Nature Environment and Pollution Technology
An International Quarterly Scientific Journal
p-ISSN: 0972-6268
e-ISSN: 2395-3454
Vol. 18 No. 1 pp.73-80 2019

Original Research Paper
Open Access

Statistical Modelling of 4-hourly Wind Patterns in Calcutta, India

Prashanth Gururaja*, Nittaya McNeil*(**)† and Bright Emmanuel Owusu*(***)
*Department of Mathematics and Computer Science, Faculty of Science and Technology, Prince of Songkla University, Mueang Pattani, 94000, Thailand
**Centre of Excellence in Mathematics, Commission on Higher Education (CHE), Ministry of Education, Ratchathewi, Bangkok, 10400, Thailand
***Department of Information and Communication Technology/Mathematics, Faculty of Science and Technology, Presbyterian University College, Ghana
†Corresponding author: Nittaya McNeil

Nat. Env. & Poll. Tech.
Website: www.neptjournal.com

Received: 05-05-2018
Accepted: 02-08-2018

Key Words:
Wind prevalence
Wind patterns
Logistic and linear regression
Speed and gust

ABSTRACT

The rising energy demands of the world and minimal availability of conservative energy sources have considerably increased the role of non-conventional sources of energy like solar and wind. The modelling of the prevalence of wind speed and trends helps in estimating the energy produced from wind farms. This study uses statistical models to analyse the wind patterns in India. Hourly wind data during 2004-2008 were obtained from the National Renewable Energy Laboratory for the study. A logistic regression model was initially used to investigate 4-hourly wind prevalence and the pattern of wind gust. A linear regression model was then applied to investigate wind speed trends. The 4-hour periods of the day, months, and year factors of wind were used as the independent variables in the statistical analysis. The results showed that wind prevalence was mostly higher between 4 AM to 4 PM within the day (90%). Analysis of the monthly wind prevalence revealed higher percentage between April to June (90%), while higher annual prevalence was revealed in 2007 and 2008 (85%). Wind speed trends (4-hourly periods) was observed to increasing from 4 AM to 4 PM within which the maximum occurred. Monthly wind speed was seen to be increasing from January to April where it attains the maximum (13 ms^{-1}) and reduces it to minimum in November (3 ms^{-1}). Annual mean wind speed has reduced by 4 ms^{-1} between 2004 and 2008.

INTRODUCTION

Wind plays a pivotal role in climate and weather on Earth's surface. The movement of wind on Earth's surface has diverse ranges of magnitudes, different directions and various time intervals from minute to few hours. Wind circulation on the Earth's surface commonly known as wind prevalence describes the motion of wind with internment momentarily rates (Greene et al. 2010). The wind speed intriguing behaviour has a vast impact on global climate and weather conditions (Csavina et al. 2014) nurturing of ecosystems, and human life imbalance (Mitchell 2012). Wind gusts rapid and internment speeds have an enormous influence on climate and weather events (Cheng et al. 2014). In addition, its extreme can cause enormous damages or destruction to human-made structures, devastation to humans and ecosystems, and dangerous situations in aircrafts (Jain et al. 2001, Schindler et al. 2012, Jamaludin et al. 2016). It plays a significant factor in wind characteristics often combined and denoted as wind velocity. Further, six major wind belts, three each in the northern and southern hemisphere, encircle the surface of the Earth. These belts lie from pole to equator namely polar easterlies, westerlies, and trade winds describe the wind pattern on the Earth's surface (Myrl 2012).

The variant behaviours of wind cause a difference in absorption of solar energy among the climate zones of earth and atmospheric circulation by differential heating between equator and poles (Chapin et al. 2002). Therefore, wind with its volatile behaviour can be used productively to harness energy, operate transport and warfare equipment. Thus, statistical analysis of wind characteristics will be beneficial.

