ISSN NO. 2320-5407

Journal homepage: http://www.journalijar.com
Journal DOI: 10.21474/IJAR01

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH

RESEARCH ARTICLE

The inter-relationship between wind direction and wind speed for 5 meteorological stations across Assam, India: A case study.

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Manuscript Info

Manuscript History:

Received: 19 March 2016
Final Accepted: 16 April 2016
Published Online: May 2016

Key words:
Wind direction,
Wind speed,
Circular statistical tools,
Season-wise comparison,
Non-parametric techniques

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Abstract

Several studies have reported that wind direction and speed prevailing at a place plays a significant role in the sediment re-suspension and bacteria deposition in the water bodies located in its vicinity. Through this paper, an attempt has been made to explore the pattern of wind direction and wind speed; the inter-relationships between them in 5 Meteorological stations across Assam, India, selecting one from each zone, using both linear and circular statistical tools. Also, a season-wise comparison of the stations with respect to the wind speed and direction has been carried out using non-parametric techniques. That the wind in Assam, on average, has been found to emanate from north-east direction during both morning and evening and the association between wind speed and direction for winter season is non-significant for all the places, constitute two important findings of the study.

Introduction:-

Wind energy is one of the few natural resources which are pollution-free and economical at the same time. A rapid advance in the wind turbine technology has caused the enhanced usage and dependence on wind power generation. Wind direction and wind speed are two characteristics of the wind the study of whose inter-relationships may give us an insight into the prevailing weather condition at a particular place.

Wind speed describes the rate at which air is moving past a certain point. It is usually reported in knots, miles per hour or meters per second. It deserves mention here that one mile per hour is equal to 0.45 meters per second or 0.87 knots. Wind speed is measured using either a cup or propeller anemometer (Fondriest Environmental Science Library, url: http://www.fondriest.com/science-library/weather/wind, online resource). Wind direction describes the direction on the compass from which the wind emanates. It is typically reported in degrees. Of the many impacts that wind speed and direction have on weather pattern, the most important remains that on surface water, rates of evaporation and formation of storm surges and seiches. Each of these processes, in turn, affects the water quality and water level (Environmental Monitor, url: http://www.fondriest.com/news/wind-speed-and-direction.htm, online resource).

The findings of a study carried out by Smith et al. (1999) on the relationship between wind and the distribution of sewage-associated bacteria, undertaken at Galway city, at a location where the sewage was discharged into the sea adjacent to the mouth of the river Corrib, revealed that wind direction and speed at the time of sampling had a significant influence on the number of E.Coli bacteria detected in any sea-water sample. Krstulovic and Solic (1991) had undertaken a study of water samples containing faecal indicator bacteria which showed to be significantly influenced by dominant winds at the time of sampling. Roslev et al. (2008) had carried out a study in a Danish estuary and the findings revealed that wind from mainly North-East, North, North-West, West and South-West at wind speeds exceeding 6-8 m/s could result in re-suspension of surface sediment at the beach sites. This in turn, affects the water quality and if the quality of bathing water fails to adhere to the bacteria standards, subsequently results in beach closures. All these studies exhibit the influence that wind speed and direction prevailing at the places where water bodies are located, exerts upon the quality of water in them, which is prone to get contaminated by different kind of bacterial sewage.

This paper aims to carry out an extensive and multi-dimensional analysis of the wind direction and wind speed pattern, measured both during the morning and evening, and the inter-relationships between wind direction and wind speed in the five different meteorological stations viz. Dhubri, Dibrugarh (Mohanbari), Guwahati, Silchar and Tezpur, one being selected from each zone, through the use of both linear and circular descriptive statistics and regression tools. Also, a season-wise comparison of the five stations with respect to the wind speed and direction has been carried out to reveal the trend in the wind direction and speed pattern, if any. An understanding of the behavior of wind will help the concerned authorities to maintain quality of water of the water bodies located in the vicinity of each of the study area.

