aerodynamic torque applied by the wind and the electrical torque applied by the generator. The power coefficient is a measure of mechanical power delivered by the rotor to the turbine low-speed shaft. It is defined as the ratio of the mechanical power to the power available in the wind;

$$C_p = \frac{P}{P_w} \qquad (5)$$

The extent to which wind can be exploited as a source of energy depends on the probability density of the occurrence of different speeds at the site, which is essentially, location specific (Odo et al., 2013). However, the development of new wind projects continues to be hampered by the lack of reliable and accurate wind resource data, in many parts of Nigeria. Earlier on (Enibe, 1987; Ugwuoke et al., 2008; Odo et al., 2010), the theoretical potentials of wind at various altitudes, based on annual average values of wind speed, have been investigated for many Nigerian locations. These analyses were carried out using measured data over various periods ranging from 1 to 10 years. In this paper, an in situ measurement of monthly average wind speed of three locations in the eastern part of Anambra State, namely: Ugwu-Osu, Okegbe, and Ogba-Ukwu, over an interval of one year, was undertaken. The measured data of the dependent and independent variables were fitted using the Weibull and Cauchy models. The results of these analyses show that building a wind turbine in the investigated locations is a viable option; and would be useful to designers.

2. MATERIAL AND METHOD

Data gathering for the analyses commenced on 18th February 2016 and ended on 15th March 2017. The electronic digital anemometer was used to measure the average wind velocity, mean daily temperature, and relative humidity, in the designated areas. The kind of device used here, is an improved technology; it is altitude free and insensitive. A researcher only needs to key-in the required altitude or height, in meters, at which the device is to operate. This is done standing on the ground. If, for instance a 10m height is preferred, the device is kept on a place with minimal disturbance, where it can record the variables at the designated height. The recording of the wind velocity is a minute by minute process. These readings are collated every two days, and the process continues. A lithium cell (battery) with a life expectancy of about five years, ensures a smooth running of this contrivance. The *modus operandi* of the anemometer can be summarized thus;

- Place a small table on a level land with minimal or no disturbance, in the site already mapped out.
- Power the anemometer
- Achieve a Bluetooth connectivity between the device and a laptop
- Key-in the altitude of interest in the device (in our case, 10 m)
- Press the start button for the appliance to begin to work

The battery of the anemometer is recharged when it gets to 15 % threshold. At such times, a spare battery makes data collection possible. Besides, to ensure that there is no interruption in this important stage of the research, another anemometer of the same capacity is powered for use when transferring stored readings of wind speed to the computer.

The results of the measurements obtained for different locations are contained in Tables 1, 2 3, 4, and 5 below.

3. RESULTS AND DISCUSSION

Table 1: Measured Wind Speed Distribution Parameters at 10m

Month	Ugwu-Osu	Okegbe	Ogba-Ukwu	Average Wind Speed
January	5.5	5.6	5.4	5.5
February	5.6	5.6	5.5	5.6
March	6.5	6.5	6.4	6.5
April	6.7	6.5	6.5	6.6
May	5.4	6.7	5.3	5.8
June	5.3	5.4	5.3	5.3
July	5.6	5.7	5.5	5.6
August	5.7	5.8	5.5	5.7
September	5.3	5.3	5.2	5.3
October	5.2	5.1	5.0	5.1
November	5.0	4.8	4.8	4.9
December	5.3	5.5	5.4	5.4
Average Speed	5.6	5.6	5.5	5.6

Table 2: Average Monthly Temperature and Relative Humidity in Owerre-Ezukala for Location 1 (Ugwu-Osu)

Month	Wind Speed (m/s)	Wind Power (w)	Max. Temp. (^{o}C)	Min. Temp. (^{o}C)	Mean Temp. (^{o}C)	Rel. Hum. %
Jan.	5.5	17936.80	32	18	25	76
Feb.	5.6	18933.07	33	22	27.5	80
March	6.5	29607.18	35	25	30	76
April	6.7	32425.10	34	24	29	81
May	5.4	16976.11	32	23	27.5	81
June	5.3	16050.35	30	22	26	85
July	5.6	18933.07	28	21	24.5	89
Aug.	5.7	19965.56	29	22	25.5	87
Sept.	5.3	16050.35	28	23	25.5	86
Oct.	5.2	15158.87	28	23	25.5	85
Nov.	5.0	13476.18	33	23	28	73
Dec.	5.3	16050.35	34	19	26.5	76