In recent decades, many studies have investigated wind patterns over the Earth's surface. A study by Klink (2002) investigated trends and interannual variability of wind speed distributions in Minnesota. The research results showed reducing wind speed trend below the overall mean for most of the stations. However, only few stations showed increasing trends above the overall mean. Nchaba et al. (2016) studied long-term austral summer wind speed trends over southern Africa. The results revealed evidence of a decline in wind speeds, results in deceleration of mid latitude westerly, and Atlantic southeasterly winds with a poleward shift in the subtropical anticyclone. Increasing trends in the annual frequency of summer circulation weather types, and the weakening of the subtropical continental heat. Another study by Klink (1999) studied on trends in mean monthly maximum and minimum surface wind speeds in the coterminous United States, 1961 to 1990. The results showed reducing trends in the maximum and minimum winds observed in spring and summer reduced. The decreasing wind speed occurred in western and southeastern United States may be due to variable topography and high pressure mostly all through the year. However, central and the northeastern United States having gentle topography and are near common storm tracks had the highest maximum and minimum winds. Also, a study by Bett et al. (2013) investigated European wind variability over 140 years. The results revealed strong highly-variable wind in the north-east Atlantic. Also, findings do not show any clear long-term trends in the wind speeds across Europe and the variability between decades is large. However, the year 2010 had the lowest mean wind speed on record for this region. Mohanan et al. (2011) investigated the probability distribution of land surface wind speeds. The results illustrated daytime surface wind speeds to be broadly consistent, whereas night time surface wind speeds are more positively skewed. However, in the mid latitudes, these strongly positive skewnesses are shown to be associated with conditions of strong surface stability and weak lower-tropospheric wind shear. Moreover, research by Troccoli et al. (2012) studied long-term wind speed trends over Australia. The results showed that light winds tend to increase more rapidly than the mean winds, whereas strong winds increase less rapidly than the mean winds. The trends in both light and strong winds vary in line with the mean winds. Chen et al. (2013) investigated wind speed trends over China, quantifying the magnitude and assessing causality. The results exhibited pronounced downward trends especially in the upper percentiles and during spring. The warm and cold Arctic Oscillation and El Niño-Southern Oscillation phases have significant influence on the probability distribution of wind speeds. Thus, internal climate variability is a major source of both interannual and long-term variability.

Reddy et al. (2015) used statistical analysis to estimate wind energy over Gadanki, India from 2007 to 2012 using Weibull, Rayleigh and Gamma parametric methods. They showed that Weibull distribution fitted well. A study by Gupta & Biswas (2010) analysed wind velocity of Silchar (Assam, India) from 2003-2007 by applying Rayleigh's and Weibull methods. The results revealed that average wind velocity in Silchar is about 3.11 kmh^{-1}, which is considerably low. Lakshmanan et al. (2009) studied on the basic wind speed map of India with long-term hourly wind data from 1983-2005 using Gumbel method. The study results showed that certain regions require improvement to higher wind zones from the current benchmark wind zones. They also suggested the need to revised basic wind speed map with upgraded wind speed zones for India. Even though many aspects of wind in India have been analysed, not much has been on the description of wind prevalence rates, wind speed trends and wind gust patterns. The objectives of this study are to describe the wind and wind gust prevalences and analyse the wind speed patterns using statistical models.

MATERIALS AND METHODS

India has nine meteorological stations specified by National Renewable Energy Laboratory (NREL). Hourly wind observations from Calcutta during 2004-2008 were obtained from NREL (https://www.nrel.gov/international/ra_india.html) for the study. This station was selected due to its subtropical climate with moist (rain-bearing) winds and frequent thunderstorms (Mukhopadhyay et al. 2009). The winds can vary from frigid winds, may be related to large storm systems such as Nor'westers and Western disturbances (Reddy 2008). It is also in wind and cyclone zone of very 'high damage risk' (UNDP 2006).

Data were arranged based on the Earth's surface wind direction patterns for Indian subcontinent (Wiegand 2004, Kious & Tilling 1996, IMD 2015). The data, which did not fall under the wind direction for the particular month, were discarded from the study resulting in 38,157 observations during the period of study. The hourly wind occurrence had fluctuations that were smoothened by accumulating data to 4 hour periods, and these were used for the analysis. The measurements recorded for consecutive 4-hourly periods were associated as per the well-known ancient time metrics of Babylon and Egyptian system which can be represented in 4-hourly periods of 6 intervals of a day (Gillings 1972). Moreover, 6 periods of 4 hours each of the day classified into clear time intervals like mid-night, dawn, morning, noon, mid-noon, night (Glickman & Zenk 2000) which is indicated as a period of the day, and other predictors are months and year. Observations on February 29 were discarded to have uniform number of observations for each year and also associated with heuristic 365 day climate data observations, therefore totalling to 9,540 observations for the study.

STATISTICAL METHODS

Logistic regression was initially fitted to model the prevalence of 4-hourly wind. The 4-hourly wind speed less than 0.775 ms^{-1} was kept as the non-occurrence of wind, and at least 0.775 ms^{-1} was considered as the occurrence of wind.

