Modelling Wind Speed Distributions in Selected Weather Stations

W. P. L. Fernando and D. U. J. Sonnadara
Department of Physics, University of Colombo, Sri Lanka

ABSTRACT

Modelling daily wind speed data by using the two parameter Weibull distribution for ten selected weather stations in Sri Lanka is presented. The daily wind speed data measured by the Department of Meteorology at the heights of 6m-15m during the years 2001 and 2004 were used in this work. The annual variation of the fitted Weibull parameters, the shape parameter *k* and the scale parameter *c* ranged from 0.80 to 3.58 and 2.79 ms^{-1} to 19.78 ms^{-1} respectively. The highest values of the parameters were found in Hambantota and the lowest values were found in Kurunegala. It was seen that the daily wind speed distribution can be modelled with a reasonable accuracy, using the two parameter Weibull distribution for the stations considered in this work.

1. INTRODUCTION

Sri Lanka is an island with a land area of approximately 65,610 Sq. km situated in the southern tip of the Indian subcontinent between longitudes 80° - 82° East and latitudes 6° - 10° North. The island has a population of about 16 million inhabitants. The gross energy supply of the country is fulfilled by non-commercial fuel wood (57%), fossil fuels (31%) and electricity (11%), which is generated mainly through Hydro and Thermal power. Although, Sri Lanka has no mineral resources, the country has adequate natural resources such as, Hydro, Solar and Wind. However, 90% of the electricity in Sri Lanka is still produced through Hydro power. Thus, assessment of other alternative resources such as Wind and Solar is important for policy implications [1, 2].

Sri Lanka is situated in the belt of monsoon climates in South Asia. The climate of the island is governed by its tropical location as well as by the monsoonal regime, thus has a strong seasonal and spatial dependence. On the basis of the two monsoons and two transitional periods in-between, four seasons are identified. They are the North-East monsoon from December to February, First inter-monsoon from March to mid May, South-West monsoon from mid May to September and Second inter-monsoon from October to November.

In general the winds during the monsoons are somewhat stronger. During the inter-monsoon periods the winds are weaker and variable. Based on extensive analysis of the existing wind data, it has been concluded from past studies that the Southern lowlands have the most favourable wind resources throughout the year [3].

The South-West monsoon winds are recorded to have a remarkable persistent in direction and sustain from about middle of May till early October whereas the North-Easterly winds commence in December and continue till about late February. During the inter-monsoonal periods, wind prevails from March till mid May for the first inter monsoon period and from October till November for the second inter-monsoon period. The inter-monsoonal periods are also marked by long periods of calm and weak winds with variability in directions.

The objective of this study is to model the daily wind speed distributions and determine the two parameters, k and c, of a Weibull function that can describe the wind speed distributions in a few selected weather stations scattered around the island.

2. DATA SAMPLE

Daily average wind speed data at the heights of 6 m -15 m measured by the Department of Meteorology Sri Lanka during the years 2001 and 2004 was used in this work. Stations were selected with the aim of covering different geographical regions in Sri Lanka. However, due to the difficulty in obtaining reliable data, the number of stations was limited to a total of ten. The details of the location of the stations and their altitudes are summarized in Table 1.

Table 1: Longitude, Latitude and Elevation of the selected weather stations

Station	**Longitude**	**Latitude**	**Elevation**
Jaffna	80° 01' E	9° 39' N	4 m
Anuradhapura	80° 23' E	8° 21' N	93 m
Ratnapura	80° 24' E	6° 41' N	34 m
Kurunegala	80° 22' E	7° 28' N	116 m
Hambantota	81° 08' E	6° 07' N	16 m
Batticaloa	81° 42' E	7° 43' N	3 m
Maha-Illuppallama	80° 28' E	8° 07' N	138 m
Trincomalee	81° 15' E	8° 35' N	3 m
Puttalam	79° 50' E	8° 02' N	2 m
Bandarawela	81° 00' E	6° 05' N	1,372 m

3. WEIBULL DISTRIBUTION

Measurements of wind speed distribution or frequency distribution is an essential ingredient in calculating the output of the wind energy at a particular site. The wind speed distribution can be mathematically represented by several analytical functions.