Table 3: Location 2 (Okegbe)

Month	**Wind Speed (m/s)**	**Wind Power (w)**	**Max. Temp. (^oC)**	**Min. Temp. (^oC)**	**Mean Temp. (^oC)**	**Rel. Hum. %**
Jan.	5.6	18933.07	32	18	25	76
Feb.	5.6	18933.07	33	22	27.5	80
March	6.5	29607.18	35	25	30	76
April	6.5	29607.18	34	24	29	81
May	6.7	32425.10	32	23	27.5	81
June	5.4	16976.11	30	22	26	85
July	5.7	19965.56	28	21	24.5	89
Aug.	5.8	21034.92	29	22	25.5	87
Sept.	5.3	16050.35	28	23	25.5	86
Oct.	5.1	14301.03	28	23	25.5	85
Nov.	4.8	11922.86	33	23	28	73
Dec.	5.5	17936.80	34	19	26.5	76

NB: The values of wind power in the above tables were obtained using Equation 2

Table 4: Location 3 (Ogba-Ukwu): Table 4

Month	**Wind Speed (m/s)**	**Wind Power (w)**	**Max. Temp. (^oC)**	**Min. Temp. (^oC)**	**Mean Temp. (^oC)**	**Rel. Hum. (%)**
Jan.	5.4	16976.11	32	18	25	76
Feb.	5.5	17936.80	33	22	27.5	80
March	6.4	28261.61	35	25	30	76
April	6.5	29607.18	34	24	29	81
May	5.3	16050.35	32	23	27.5	81
June	5.3	16050.35	30	22	26	85
July	5.5	17936.80	28	21	24.5	89
Aug.	5.5	17936.80	29	22	25.5	87
Sept.	5.2	15158.87	28	23	25.5	86
Oct.	5.0	13476.18	28	23	25.5	85
Nov.	4.8	11 922.86	33	23	28	73
Dec.	5.4	16976.11	34	19	26.5	76

Table 5: Average Wind Speed Data of the three Locations

Month	Av.Wind Speed (m/s)	Max. Temp. (^{o}C)	Min. Temp. (^{o}C)	Mean Temp. (^{o}C)	Rel. Hum. (%)
Jan.	5.5	32	18	25	76
Feb.	5.6	33	22	27.5	80
March	6.5	35	25	30	76
April	6.6	34	24	29	81
May	5.8	32	23	27.5	81
June	5.3	30	22	26	85
July	5.6	28	21	24.5	89
Aug.	5.7	29	22	25.5	87
Sept.	5.3	28	23	25.5	86
Oct.	5.1	28	23	25.5	85
Nov.	4.9	33	23	28	73
Dec.	5.4	34	19	26.5	76

3.1: Weibull and Cauchy Distribution Analysis

3.1.1: Result of Weibull Distribution Analysis

Weibull Distribution Analysis for X1(Av. Wind Speed): Table 6 presents the estimated Weibull parameters for variable X1 (Av. Wind Speed) which comprises of the shape parameter of 138.78975 and the Scale parameter of 24.74705 with their corresponding standard error of 56.59276 and 10.10904 respectively.

Table 6: Parameters for the Weibull distribution.

Parameter	Type	Estimate	S.E.
Shape	shape	138.78975	56.59276
Scale	scale	24.74705	10.10904

Weibull Distribution Analysis for X2 (Max.Temp.)

Table 7 presents the estimated Weibull parameters for variable X2 (Max Temp) which comprises of the shape parameter of 155.8769 and the Scale parameter of 4.974793with their corresponding standard error of 63.56853 and 2.032041respectively.

Table 7: Parameters for the Weibull distribution.

Parameter	Type	Estimate	S.E.
Shape	shape	155.8769	63.56853
Scale	scale	4.974793	2.032041

Weibull Distribution Analysis for X3 (Min. Temp)

Table 8 presents the estimated Weibull parameters for variable X3 (Min. Temp.) which comprises of the shape parameter of 129.1527and the Scale parameter of 5.848425 with their corresponding standard error of 52.65848and 2.389157 respectively.

Table 8: Parameters for the Weibull distribution

Parameter	Type	Estimate	S.E.
Shape	Shape	129.1527	52.65848
Scale	Scale	5.848425	2.389157

Weibull Distribution Analysis for X4 (Mean Temp.)

Table 9 presents the estimated Weibull parameters for variable X4 (Mean Temp.) which comprises of the shape parameter of 275.1669 and the Scale parameter of 10.30265 with their corresponding standard error of 112.2684 and 4.207318 respectively.