In modelling the prevalence of 4-hourly wind, if p_i is the probability of wind for the *i*th period in the data set, restricted on the variables x_i, then the model takes the form:

$$\ln\left(\frac{p_i}{1-p_i}\right) = \alpha + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_m x_m, \qquad \ldots(1)$$

Where, α is a constant, $\beta_i \ (i = 1, 2, 3, \ldots, m)$ are the slope coefficients of the model and $x_i \ (i = 1, 2, 3, \ldots, m)$ are the predictors and m is the number of predictors. The predictors are the 4-hourly periods, month and year factors.

Model (1) was also used to estimate the prevalence of wind gust. Wind speed of at least 5 ms^{-1} (Geer 1996) was classified as gust occurrence and classified as the non-occurrence of a gust if otherwise. The modelling process of estimating the wind gust occurrence is similar to that of the wind prevalence. The predictors are also the 4-hourly periods, month and year factors. These models were assessed using the receiver operating characteristic (ROC) curve.

The ROC curve is popularly known for determining the capability of prediction a binary outcome (Westin 2001). The ROC curve plots sensitivity against the false positive rate of the 4-hourly wind prevalence.

Multiple regression was then used to describe the trends of wind speed of at least 0.775 ms^{-1}. The model takes the form

$$y_{ijk} = \alpha + \beta_1 x_i + \beta_2 x_j + \beta_3 x_k + \gamma_{t-1}, \qquad \ldots(2)$$

Where, y_{ijk} represents wind speed trends, α is a constant, β's are the regression coefficients, x_i, x_j, x_k is time indicating the predictors 4-hour periods, month and year, γ denotes the regression coefficients of the trimmed lag 1 term and *t*-1 indicates lag 1 period. The goodness of fit of the model was assessed using the coefficient of determination (R-square) and the Q-Q plots.

Further, since the normality assumption was not satisfied as the data were not normally distributed, due to heavy tails; the wind speed values were transformed by square roots, to satisfy the statistical assumption of normality. Subsequently, the wind speed observation anomalies were filtered by removing the auto correlations at lag 1 term (Chatfield 1996). The filtered autocorrelations at lag 1 term were then added to fit linear regression model (Venables & Ripley 2002) that investigated the wind speed trends.

The sum contrasts (Tongkumchum & McNeil 2009) were applied to obtain 95% confidence intervals (CI) to compare the fitted model means with the overall wind means. This contrast gives criteria to classify levels of the factor into three groups, according to whether each relating CI is greater than or equal to, or is less than the overall mean. All analysis was done in R (R Development Core Team 2008)

RESULTS

A logistic regression model was fitted to 4-hourly wind periods for 2004-2008.

The model for the 4-hourly mean of wind prevalence was made of 3 predictors. The first predictor was the 4-hourly period of the day and had 6 factors, the second predictor was the months with 12 factors, and the third factor was the year having 5 factors. There were 24 parameters including the constant term in the model. The parameters were highly significant and influential in the model.

Assessing the goodness of fit of the model by the ROC curve (Fig. 1) revealed an area under ROC curve (AUC) value of 0.75 which show a sound classification of the prevalence and non-occurrence of wind.

The overall accuracy of the classification on the occurrence and non-occurrence of wind was 85% having a true positive rate of 99.7% with a false positive rate of 61.5%.

The plot of confidence intervals illustrates the pattern of wind prevalence percentage for period of the day, month and year and the crude percentage (Fig. 2). The horizontal red line denotes the overall mean of the wind prevalence, which is approximately 70%.

Analysis of the 95% confidence interval plots revealed that the wind prevalence patterns for period of the day were significantly different from the overall mean.

The period from dawn (period 2) to afternoon (period 4) observed high wind prevalence rates with the maximum

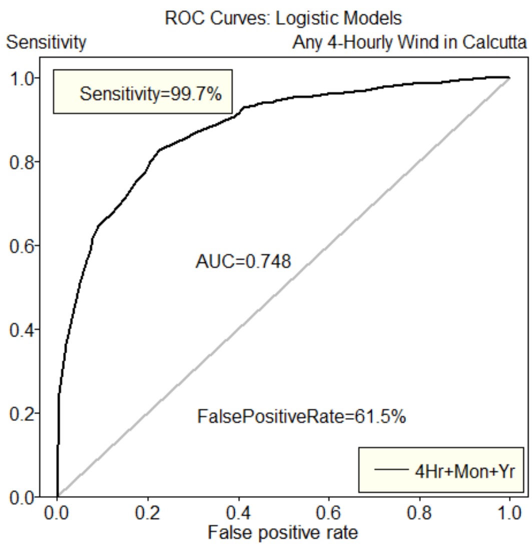

Fig. 1: ROC curve of the logistic model for 4-hour period of wind to investigate the prevalence of wind.

