Journal of Wind Engineering
and Industrial Aerodynamics 96 (2008) 78–82

JOURNAL OF wind engineering AND industrial aerodynamics

www.elsevier.com/locate/jweia

Short note

Extreme value frequency analysis of wind data from Isfahan, Iran

M.R. Rajabi, R. Modarres*

Faculty of Natural Resources, Isfahan University of Technology, Isfahan, Iran

Received 16 July 2006; received in revised form 9 November 2006; accepted 21 March 2007
Available online 4 May 2007

Abstract

Estimating maximum wind speed is an essential task in many fields of environmental and engineering risk analysis. This study used prevalent westerly annual maximum wind speeds for the period of 1983–1998 for East Isfahan station in Isfahan Province, Iran. The frequency analysis of AM data wind speeds obtained by averaging the wind data over some chosen averaging periods showed that extreme value Type I distribution is the best distribution for 15, 30, 60 and 120 min wind durations. The frequency and average corresponding duration were then plotted. This plot gives the average wind duration and speed for any given return period.

Keywords: Wind speed; Frequency analysis; Wind duration; Extreme value distribution

1. Introduction

Extreme wind speed frequency estimation is usually important in many fields of environmental studies such as climatology, hydrology, developing wind energy facilities, agricultural management and structure designing (Lopez, 1998; Gomes et al., 2003). Many investigators have tried to fit different frequency distributions to wind data. The families of extreme value distributions are also good candidates for extreme wind frequency analysis (Rohan and Dale, 1987). Celik (2003) used Weibull distribution to estimate wind energy output of large- and small-scale turbines. Recently, Pandey et al. (2003) fitted Generalized

*Corresponding author.
E-mail address: r_m5005@yahoo.com (R. Modarres).

0167-6105/$ - see front matter
doi:10.1016/j.jweia.2007.03.005

Pareto distribution to peak-over-threshold extreme wind speed through bootstrapping. Holmes and Moriarty (1999) also suggested generalized Pareto distribution to fit to extreme wind speed in Australia. This study aims to find the best frequency distribution to the annual maximum wind speed of Isfahan station in Central Iran and merging wind speed and duration with wind frequency.

2. Methodology

2.1. Wind speed duration

The recorded graph at each station contains monthly graphs that show wind speed and duration. To extract wind intensity (speed) duration from these graphs, one has to use especial rulers that have the same width of 32 mm as the wind graphs. The smallest extractable duration on these graphs is 1 h. Because we have to derive durations smaller than 1 h (for example 30 and 15 min) for practical reasons, we used simple rulers to derive smaller wind durations from wind graphs. As the wind speeds are recorded at 2 m level, we convert 2 m wind speeds to standard 10 m speeds.

2.2. Wind frequency distributions

After deriving wind speed duration in the first step in a period of time, frequency analysis is applied to estimate desired wind speed quantiles (return periods). As we are trying to find the best distribution for extreme wind speeds, we use the family of extreme value distributions (An and Pandy, 2005). The generalized extreme value (GEV) distribution is written as follows:

$$F(x) = \exp\left\{-\exp[-(x-u)/\alpha]^{1/k}\right\}, \quad (1)$$

where x is the random variable, u, α and k are respectively, location, scale and shape parameters that should be estimated from sample. If $k = 0$, the Eq. (2) reduces to extreme value Type I (Gumbel) distribution, if $k>0$, the equation becomes extreme value Type III or Weibull distribution and if $k<0$, it is extreme value Type II. Extreme value Type I (Gumbel) distribution is written as follows:

$$F(x) = \exp\{-\exp[-(x-u)/\alpha]\}, \quad (2)$$

where α, β and γ are distribution parameters which should be estimated from sample.

The methods of parameter estimation for each distribution are also discussed in details in Rao and Hamed (2000). In this study, we apply the method of moments and maximum likelihood to estimate distribution parameters and quantiles. The root mean square error is then used to select the appropriate distribution.

3. Results

3.1. Preliminary processing of data

It would be reasonable to check the data for randomness, outliers, homogeneity and independency. A number of non-parametric tests were applied, such as Run Test for randomness, Grubbs and Beck test for outliers, Wald–Wolfowitz test for independent and Mann–Whitney U test for homogeneity. The annual maximum wind speed time series passed all the above tests successfully in 95% significant level.