Table 9: Parameters for the Weibull distribution.

Parameter	**Type**	**Estimate**	**S.E.**
Shape	shape	275.1669	112.2684
Scale	scale	10.30265	4.207318

Weibull Distribution Analysis for X5 (Rel. Hum.)

Table 10 presents the estimated Weibull parameters for variable X5 (Rel. Hum.) which comprises of the shape parameter of 265.6526 and the Scale parameter of 3.269549 with their corresponding standard error of 108.3842 and 1.335207 respectively.

Table 10: Parameters for the Weibull distribution.

Parameter	**Type**	**Estimate**	**S.E.**
Shape	shape	265.6526	108.3842
Scale	scale	3.269549	1.335207

Table11 presents the estimated Weibull density values for variable X1 to X5 across the months. The mean density value was obtained in the following order of magnitude X1= 0.609816, X4=0.168896, X3=0.147597, X2=0.102285and X5=0.052605. This result implies that X1(Av. Wind Speed) recorded the highest mean density value while X5 (Rel. Hum) recorded the least mean density value. Figure 2 validated the result afore-stated where dX1 (density value for X1) was observed to have a steeply increasing trend than the other variables.

Table 11: Summary of Density Count of the Variables using the Weibull Distribution

Month	**dX1**	**dX2**	**dX3**	**dX4**	**dX5**
Jan	0.831903	0.150249	0.020164	0.146967	0.047898
Feb	0.838636	0.121914	0.205759	0.21368	0.078711
March	0.147674	0.052813	0.064304	0.031928	0.047898
April	0.101901	0.085803	0.119176	0.087485	0.080149
May	0.74814	0.150249	0.176778	0.21368	0.080149
June	0.712813	0.143502	0.205759	0.230576	0.058119
July	0.838636	0.068754	0.183729	0.099745	0.023439
Aug	0.809075	0.108916	0.205759	0.194049	0.039583
Sept	0.712813	0.068754	0.176778	0.194049	0.04883
Oct	0.501884	0.068754	0.176778	0.194049	0.058119
Nov	0.285846	0.121914	0.176778	0.17299	0.020473
Dec	0.788473	0.085803	0.059403	0.247557	0.047898
Mean Density value	0.609816	0.102285	0.147597	0.168896	0.052605