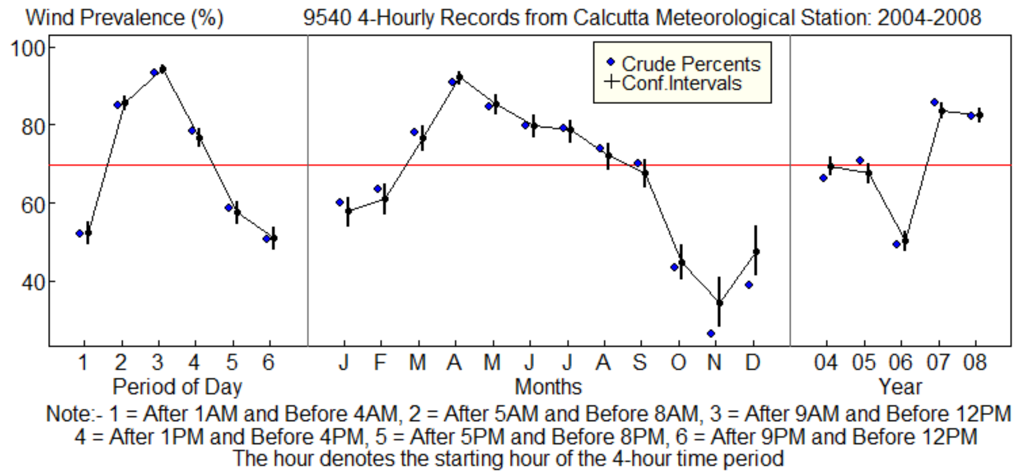

Fig. 2: Logistic model confidence interval plot for percentages of wind prevalence.

prevalence of around 90% observed in noon (period 3). The low wind prevalence rates were observed from midnight to dawn (period 1), evening (period 5) tonight (period 6) with the minimum prevalence of around 50 % in the night (period 6) respectively.

The monthly wind prevalence patterns were observed to have high wind prevalence rates from March to July with maximum wind prevalence of 90% observed in April. Moderate wind prevalence rate was observed during August and September with modest wind prevalence of 70% aligned with the overall mean. Wind prevalence rates were observed to be less than the overall mean during January and February. It increases gradually to attain its maximum (90%) in April, decreases steadily, attain its minimum (30%) in November.

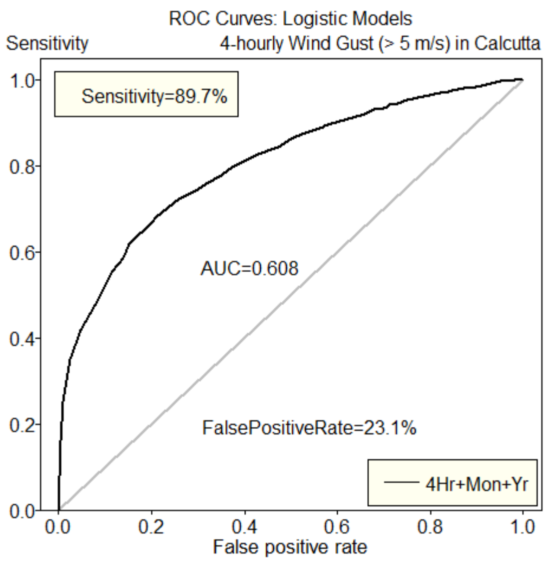

Fig. 3: ROC curve of the logistic regression model for the 4-hourly wind gust prevalence.

The yearly wind prevalence patterns were not significantly different from the overall mean between 2004 and 2005. It reduced considerably to its minimum in 2006 and rose steadily to its maximum in 2007, where it began to reduce slightly. The yearly wind prevalence ranged from 50 to 85% and observed to be higher than the overall mean between 2007 and 2008.

Model (1) was also used to examine the 4-hourly period wind gust prevalence from 2004-2008. The 4-hourly mean wind gust prevalence model was also made of 3 predictors.

Assessing the goodness of fit of the model by the ROC curve (Fig. 3) revealed an area under ROC curve (AUC) value of 0.61 which show classification of the occurrence and non-occurrence of wind. The overall accuracy of the classification on the occurrence and non-occurrence of wind gust was 81.67% having a true positive rate of 89.7% with a false positive rate of 23.7%.

In Fig. 4, the horizontal line denotes the overall mean of the prevalence of wind gusts, which is around 10 % during the study period. The wind gust patterns for period of the day were significantly different from the overall mean. The period from midnight (period 1) to noon (period 3) observed increasing wind gust prevalence rates with the maximum prevalence of around 18% observed in noon (period 3). It then decreases steadily from this period to the night. The minimum wind gust prevalence of 4% occurred in midnight (period 1).

