ANALYSIS OF WIND SPEED AND DIRECTION DATA IN HAMBANTOTA DISTRICT OF SOUTHERN SRI LANKA

M.A.M. Abraj* and P. Wijekoon
Faculty of Science, University of Peradeniya
**Corresponding author (email:abrajsz20@ymail.com*)

Introduction

Hambantota district is in the Southern Province of Sri Lanka and its geographical location is 6° 07'28'' North latitude and 81° 07'21'' East longitude. This district has a land area of about 2,609 sq. km. Sri Lanka is located in the belt of monsoon climates in South Asia, and it's climate has a strong seasonal and spatial dependence. The four monsoon periods active in the island 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 (Department of Meteorology Sri Lanka). The intensity of wind during the monsoons is relatively stronger when compared to the inter-monsoon periods. Currently wind energy and wind speed are considered as a popular energy production source since it does not lead to any environmental pollution. Also, the information regarding these two factors are used to forecast weather conditions for the construction of engineering structures, such as towers, bridges, and tall buildings. Furthermore, wind speed and wind direction have numerous impacts on surface water; they affect rates of evaporation, mixing of surface waters, and the development of seiches and storm surges, and finally to the water quality and water level.

In recent studies based on environment factors, the method of copula is widely used since it is an assumption free method which gives the correlation structure between two or more variables, and the joint probabilities. The method of copula is well demarcated by Nelson and Roger [1]. Trepanier [2] have used this method to understand the correlation structure of Surge and Wind Risk of Hurricanes in Galveston, Texas. Madadgar and Moradkhani [3] have used copula method for Drought Analysis under Climate Change in the Upper Klamath River basin in Oregon, USA. The objective of this study was to use copula method to identify the best fitted joint distributions for wind speed and wind direction, and the joint return periods for daily, monthly and monsoons data in Hambantota district.

Materials and Methods

The daily averages of wind speed (ms^{-1}) and wind direction (degree) data measured at the Hambantota Meteorological station from January 2008 to December 2012 were collected from the Department of Meteorology, Sri Lanka.
The monthly averages were calculated using daily averages and the daily averages were also divided into four monsoon seasons.

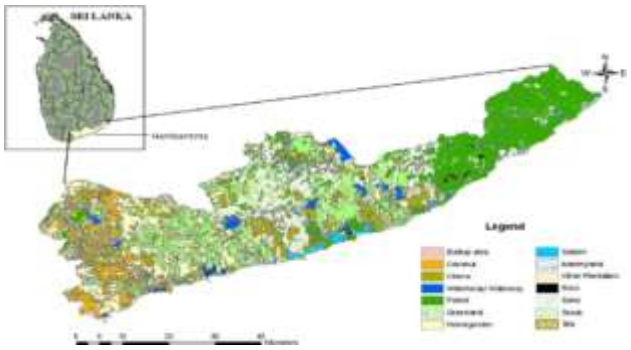

Figure 1. Indicates the map of the Hambantota district, and downloaded from the secondary resource (http://hambantotatour.blogspot.com).

First, Correlation between averages of wind speed and wind direction was calculated using the Kendall's τ rank correlation. Since wind direction is a circular variable, circular statistics is used for the analysis. The marginal distribution for averages of wind speed were fitted using the Normal, Gamma, Weibull, Lognormal and Exponential distribution, and the best fitted distributions were identified by using Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) values. Since wind direction is a circular variable, the marginal distribution for averages of wind direction were fitted using the von-Mises, wrapped Cauchy, wrapped exponential and circular uniform distributions and the best fitted distributions were identified by using Mean Circular Error (MCE) values. Consequently, using the identified distributions; Normal, Clayton, Gumbel, Frank and Students' t were fitted and the best fitted copulas were identified by using AIC and BIC values. Finally, the joint probability distribution was obtained and using the fitted joint distribution, joint return periods were calculated using the following formula [4].

$$T_{X,Y}(x,y) = \frac{1}{1 - F_{X,Y}(x,y)}$$

Where, $F_{X,Y}(x,y)$ is the joint cumulative distribution function defined $F_{X,Y}(x,y) = P(X \leq x, Y \leq y)$ and X and Y represent the wind speed and wind direction respectively.The open source R is used for the analysis.

Results and Discussions

Table 1 given below, indicates moderate positive correlation between monthly averages; weak and positive correlation between daily, first-inter monsoon , South West monsoon and second-inter monsoon averages; and weak and negative correlation between North East monsoon averages.

The two variables are linearly dependent, since all the pairs of wind speed and wind direction averages are significant at 5% significance level.