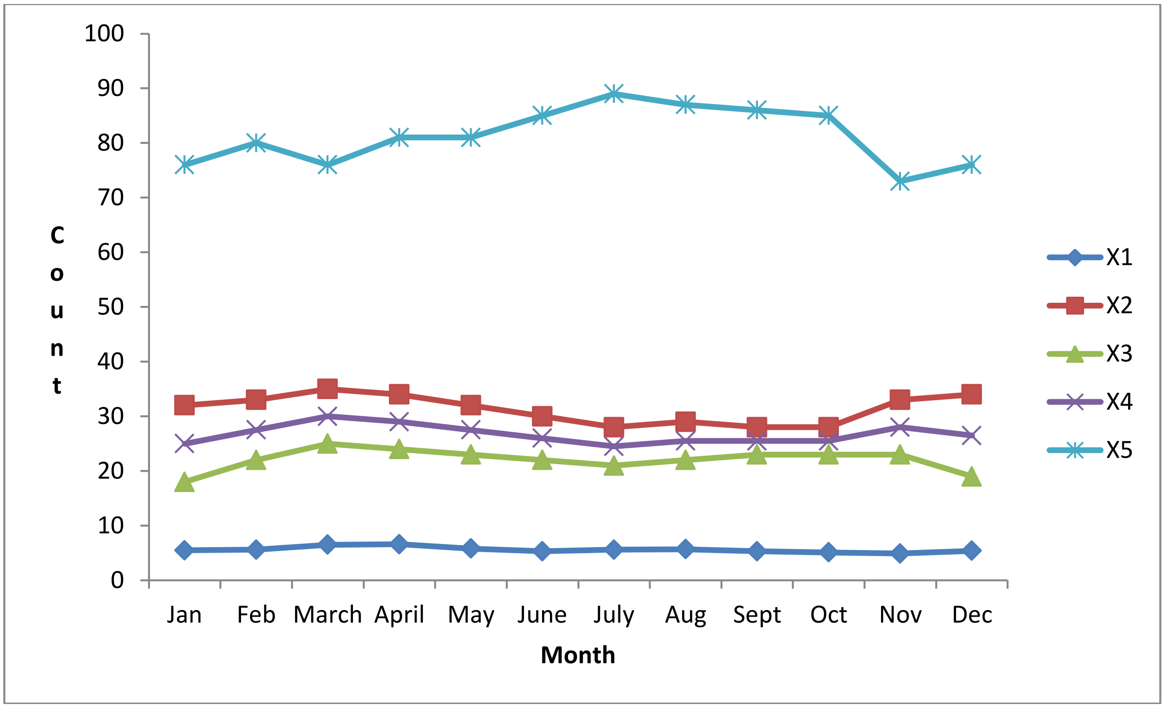

Figure 1: Graph showing the Observed values for the Variables

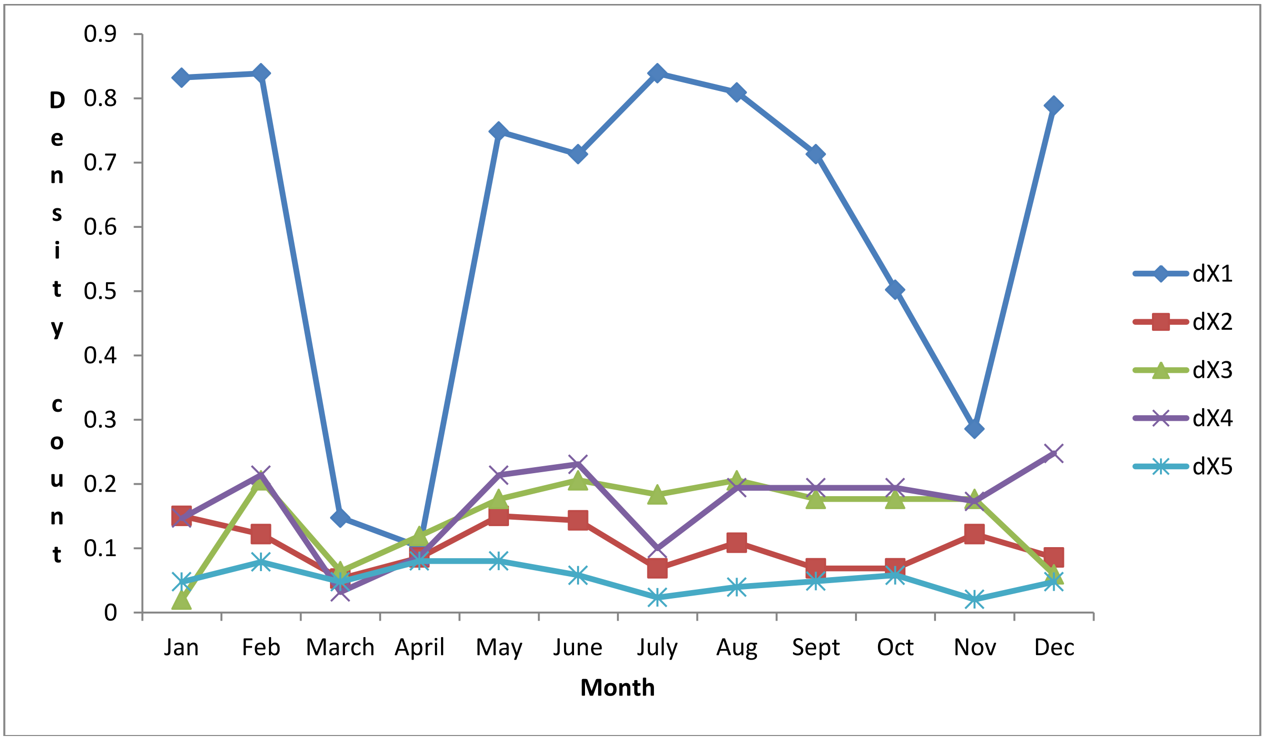

Figure 2: Graph showing the Density Count using the Weibull Distribution

3.1.2: Result of Cauchy Distribution Analysis

Cauchy Distribution Analysis for X1 (Av. Wind Speed)

Table 12 presents the estimated Cauchy parameters for variable X1 (Av. Wind Speed) which comprises of the location parameter of 0.96306 and the Scale parameter of 0.62383with their corresponding standard error of 0.17053 and 0.40825 respectively.