The monthly wind gust patterns revealed increasing pattern from January to April, where the maximum was attained. It was constant between April and decreases steadily until August, where it increased again until September. It then decreases sharply to minimum in November. The wind

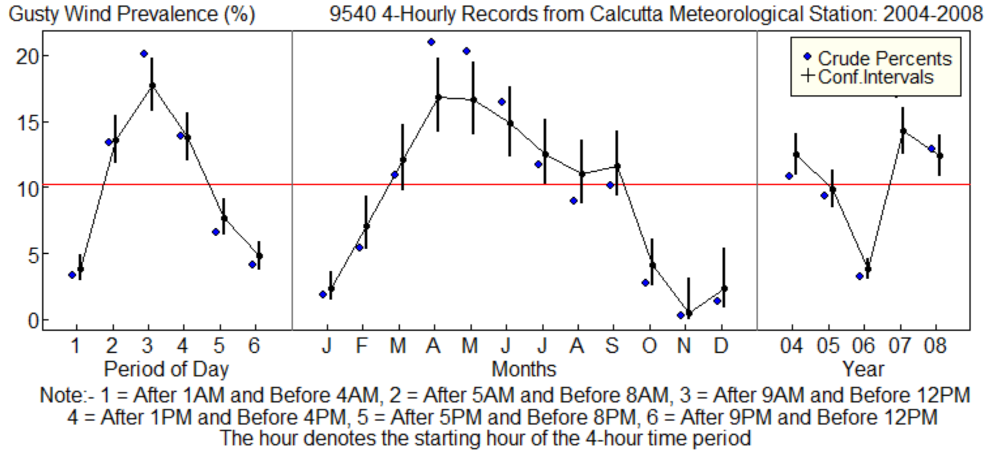

Fig. 4: The 95% confidence interval plot for the percentage of wind gusts using logistic regression.

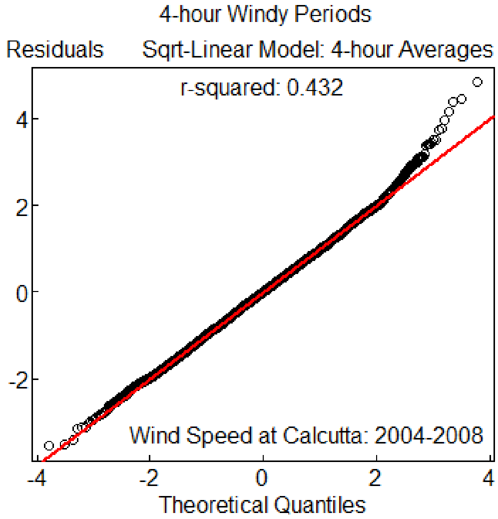

Fig. 5: Q-Q plots for the linear model of the wind speed.

gust prevalence was observed to be mostly above the overall mean between March and September.

The yearly wind gust prevalence revealed decreasing pattern from 2004 to 2006, where it attained the minimum of 4% and increased sharply to its maximum of 14% in 2007. There was a decreasing pattern between 2007 and 2008.

The linear regression model (model 2) was fitted to the 4-hourly wind speed to examine the trends. The model for 4-hourly period wind speed from 2004 -2008 was also made of 3 predictors. There were 25 parameters including the constant and AR(1) terms in the model. Most of the parameters were highly significant and influential in the model. The coefficient of determination (r-squared) and the quantile-quantile plots was used to evaluate the goodness of fit of the model. The r-squared value of 0.432 shows that 43% of the wind speed patterns are explained by the model (2).

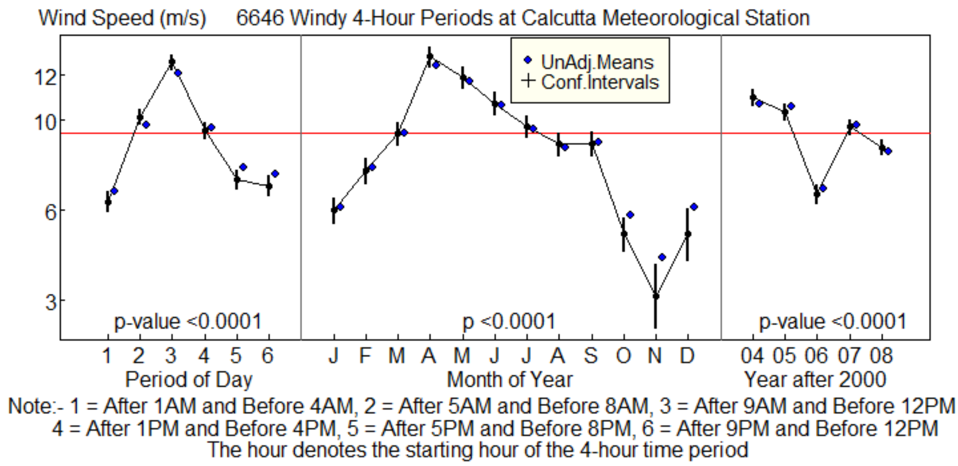

Fig. 6: Linear model confidence interval plot of wind speed trends.