Data Source:-

For attaining the objectives of this study, daily data on wind direction and speed, measured at 08:30 a.m. and 05:30 p.m. for the years 2012 and 2013 have been procured from the Regional Meteorological Center (RMC), Guwahati, Assam, India for the five Meteorological stations viz.- Dhubri/Mohanbari (West Zone); Dibrugarh (East Zone); Guwahati (Central Zone); Silchar (South Zone) and Tezpur (North Zone). These stations have been chosen by taking resort to simple random sampling technique. There are a total of 731 observations of wind speed and direction. The wind direction has been reported in degrees as measured in 16 Compass whereas the wind speed has been reported in Kilometer/hour. A station from each zone has been selected to have an idea about zone-wise prevailing overall wind pattern. The classification of the seasons has been done in accordance with the norms of RMC, Guwahati as given below:

Winter: January-February
Pre-monsoon: March-May
Monsoon: June-September
Post-monsoon: October-December

Material and Methods:-

Rose diagram:-

The wind direction of Assam averaged over the five stations during both morning and evening has been graphically represented using rose diagram. A Rose Diagram is a special type of circular histogram in which the bars corresponding to each group are replaced by sectors (Fisher, 1993). To make the area of each sector proportional to the frequency in the corresponding group, the radius of each sector is usually taken to be proportional to the square root of the relative frequency of that group (Mardia and Jupp, 2000). The interpretation remains the same as in the case of linear histograms.

Circular descriptive statistics:-

Circular variables are the ones which are measured in degrees (converted into radians for suitable analysis) and they are represented in the circumference of a unit circle. Since the value assigned to the variable depends upon the choice of the zero direction and sense of rotation (whether clockwise or anti-clockwise) (Jammalamadaka and Lund, 2006), the techniques of analysis of linear data will produce misleading results if applied to the circular data. We, therefore, need some specialized techniques for working with circular data, what are known as the circular descriptive statistics.

Given a set of n observations on a circular variable θ, say, $\theta_1, \theta_2, \ldots, \theta_n$, the sample mean (Jammalamadaka and Sengupta, 2001) is defined as

$$\bar{\theta}_0 = arctan^* \left(\frac{S}{C}\right)$$

where

$$\bar{\theta}_0 = \begin{cases} arctan\left(\frac{S}{C}\right), & if\ C > 0, S \geq 0; \\ \frac{\pi}{2}, & if\ C = 0, S > 0; \\ arctan\left(\frac{S}{C}\right) + \pi, & if\ C < 0; \\ arctan\left(\frac{S}{C}\right) + 2\pi, & if\ C < 0, S < 0; \\ undefined, & if\ C = 0, S = 0 \end{cases}$$

and

$$S = \sum_{i=1}^{n} \sin\theta_i$$

$$C = \sum_{i=1}^{n} \cos\theta_i$$

The circular variance is defined as $V = 1 - \bar{R}$, where $\bar{R} = \frac{R}{n}$, $R = \sqrt{S^2 + C^2}$ being the resultant length of the set of observations. Since $\bar{R}$ can take any value from 0 to 1, V also lies in the interval $[0,1]$. A value close to 1 indicates high dispersion in the data and that close to 0 indicates high concentration around a given direction. The descriptive statistics for the wind direction are calculated using the above techniques and those for the wind speed are calculated using the usual linear descriptive statistics.

Watson-wheeler test for homogeneity of multiple samples:-

One may often intend to test the homogeneity of multiple samples, with respect to either the mean or variance. Suppose we have q populations and we want to test the null hypothesis:

$$H_0: F_1 = F_2 = \cdots = F_q \text{ against } H_1: F_1, F_2, \ldots, F_q\ are\ not\ all\ same$$

where $F_1, F_2, \ldots, F_q$ are the distribution functions of the q populations. The data in hand will comprise of q independent random samples $\theta_{ij}; j = 1,2, \ldots, n_i,\ i = 1,2, \ldots, q$ of size $n_1, n_2, \ldots, n_q$ respectively. Also, $n = n_1 + n_2 + \cdots + n_q$.