Table 12: Parameters for the Cauchy Distribution

Coefficients	**Estimate**	**Std. Error**	**z value**	**Pr(>|z|)**
(Intercept): loge(location) 1	0.96306	0.17053	5.647	1.63e-08
(Intercept): loge(scale) 2	0.62383	0.40825	1.528	0.126
X1	0.50570	0.02883	17.539	<2e-16

Cauchy Distribution Analysis for X2= Max Temp

Table 13 presents the estimated Cauchy parameters for variable X2 (Max Temp) which comprises of the location parameter of -13.5034 and the Scale parameter of 15.53909 with their corresponding standard error of 1.56905 and 0.40825 respectively.

Table 13: Parameters for the Cauchy Distribution

Coefficients	**Estimate**	**Std. Error**	**Zvalue**	**Pr(>|z|)**
(Intercept): loge(location) 1	-13.5034	1.56905	-8.606	<2e-16
(Intercept): loge(scale) 2	15.53909	0.40825	38.063	<2e-16
X2	0.94034	0.04522	20.795	<2e-16

Cauchy Distribution Analysis for X3 (Min. Temp)
Table 14 presents the estimated Cauchy parameters for variable X3 (Min Temp) which comprises of the location parameter of 0.9999 and the Scale parameter of 0.6659 with their corresponding standard error of 5.93 * 10^-05 and 0.4082 respectively.

Table 14: Parameters for the Cauchy Distribution

Coefficients	**Estimate**	**Std. Error**	**Zvalue**	**Pr(>|z|)**
(Intercept): loge(location) 1	0.9999	5.93E-05	16880	<2e-16
(Intercept): loge(scale) 2	0.6659	0.4082	1.631	0.103
X3	0.5	2.46E-06	203100	<2e-16

Cauchy Distribution Analysis for X4 (Mean Temp)
Table 15 presents the estimated Cauchy parameters for variable X4 (Mean Temp) which comprises of the location parameter of 1.72065 and the Scale parameter of 10.46801 with their corresponding standard error of 0.112861 and 0.408248 respectively.

Table 15: Parameters for the Cauchy Distribution

Coefficients	**Estimate**	**Std. Error**	**Zvalue**	**Pr(>|z|)**
(Intercept): loge(location) 1	1.72065	0.112861	15.25	<2e-16
(Intercept): loge(scale) 2	10.46801	0.408248	25.64	<2e-16
X4	0.472234	0.003874	121.88	<2e-16

Cauchy Distribution Analysis for X5 (Rel. Hum)

Table 16 presents the estimated Cauchy parameters for variable X5 (Rel. Hum) which comprises of the location parameter of -14.9554 and the Scale parameter of 40.63299 with their corresponding standard error of 0.210025 and 0.408248 respectively.

Table 16: Parameters for the Cauchy Distribution

Coefficients	**Estimate**	**Std. Error**	**Zvalue**	**Pr(>|z|)**
(Intercept): loge(location) 1	-14.9554	0.210025	-71.21	<2e-16
(Intercept): loge(scale) 2	40.63299	0.408248	99.53	<2e-16
X5	0.70094	0.002365	296.43	<2e-16

Table 17 presents the estimated Cauchy density values for variable X1 to X5 across the months. The mean density value was obtained in the following order of magnitude X1=0.009304, X4=0.004578, X2=0.002212, X5=0.001192 and X3=0.000489. This result implies that X1(Av. Wind Speed) recorded the highest mean density value while X3 (Min Temp) recorded the least mean density value. Figure 3 validated the result afore-stated where dX1 (density value for X1) was observed to have a clear increasing trend than the other variables.

Table 17: Summary of Density Count of the Variables using the Cauchy Distribution

Month	dY1	dY2	dY3	dY4	dY5
Jan	0.009468	0.002139	0.000732302	0.005114	0.001303
Feb	0.009071	0.002057	0.000480153	0.004304	0.001212
March	0.006396	0.001907	0.000367704	0.003664	0.001303
April	0.006174	0.00198	0.000400346	0.003903	0.001191
May	0.008349	0.002139	0.000437534	0.004304	0.001191
June	0.010343	0.002318	0.000480153	0.004766	0.001111
July	0.009071	0.002518	0.000529314	0.005302	0.001038
Aug	0.008699	0.002415	0.000480153	0.004936	0.001074
Sept	0.010343	0.002518	0.000437534	0.004936	0.001092
Oct	0.011345	0.002518	0.000437534	0.004936	0.001111
Nov	0.012498	0.002057	0.000437534	0.004164	0.001378
Dec	0.009891	0.00198	0.000653304	0.004605	0.001303
Mean Density Value	0.009304	0.002212	0.000489464	0.004578	0.001192