The quantile-quantile (Q-Q) plot illustrates that the residuals from the model are approximately normally distributed (Fig. 5) which shows that the model fitted the data reasonably well. However, there were some deviations from the upper tail of the model. This deviation may be due to extreme values in the data and some variations that could not be explained by the predictors.

Fig. 6, the horizontal line denotes the overall mean of the wind speed is approximately 9 ms^{-1}. The wind speed trends for the period of the day were significantly different from the overall mean. The period during dawn (period 2) to noon (period 3) had the maximum wind speed of around 13 ms^{-1} observed during noon (period 3). Moderate wind speed trend was observed during the afternoon (period 4) with a modest wind speed of approximately 9 ms^{-1} aligning with overall mean. The low wind speed trends were observed during midnight (period 1) to dawn (period 2), evening (period 5) to night (period 6) with a minimum wind speed of around 6 ms^{-1} in midnight (period 1) respectively.

The monthly wind speed trends revealed rising trends during April to June with a maximum wind speed of around 13 ms^{-1} observed during April. Moderate wind speed trend was observed during March and July to September with a modest wind speed of approximately 9 ms^{-1} aligning with overall mean. The low wind speed trends were observed during January to February, and October to December with a minimum wind speed of around 3 ms^{-1} in November. The monthly and yearly wind speed trends revealed values either greater, equal to or lower than the overall mean. The yearly wind speed revealed increasing trends during 2004 and 2005 with a maximum wind speed of around 11 ms^{-1} observed during 2004. Moderate wind speed was observed during 2007 with a modest wind speed of approximately 9 ms^{-1} aligning with overall mean. The reducing trends were observed during 2006 and 2008 with a minimum wind speed of around 7 ms^{-1} in 2006.

CONCLUSION AND DISCUSSION

Statistical models were used to investigate the 4-hourly wind observations of Calcutta, India during 2004-2008. The wind and wind gust prevalence patterns together with the wind speed trends were investigated. The wind prevalence pattern, wind speed trend and wind gust prevalence for the period of the day, month and year illustrated distinct divergent patterns. Logistic regression model fitted wind prevalence and wind gust pattern reasonably well. The overall wind prevalence was observed to be 70% all through the year. The period of the day factors revealed the wind prevalence above the overall mean between period 2 and period 4. This pattern may be due to stronger breeze during early morning to afternoon (Zhong 1992). The observed wind prevalence below the overall mean during the other periods of the day may be due to lighter land breeze during the night (Mandal et al. 2013). The observed monthly maximum wind prevalence of 90% during March and June may be due to the high rates of wind such as breeze, storm during the first and second quarter of the year (Gadgil 2003, Rajeevan et al. 2012). However, the minimum wind prevalence occurred between October and December which may be as a result of the lighter rates of wind blown such as squall on the surface of the Earth (Gadgil 2003, Rajeevan et al. 2012). The yearly wind prevalence was mostly below the overall mean during 2004 to 2006, but above the overall mean between 2007 and 2008 where the maximum occurred (85%). This pattern was partly because of stronger breeze and monsoon winds during the initial period of the decadal period from the year 2000, and lighter and weak monsoon winds from the final period of decade 2000 (Kumar et al. 2006). The results of the 95% confidence interval plot for the wind gust was similar to that of wind prevalence.

Linear regression model revealed an increasing trend for the period of the day factors period 1 to period 3 and decreasing trend between period 3 and period 6. The observed trend may be due to the stronger intensity of sea breeze and prevailing wind during early morning to afternoon and low intensity of land breeze and prevailing wind during the night (Chaudhuri et al. 2013). The monthly wind speed trend showed increasing trend between January and April and reducing trend from April to November. These trends observed partly due to vigorous variation of wind speed near to the surface of the land (Torralba et al. 2017), global warming (Mclnnes et al. 2011) strong monsoon (Loo et al. 2015), and weaker monsoon (Vishnu et al. 2016). The yearly wind speed trend displayed reducing trend between 2004 and 2006 and increasing trend between 2007 and 2008. This observed trends may be due to the effect of global warming and ocean warming on monsoon patterns (Mojgan et al. 2017).