Table 1. The correlation measures between wind speed and wind direction

		Kendall's Tau rank correlation(τ)	p-value
Daily		0.207	< 0.0001
Monthly		0.418	< 0.0001
Monsoons	**North-East**	-0.144	< 0.0001
	First-Inter	0.201	< 0.0001
	South-West	0.125	< 0.0001
	Second-Inter	0.103	< 0.0001

Table 2. The best fitted copulas for wind speed and wind direction

Averages	Copula	Parameter
Daily	Frank	1.9269
Monthly	Gaussian	0.6100
North-East monsoon	Frank	-1.3172
First-Inter monsoon	Frank	1.8669
South-West monsoon	Gaussian	0.1954
Second-Inter monsoon	Gaussian	0.3131

Table 3. CDFs formulas best fitted copulas

Averages	Cumulative Distribution Function of Copulas (CDFs)
Daily	$-\frac{1}{1.9269}\ln\left(1+\frac{(e^{-1.9269u}-1)(e^{-1.92691v}-1)}{(e^{-1.9269}-1)}\right)$
Monthly	$\int_{-\infty}^{\emptyset^{-1}(u)}\int_{-\infty}^{\emptyset^{-1}(v)}\frac{1}{2\pi(1-0.61^2)^{0.5}}exp\left\{-\frac{x^2-2*0.61xy+y^2}{2(1-0.61^2)}\right\}dxdy$
North-East	$\frac{1}{1.3172}\ln\left(1+\frac{(e^{1.3172u}-1)(e^{1.3172v}-1)}{(e^{1.3172}-1)}\right)$
First-Inter	$-\frac{1}{1.8669}\ln\left(1+\frac{(e^{-1.8669u}-1)(e^{-1.8669v}-1)}{(e^{-1.8669}-1)}\right)$
South-West	$\int_{-\infty}^{\emptyset^{-1}(u)}\int_{-\infty}^{\emptyset^{-1}(v)}\frac{1}{2\pi(1-0.19^2)^{0.5}}exp\left\{-\frac{x^2-2*0.19xy+y^2}{2(1-0.19^2)}\right\}dxdy$

Second-Inter

$$\int_{-\infty}^{\emptyset^{-1}(u)} \int_{-\infty}^{\emptyset^{-1}(v)} \frac{1}{2\pi(1-0.31^2)^{0.5}} exp\left\{-\frac{x^2 - 2*0.31xy + y^2}{2(1-0.31^2)}\right\} dxdy$$

Table 2 gives the best fitted copulas based on the minimum AIC and BIC values. The Cumulative Distributions Functions (CDFs) of the fitted copulas for each case are given in Table 3.

Using the respective copulas given in Table 3, the joint CDFs and joint return periods were calculated for maximum values of the daily, monthly and monsoons average wind speed with the corresponding wind direction values, and the results are shown in Table 4 and Table 5.

Table 4. CDFs, and joint return periods for the maximum values of daily, monthly wind speed

Wind speed (x/ms^{-1})		Wind direction (y/degrees)		CDFs P(X<x ,Y<y)		Return Periods	
Daily	**Monthly**	**Daily**	**Monthly**	**Daily**	**Monthly**	**Days**	**Months**
39.0	20.6	**270**	211.2	0.749	0.128	**4**	2
37.2	20.2	225	219.2	0.624	0.129	3	2
37.0	19.7	225	218.3	0.624	0.132	3	2
36.6	19.7	180	218.3	0.499	0.132	2	2

The values shown in bold in Table 4 indicate that the joint return periods for daily averages are four days when wind speed and wind direction are 39ms^{-1} and 270^0 respectively. Accordingly the other results can also be interpreted.

Table 5. Joint return periods for the maximum wind speed values for four monsoon seasons.

Wind speed (x/ms^{-1})				Wind direction (y/degrees)				Return Periods (No. of seasons)			
NE	**FI**	**SW**	**SI**	**NE**	**FI**	**SW**	**SI**	**NE**	**FI**	**SW**	**SI**
31.6	34.8	37.2	35.4	90	225	225	180	2	3	2	2
31.6	30.0	37.0	32.4	90	0	202	315	2	1	2	2
30.6	29.4	36.0	30.6	90	225	202	225	2	3	2	2
30.6	28.8	36.0	30.6	90	45	225	270	2	2	2	2

The values shown in bold in Table 5 indicate that the joint return periods for North East monsoon is two monsoon seasons when wind speed and wind direction is 31.6 ms^{-1}, the joint return periods for first-inter monsoon is three monsoon seasons when wind speed is 34.8 ms^{-1} and so on. Accordingly, other results also can be interpreted.

Conclusion

This study revealed that Frank copula is the best fitted copula for daily, north-east monsoon, first-inter monsoon averages, and Gaussian copula is the best fitted copula for monthly, south-west monsoon, second-inter monsoon averages. The joint return periods for the pairs of maximum wind speed with corresponding wind direction were calculated using the joint probability distributions fitted. The joint

return periods of wind speed and wind direction for daily, monthly and four monsoon periods in Hambantota district were obtained by using the best fitted joint probability distributions. This information can be used for future predictions of wind speed and wind direction data in this area, and the same analysis can be applied for any other area if the data are available.

References

[1] B. Roger Neslon, *An Introduction to Copulas*, 2nd Edition, New York, NY: Springer, 2006.

[2] J .C. Trepanier, H. F. Needham, J. B. Elsner and T. H. Jagger , "Combining Surge and Wind Risk from Hurricanes Using a Copula Model," *The Professional Geographer*, 67(1),pp.52–61,2015.

[3] S. Madadgar and H. Moradkhani (2011, Oct). "Drought Analysis under Climate Change Using Copula", *Journal of Hydrologic Engineering,* vol.18, pp.746-759, July 2013.

[4] G. Salvadori and C. De Michele, "On the use of copulas in hydrology: theory and practice," *Journal of Hydrologic Engineering*, ASCEI2 (4), pp. 369-380, 2007.

[5] Department of Meteorology Sri Lanka. (2016, June.26). Climate of Sri Lanka