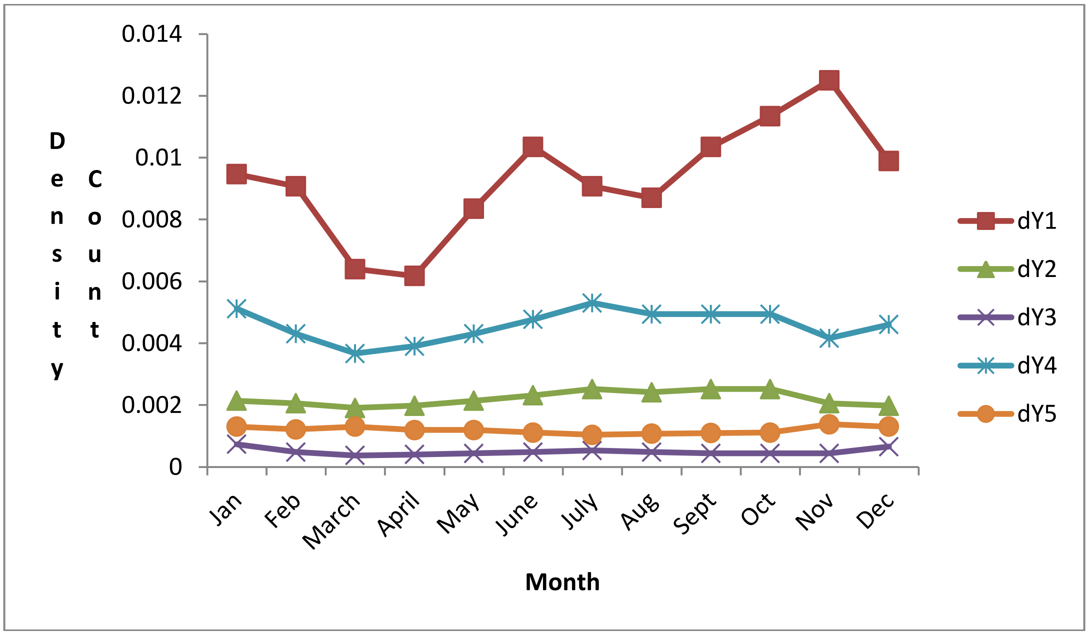

Figure 3: Graph showing the Density Count using the Cauchy Distribution

Definition of variables in R-console 3.32 version window of Weibull and Cauchy Distribution Analysis on the (Variables).

4. CONCLUSION

Wind is inherently stochastic; it varies from time to time. A change in location will definitely alter the value of any measurement of wind speed. Wind energy assessments, therefore, are location specific and hence are limited in terms of accuracy due to the non-linear variability of wind characteristics in space and time. The results obtained from few sites can be misleading when used to average for a whole state or nation. It becomes expedient to embark on a robust statewide or nationwide assessment of wind energy potentials for more dependable and accurate results.

REFERENCES

Enibe, S. O. (1987). A Method of Assessing Wing Energy Potential in a Nigerian Location, *NJSE*, 6, 14.

Muljadi, E., Green, J. (2002). Cogging Torque Reduction in a Permanent Magnet Wind Turbine Generator, NREL/CP-500-30768, National Renewable Energy Laboratory, Golden Colorado, U.S.A.

Odo, F. C., Igwebuike M. N., Ezeugwu, C. I., (2010). Preliminary Assessment of Enugu Location for Setting up a 1 KW Wind Turbine for Electricity Generation, *NJSE* 21, 182

Odo, F. C., Ugbor D. O., Ugwuoke P. E. (2013). Twenty-Five Years of Wind Data in South-Eastern Locations of Nigeria: Modeling and Prediction of Wind Potentials, *IJPS* 8(2), 83-88

Taylor, R. H. (1983). *Alternative Energy Sources for the Centralized Generation of Electricity*, Bristol: Adam Hilger, p. 56

Ugwuoke, P. E., Bala, E. J., Sambo, A. S., Argungu, G. M. (2008). Assessment of Wind Energy Potentials for Electricity Generation in Nigerian Rural Setting, *NJSE*, 19, 98

Vosburgh, P. N. (1983). *Commercial Application of Wind Power.*, New York: Van Nostrand Rainhold, p. 12.