This study has provided a description of wind trends and patterns, which helps in obtaining descriptive and knowledgeable information of wind circulation over Calcutta, India. These trends are vital in the development of wind resources distribution in several areas of India. Future studies on wind could include data on dewpoint, wind chill and heat index along with different statistical methods.

ACKNOWLEDGMENT

The work has been supported by the Higher Education Research Promotion and Thailand's Education Hub for Southern Region of ASEAN Countries Project Office of the Higher

Education Commission under grant no. THE/033. We thank Emeritus Prof. Dr. Don McNeil for supervising this work. Thanks to Centre of Excellence in Mathematics, Commission on Higher Education, Thailand.

REFERENCES

Bett, P.E., Thornton, H.E. and Clark, R.T. 2013. European wind variability over 140 yr. Advances in Science and Research, 10(1): 51-58.

Chapin, F.S., Matson III, P.A. and Mooney, H. 2002. Principles of Terrestrial Ecosystem Ecology. Springer-Verlag, New York, New York, USA.

Chatfield, C. 1996. The Analysis of Time Series. Chapman and Hall: Melbourne.

Chaudhuri, S. and Middey, A. 2013. Nowcasting lightning flash rate and peak wind gusts associated with severe thunderstorms using remotely sensed TRMM-LIS data. International Journal of Remote Sensing, 34(5): 1576-1590.

Chen, L., Li, D. and Pryor, S.C. 2013. Wind speed trends over China: quantifying the magnitude and assessing causality. International Journal of Climatology, 33(11): 2579-2590.

Cheng, C.S., Lopes, E., Fu, C. and Huang, Z. 2014. Possible impacts of climate change on wind gusts under downscaled future climate conditions: Updated for Canada. Journal of Climate, 27(3): 1255-1270.

Csavina, J., Field, J., Félix, O., Corral-Avitia, A.Y., Sáez, A.E. and Betterton, E.A. 2014. Effect of wind speed and relative humidity on atmospheric dust concentrations in semi-arid climates. Science of the Total Environment, 487(1): 82-90.

Gadgil, S. 2003. The Indian monsoon and its variability. Annual Review of Earth and Planetary Sciences, 31: 429-467.

Geer, I.W. 1996. Glossary of Weather and Climate: With Related Oceanic and Hydrologic Terms. Boston, Mass: American Meteorological Society, pp. 272.

Greene, S., Morrissey, M. and Johnson, S.E. 2010. Wind climatology, climate change, and wind energy. Geography Compass, 4(11): 1592-1605.

Gillings, R.J. 1972. Mathematics in the Time of the Pharaohs. Dover Publications Inc, New York, USA.

Glickman, T.S. and Zenk, W. 2000. Glossary of Meteorology. American Meteorological Society, Boston, USA.

Gupta, R. and Biswas, A. 2010. Wind data analysis of Silchar (Assam, India) by Rayleigh's and Weibull methods. Journal of Mechanical Engineering Research, 2(1): 010-024.

IMD 2015. Indian Meteorological Department, Monsoon. Available at http://www.imd.gov.in/pages/monsoon_main.php [February 5, 2017].

Jain, A., Srinivasan, M. and Hart, G.C. 2001. Performance based design extreme wind loads on a tall building. Structural Design of Tall Buildings, 10(1): 9-26.

Jamaludin, A.R., Yusof, F., Kane, I.L. and Norrulasikin, S.M. 2016. A comparative study between conventional ARMA and Fourier ARMA in modeling and forecasting wind speed data. In: Advances in Industrial and Applied Mathematics, Proceedings of 23rd Malaysian National Symposium of Mathematical Sciences (SKSM23), 1750: 60022.

Kious, W.J. and Tilling, R.I. 1996. This Dynamic Earth: The Story of Plate Tectonics. DIANE Publishing, Darby, USA.

Klink, K. 2002. Trends and interannual variability of wind speed distributions in Minnesota. Journal of Climate, 15(22): 3311-3317.

Klink, K. 1999. Trends in mean monthly maximum and minimum surface wind speeds in the coterminous United States, 1961 to 1990. Climate Research, 13(3): 193-205.

Kumar, K.K., Rajagopalan, B., Hoerling, M., Bates, G. and Cane, M. 2006. Unraveling the mystery of Indian monsoon failure during El Niño. Science, 314(5796): 115-119.

Lakshmanan, N., Gomathinayagam, S., Harikrishna, P., Abraham, A. and Ganapathi, S.C. 2009. Basic wind speed map of India with long-term hourly wind data. Current Science, 96(7): 911-922.