Any test of uniformity corresponds to a q-sample test. In particular, if the test of uniformity is the Rayleigh Test, then Watson-Wheeler test consists in rejecting the null hypothesis for large values of W, (Mardia and Jupp, 2000) where

$$W = 2\sum_{i=1}^{n} \frac{R_i^2}{n_i}$$

R_i being the resultant length of those uniform scores in the combined sample which comes from the i^{th} sample. For large samples,

$$W \sim \chi^2_{2(q-1)}$$

The assessment of the wind direction across the five stations for each season will be done using this test.

Kruskal Wallis rank sum test:-

When the interest lies in assessing the homogeneity of two or more samples, one may refer to the Kruskal Wallis Rank Sum test, which is a non-parametric method for assessing whether two or more independent samples have come from the same distribution (Eurostat, url: https://ec.europa.eu/eurostat/sa-elearning/kruskal-wallis-test, online resource). It is also referred to as the "One-way ANOVA on Ranks". This test does not make any assumption regarding normality of the samples. The test is based on the sum of the ranks of the observations. The test statistic is

$$W = \frac{12}{n(n+1)}\sum_{i=1}^{k} \frac{S_j^2}{n_j} - 3(n+1)$$

where

n_j = number of observations in group j;

$n = \sum_{j=1}^{k} n_{j} =$ total number of observations;

S_j = sum of the rank of the observations from the j^{th} sample within the whole sample of n observations.

Under the null hypothesis of equality of samples,

$$W \sim \chi^2_{k-1}$$

The homogeneity of the wind speed across the five stations for each season will be assessed using this test.

Linear-linear (Karl Pearson's) correlation coefficient:-

For assessing the extent of linear association (or correlation) between two linear variables, we make use of the Karl-Pearson's correlation coefficient (Pearson, 1920). If $(x_1, x_2, \ldots, x_n)$ and $(y_1, y_2, \ldots, y_n)$ are the datasets of size n on the variables X and Y, then the sample Karl Pearson's correlation coefficient is given by

$$r = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 \sum_{i=1}^{n}(y_i - \bar{y})^2}}$$

The value of r lies between -1 and 1. This formula will be used to adjudge the association between the wind speed measured during morning and evening.

Circular-circular correlation coefficient:-

If α and β are two circular variables, then analogous to the linear case, a measure of circular correlation coefficient developed by Jammalamadaka and Sarma (1988) is defined as

$$\rho_c(\alpha, \beta) = \frac{E\{\sin(\alpha - \mu)\sin(\beta - \vartheta)\}}{\sqrt{Var\{\sin(\alpha - \mu)\}Var\{\sin(\beta - \vartheta)\}}}$$

The sample correlation coefficient between two sets of circular variables α and β, viz. $(\alpha_1, \beta_1), (\alpha_2, \beta_2), \ldots, (\alpha_n, \beta_n)$ is given by

$$r_{c,n} = \frac{\sum_{i=1}^{n}\sin(\alpha_i - \bar{\alpha})\sin(\beta_i - \bar{\beta})}{\sqrt{\sum_{i=1}^{n}\sin^2(\alpha_i - \bar{\alpha})\sum_{i=1}^{n}\sin^2(\beta_i - \bar{\beta})}}$$

Where $\bar{\alpha}$ and $\bar{\beta}$ are the sample mean directions. The sample correlation coefficient is an estimate of population correlation coefficient. The quantity $\sqrt{n}(r_{c,n} - \rho_c)$ converges in distribution to $N(0, \sigma^2)$ as n tends to ∞ (Jammalamadaka and Sengupta, 2001), where

$$\sigma^2 = \frac{\lambda_{22}}{\lambda_{20}\lambda_{02}} - \rho_c\left[\frac{\lambda_{13}}{\lambda_{20}\sqrt{\lambda_{20}\lambda_{02}}} + \frac{\lambda_{31}}{\lambda_{02}\sqrt{\lambda_{20}\lambda_{02}}}\right] + \frac{1}{4}\rho_c^2\left[1 + \frac{\lambda_{40}}{\lambda_{40}^2} + \frac{\lambda_{04}}{\lambda_{02}^2} + \frac{\lambda_{22}}{\lambda_{20}\lambda_{02}}\right]$$

and

$$\lambda_{ij} = E\{sin^i(\alpha - \mu)sin^i(\beta - \vartheta)\}; \qquad i, j = 0,1,2,3,4$$