One of the mathematical functions that have been successfully applied to fit wind speed distributions is the Weibull distribution function [4]. The general form of the Weibull distribution function, which is a two-parameter function, for wind speed is given by,

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

where $f(v)$ is the probability of observing wind speed v, k is dimensionless Weibull shape parameter and c is a scale parameter having units of wind speed.

Essentially, the scale parameter, c, indicates ‘windiness’ of a location under consideration, where as the shape parameter, k, indicates ‘sharpness’ of the wind speed distribution (i.e. if measured wind speeds are very close to a certain value, the distribution will have a high k value and be narrow)

The cumulative distribution function is given as,

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

Fitting the above equation to a set of wind speed data determines the parameters of the Weibull distribution function. Taking the natural logarithms of both sides of the above equation twice, gives,

$$\ln\{-\ln[1 - F(v)]\} = k \ln(v) - k \ln c$$

Thus, a plot of $\ln\{-\ln[1-F(v)]\}$ versus $\ln(v)$ represents a straight line. The gradient of line is k and the intercept is $-k \ln c$.

4. RESULTS AND DISCUSSION

In this study, daily average of wind speed data measured at ten weather stations over two separate years were computerized and analyzed. Based on these experimental data, frequency distributions were generated and model fitting analysis was carried out to obtain the Weibull distribution parameters.

The model fitted two Weibull parameters; the shape parameter k and the scale parameter c are shown in the Table 2 for all stations separately for 2001 and 2004. In fitting the model, data was modelled by the linear equation given above.

It can be seen that, the shape parameter k has a much smaller spatial variation than the scale parameter c. The parameter k, varies from 0.80 to 3.58, with an average value of 2.00 during the years 2001 and 2004 where as the parameter c varies from 2.79 ms^{-1} to 19.78 ms^{-1}, with an average value of 8.24 ms^{-1} during the same two years. Hambantota shows the highest value for scale parameter c. Next to Hambantota, Jaffa and Puttalam show high values for parameter c.

Table 2: Shape and scale parameters for daily wind speed distributions
(No wind speed data was available for Kurunegala for the year 2001)

Station	2001		2004	
	k	***c***	***k***	***c***
Jaffna	1.83	9.76	2.03	8.28
Anuradapura	1.59	5.59	2.17	6.00
Ratnapura	1.35	3.54	2.12	4.92
Kurunagela	-	-	1.49	2.79
Hambantota	2.68	18.80	3.58	19.78
Batticaloa	2.19	6.65	2.05	6.47
Maha-Illuppallama	0.80	10.88	2.02	8.12
Trincomalee	1.33	4.35	2.34	8.42
Puttalam	2.25	8.89	2.82	8.80
Bandarawela	1.82	7.91	1.51	6.60

In order to study the seasonal variability of model parameters, Weibull distribution was evaluated separately for monsoon seasons. The results are shown in the Table 3 for Hambantota where the highest value for parameter *c* was observed.

Table 3: Seasonal variability of model parameters for Hambantota

Season	k	c (ms^{-1})
NE	3.73	22.73
1st inter	3.28	16.60
SW	4.22	22.22
2nd inter	3.34	16.20

The results show that the seasonal shape parameter *k* ranges between 3.28 and 4.22, with an average value of 3.64 whereas the seasonal scale parameter *c* ranges between 16.20 ms^{-1} and 22.73 ms^{-1}, with an average value of 19.44 ms^{-1}. In general, compared to the parameter *c*, the variation of the parameter *k* is much less between the seasons. NE and SW monsoons show higher parameter values compared to the inter-monsoon seasons.

In order to study the temporal behaviour of wind speeds, the Weibull distribution function for each of the two years were plotted separately. The fitted model for 2001 data and comparison of reconstructed wind speed distributions through the model for 2001 and 2004 for Hambantota station are shown in Figure 1.

It can be seen that the distributions are almost similar in shape during the two years considered in this work. However, the distribution for 2001 shows a peak at wind speed of around 15.8 ms^{-1}, while 2004 shows a peak at 18.0 ms^{-1}. The model indicates that the probability of experiencing the stronger winds is slightly higher (between 14 ms^{-1} to 26 ms^{-1}) during the year 2004 compared to year 2001 in Hambantota.