Loo, Y.Y., Billa, L. and Singh, A. 2015. Effect of climate change on seasonal monsoon in Asia and its impact on the variability of monsoon rainfall in Southeast Asia. Geoscience Frontiers, 6(6): 817-823.

Mandal, S., Choudhury, B.U., Mondal, M. and Bej, S. 2013. Trend analysis of weather variables in Sagar Island, West Bengal, India: a long-term perspective (1982-2010). Current Science, pp. 947-953.

Mclnnes, K.L., Erwin, T.A. and Bathols. J.M. 2011. Global climate model projected changes in 10 m wind speed and direction due to anthropogenic climate change. Atmospheric Science Letters, 12(4): 325-333.

Mitchell, S.J. 2012. Wind as a natural disturbance agent in forests: a synthesis. Forestry, 86(2): 147-157.

Mojgan, G.M., Mehdi, M.M. and Reza, B.M. 2017. The trend of changes in surface wind in the Indian Ocean, in the period from 1981 to 2015, using reanalysis data, NCEP/NCAR. Open Journal of Marine Science, 7(4): 445-457.

Mohanan, A.H., He, Y., Mcfarlane, N. and Dai, A. 2011. The probability distribution of land surface wind speeds. Journal of Climate, 24(15): 3892-3909.

Mukhopadhyay, P., Mahakur, M. and Singh, H.A. 2009. The interaction of large scale and mesoscale environment leading to formation of intense thunderstorms over Kolkata Part I: Doppler radar and satellite observations. Journal of Earth System Science, 118(5): 441-466.

Myrl, S. 2012. The Earth's Prevailing Wind Belts. Greensboro: Mark Twain Media.

Nchaba, T., Mpholo, M. and Lennard, C. 2016. Long-term austral summer wind speed trends over southern Africa: Austral summer wind speed trends over Southern Africa. International Journal of Climatology, 37(6): 2850-2862.

R Development Core Team 2008. A Language and Environment for Statistical Computing, R Foundation for Statistical Computing, Vienna, Austria.

Rajeevan, M., Unnikrishnan, C.K., Bhate, J., Kumar, K.N. and Sreekala, P.P. 2012. Northeast monsoon over India: variability and prediction. Meteorological Applications, 19(2): 226-236.

Reddy, G.K.K., Reddy, S.V., Sarojamma, B. and Ramkumar, T.K. 2015. Statistical analysis for wind energy estimation over Gadanki, India. Research Journal of Engineering and Technology, 1(2): 30-40.

Reddy, S.J. 2008. Climate Change: Myths and Realities. JCT, Hyderabad, India.

Venables, W.N. and Ripley, B.D. 2002. Modern Applied Statistics with S Fourth edition. Springer.

Tongkumchum, P. and McNeil, D. 2009. Confidence intervals using contrasts for regression model. Songklanakarin Journal of Science and Technology, 31(2): 151-156.

Torralba, V., Doblas-Reyes, F.J. and Gonzalez-Reviriego, N. 2017. Uncertainty in recent near-surface wind speed trends: a global reanalysis intercomparison. Environmental Research Letters, 12(11): 114019.

Troccoli, A., Muller, K., Coppin, P., Davy, R., Russell, C. and Hirsch, A.L. 2012. Long term wind speed trends over Australia. Journal of Climate, 25(1): 170-183.

UNDP 2006. Hazard profile of Indian districts, Available at https://web.archive.org/web/20060519100611/http://www.undp.org.in/dmweb/hazardprofile.pdf [August 23, 2006].

Schindler, D., Bauhus, J. and Mayer, H. 2012. Wind effects on trees. European Journal of Forest Research, 131(1): 159-163.

Vishnu, S., Francis, P.A., Shenoi, S.S.C. and Ramakrishna, S.S.V.S. 2016. On the decreasing trend of the number of monsoon depressions in the Bay of Bengal. Environmental Research Letters, 11(1): 14011.

Westin, L.K. 2001. Receiver operating characteristic (ROC) analysis: evaluating discriminanceeffects among decision support systems. UMINF report, Department of Computer Science, Umea University, Sweden: Available from: https://www8.cs.umu.se/research/reports/2001/018/part1.pdf [December, 08 2017]

Wiegand, P. 2004. Oxford International Student Atlas. Oxford University Press, Chennai, India.

Zhong, S. and Takle, E.S. 1992. An observational study of sea- and land-breeze circulation in an area of complex coastal heating. Journal of Applied Meteorology, 31(12): 1426-1438.