3.2. Frequency analysis

In this study, we apply GEV distribution using FREQ program in the software package MATLAB (1999) developed by Rao and Hamed (2000). Among extreme values distributions, extreme value Type I or Gumbel distribution was considered to perform wind annual maximum speeds distribution better than the others.

Based on fitting Gumbel distribution to the annual wind speed with different durations, the wind quantile for 15, 30, 60 and 120 min wind duration were estimated using method of maximum likelihood. The probability plot for each wind duration is presented in Fig. 1 using Gringorten plotting position formula, $T = N + 0.12/m - 0.44$, suggested by Cook (2004) and Goel et al. (2004), where N is the number of observation, m is the rank of ith observation with the return period T.

In Fig. 1, it is obvious that no wind speed of higher return periods that 20 year has occurred in the available period of time and most of the observations fall within 2–10 year return periods ($0.1 \leqslant p \leqslant 0.5$) suggested that hazardous wind events

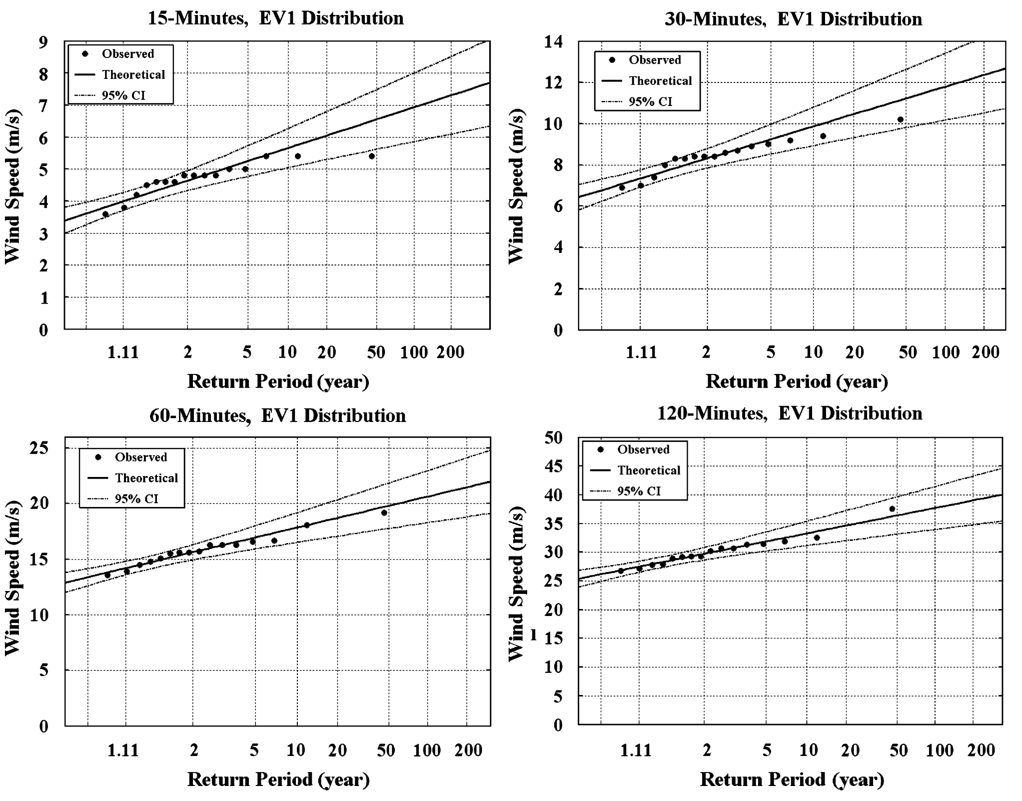

Fig. 1. Probability plots of selected distributions of annual maximum wind speed for different durations.