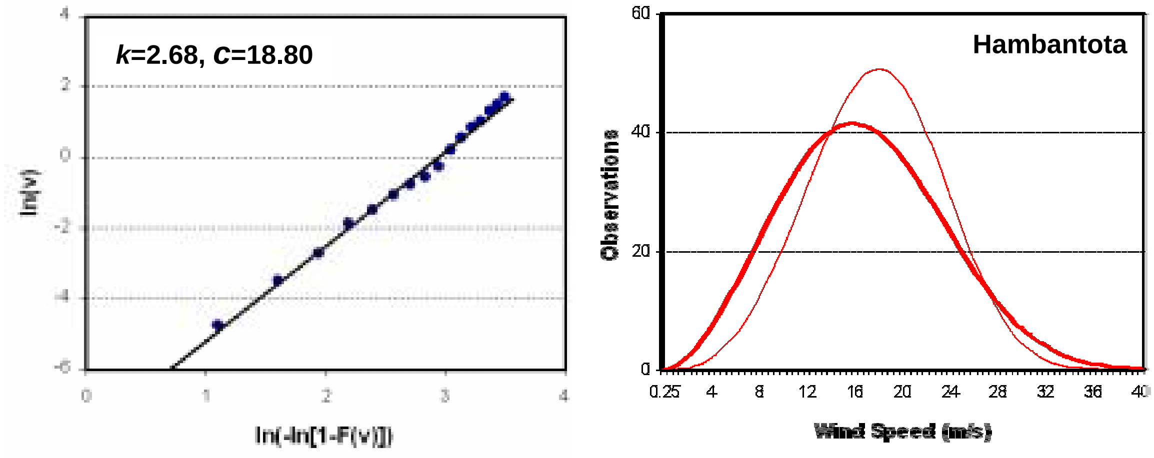

Figure1: (a) Fitted linear model for 2001 wind speed data (b) Reconstructed wind speed distributions for 2001 (thick line) and 2004 (thin line) for Hambantota

Similarly, analysis was carried out using the Weibull distribution function for two more stations; Jaffna and Puttalam from where the next leading annual wind speeds were observed. The reconstructed distributions are shown in Figure 2 for both stations.

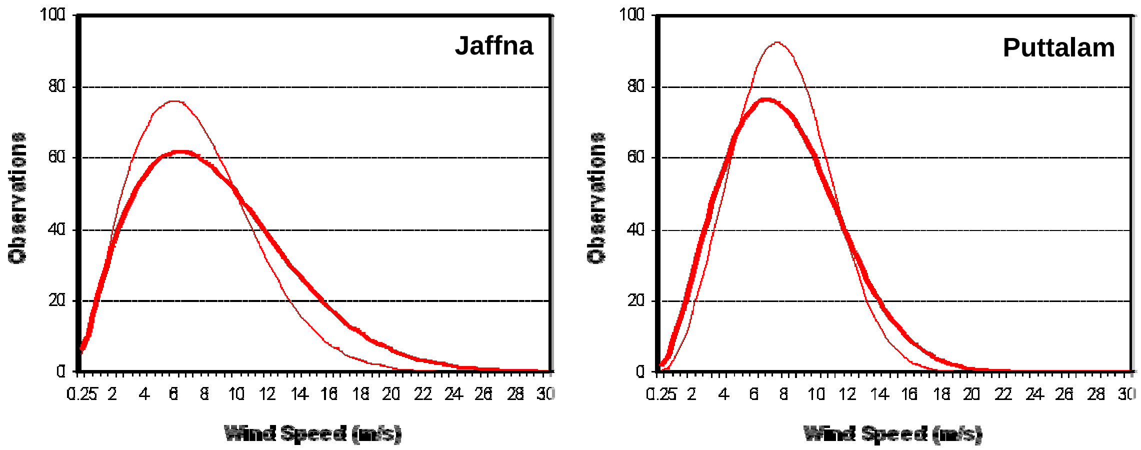

Figure 2: Weibull distribution functions for 2001 (thick line) and 2004 (thin line) for Puttalam and Jaffna

Jaffna shows a peak at wind speeds around 6.3 ms^{-1} and 5.9 ms^{-1} respectively for year 2001 and 2004. The fitted models show that the probability of experiencing the strong winds is higher (between 10 ms^{-1} to 20 ms^{-1}) during the year 2001 than the year 2004.

The wind speed distributions of Puttalam are similar, but slightly narrower. Model parameters for Puttalam shows a peak at a wind speed of around 6.9 ms^{-1} and 7.5 ms^{-1} respectively for 2001 and 2004. The distributions show that the probability of experiencing moderate winds is less (between 6 ms^{-1} to 12 ms^{-1}) and the stronger winds is higher (between 12 ms^{-1} to 20 ms^{-1}) during the year 2001 than that the year 2004.

In order to investigate the seasonal wind speed variation in Hambantota, the reconstructed Weibull distribution for four seasons is also investigated. The reconstructed distributions are shown in the Figure 3.

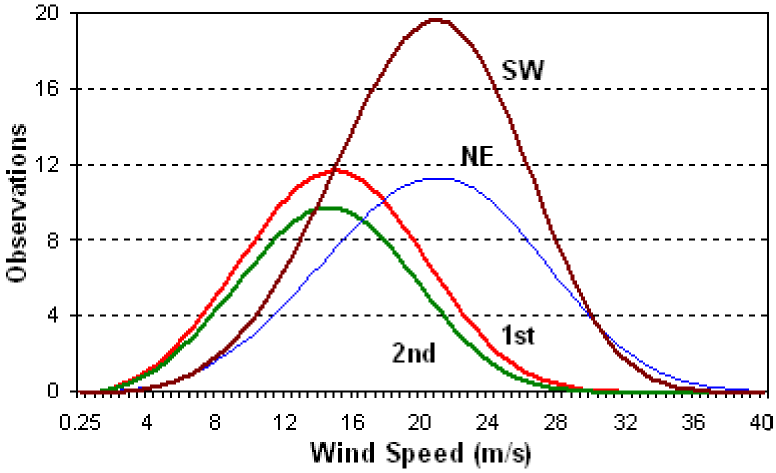

Figure 3: Seasonal Weibull distributions for Hambantota

Figure 3 indicates that, among the four seasons, SW monsoonal period has the highest probability of experiencing high wind velocities and the lowest probability of experiencing low wind velocities. The lowest probability of experiencing the high wind velocities occur during the two inter-monsoonal periods whereas the probability of occurrence is very similar.

5. CONCLUSION

Numerical modelling using two parameter Weibull distribution function was performed to describe the wind speed frequency distributions over a two time periods (2001 and 2004) in ten weather stations. The annual values of shape parameter k and scale parameter c were estimated and found to be vary between, 0.80 to 3.58 and 2.79 ms^{-1} to 19.78 ms^{-1} respectively. The highest values of k and c were recorded at Hambantota whereas the lowest values were found in the Kurunegala. The highest seasonal values of shape parameter and scale parameter were recorded during the NE and SW monsoonal periods. The two parameter Weibull distribution was found to describe the daily average wind speeds with a reasonable accuracy.

REFERENCES

1. W.J.L.S. Fernando, Wind Energy for Electricity Generation in Sri Lanka, *J. Wind Engineering and Industrial Aerodynamics*, 27 (1988) 421-432.
2. Government of Sri Lanka, Initial National Communication under the United Nations Framework Convention on Climate Change: Sri Lanka (2000)
3. K.S. Fernando, E.H. Lysen, N. Pieterse and J. Wieringa, Wind resource assessment in Sri Lanka, *J. Wind Engineering and Industrial Aerodynamics*, 39 (1992) 233-241.
4. K.Ulgen and A.Hepbasli, Determination of Weibull parameters for wind energy analysis of Izmir, Turkey, *Int. J. Energy Research*, 26 (2002) 495-506.
5. D.Weisser and T.J.Foxon, Implications of seasonal and diurnal variations of wind velocity for power output estimation of a turbine: a case study of Grenada, *Int. J. Energy Research*, 27 (2003) 1165-1179.