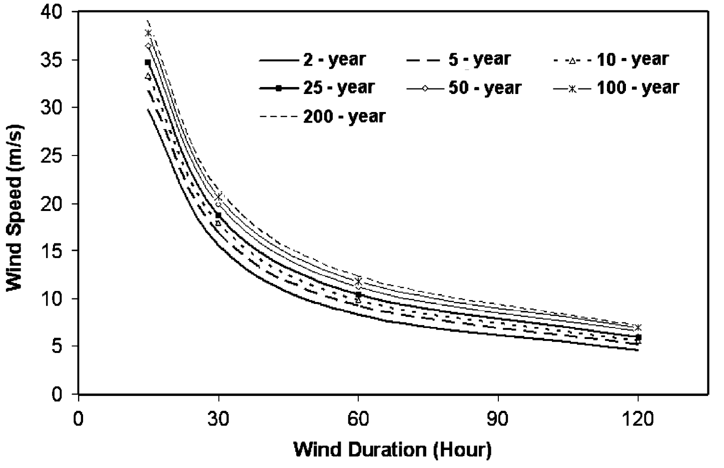

Fig. 2. Wind intensity duration frequency curves for west direction winds of East Isfahan station.

with low probability (high-return periods of 50–100) have rarely happened in the region.

Using the results of frequency analysis, the quantiles were then plotted against average wind duration. This plot is presented in Fig. 2. As the figure shows, for various return periods, the wind speed decreases as the wind duration increases, which indicates that winds with high speeds have usually short duration. In contrast, the long-duration winds usually have low speeds.

4. Conclusion

In this study, GEV distribution was fitted to annual maximum wind speed and extreme value Type I distribution or Gumbel distribution, with $k = 0$, was found to fit to data series better than other GEV distribution. Plotting the predicted wind speed quantiles at different return periods against averaging wind duration give a plot that can be used to estimate wind speed at different durations and return periods. This will help the planners and designers to derive desire wind speed and duration for any return period, or risk of occurrence, extreme wind speed that is not available in short record of observed wind data. It is also suggested that we have to find the wind speed, duration and frequency for peak over threshed (POT) data as they are usually needed in wind-related studies.

Acknowledgment

The authors gratefully acknowledge Prof. Khaled Hamed from Cairo University for providing computer program used for frequency analysis.

References

An, Y., Pandy, M.D., 2005. A comparison of methods of extreme wind speed estimation. J. Wind Eng. Ind. Aerodyn. 93, 535–545.

Celik, A.N., 2003. Energy output estimation for small-scale wind power generators using Weibull-representative wind data. J. Wind Eng. Ind. Aerodyn. 91, 693–707.

Cook, N.J., 2004. Confidence limits for extreme wind speeds in mixed climates. J. Wind Eng. Ind. Aerodyn. 92, 41–51.

Goel, N.K., Burn, D.H., Pandey, M.D., An, Y., 2004. Wind quantile estimation using a pooled frequency analysis approach. J. Wind Eng. Ind. Aerodyn. 92, 509–528.

Gomes, L., Arrue, J.L., Lopez, M.V., Sterk, G., Richard, D., Gracia, R., Sabre, M., Gaudichet, A., Frangi, J.P., 2003. Wind erosion in a semiarid agricultural area of Spain: the WELSONS project catena. Catena 52, 235–256.

Holmes, J.D., Moriarty, W.W., 1999. Application of the generalized Pareto distribution to extreme value analysis in wind engineering. J. Wind Eng. Ind. Aerodyn. 83, 1–10.

Lopez, M.V., 1998. Wind erosion in agricultural soils: an example of limited supply of particles available for erosion. Catena 33, 17–28.

MATLAB, 1999. Version 5.3.1.29215a (R11.1), The MathWorks, Inc., Computer Software.

Pandey, M.D., Van Gelder, A.J.M., Vrijling, J.K., 2003. Bootstrap simulations for evaluating the uncertainty associated with peaks-over-threshold estimates of extreme wind velocity. Environmetrics 14, 27–43.

Rao, A.R., Hamed, K.H., 2000. Flood Frequency Analysis. CRC Press, Boca Raton, FL.

Rohan, D.C., Dale, A.G., 1987. A simple estimator of the shape factor of two parameter Weibull distribution. J. Appl. Meteorol. 26, 323–325.