However, this measure of association between two circular random variables is not unique.

The association between wind direction during the morning and evening has been assessed using this measure.

Linear-circular correlation coefficient:-

One might be interested in observing whether there exists any association between a circular and a linear variable. Mardia (1976) and Johnson and Wehrly (1977) had proposed the following measure of correlation between a linear and angular variable, which is defined as the multiple correlation between the linear variable X with the components $(\cos\theta, \sin\theta)$ corresponding to the angular variable θ.

Mathematically,

$$r^2 = \frac{r_{xc}^2 + r_{xs}^2 - 2r_{xc}r_{xs}r_{cs}}{1 - r_{cs}^2}$$

where $r_{xc} = corr(x, \cos\theta), r_{xs} = corr(x, \sin\theta),\ r_{cs} = corr(\cos\theta, \sin\theta)$.

Under the hypothesis that the population measure of correlation is equal to zero, which indicates the absence of a linear relationship between X, $\cos\theta$ and $\sin\theta$, the test statistic is

$$U = \frac{(n-3)r^2}{2(1-r^2)} \sim F_{2,n-3} \qquad (1)$$

If the statistic U as mentioned in equation (1) comes out to be significant, we understand that there is a linear dependence of X on θ. We can then fit the multiple linear regression model given by

$$E(X\,/\,\theta) = a_0 + a\cos\theta + b\sin\theta$$

where the parameters a_0, a and b are estimated using the principle of least squares. The dependence of wind speed upon the wind direction for all the five stations is studied using this measure.

Result and Discussion:-

Descriptive statistics:-

Tables (1) and (2) below enlist the descriptive statistics for the wind speed and direction measured during morning and evening respectively for the 5 meteorological stations:

Table 1: Descriptive statistics of wind direction (in Degrees anticlockwise from East) and wind speed (in Km/hr) measured during morning (08:30 A.M.) for the four seasons for the five different meteorological stations of Assam

Stations	Characteristic	Variable	Seasons			
			Winter	Pre-monsoon	Monsoon	Post-monsoon
Dhubri	Wind direction	Circular Mean	101.66	117.06	121.29	111.23
		Circular Variance	0.27	0.27	0.23	0.13
	Wind speed	Mean	5.93	8.60	6.98	8.11
		Variance	21.03	27.08	15.24	17.41
Dibrugarh	Wind direction	Circular Mean	41.18	34.83	42.88	37.17
		Circular Variance	0.34	0.34	0.50	0.25
	Wind speed	Mean	8.13	9.49	8.85	8.69
		Variance	4.08	7.97	6.11	6.53
Guwahati	Wind direction	Circular Mean	41.13	42.91	39.22	43.25
		Circular Variance	0.70	0.42	0.62	0.52
	Wind speed	Mean	6.27	9.45	8.06	7.61
		Variance	6.45	14.54	10.00	6.24
Silchar	Wind direction	Circular Mean	85.95	86.08	80.41	80.02
		Circular Variance	0.16	0.36	0.26	0.19
	Wind speed	Mean	3.61	5.39	5.69	5.48
		Variance	4.37	12.59	5.95	4.93
Tezpur	Wind direction	Circular Mean	16.90	25.78	-79.18	4.21
		Circular Variance	0.54	0.36	0.90	0.27
	Wind speed	Mean	3.48	4.39	0.90	0.27
		Variance	2.06	5.03	4.14	3.61

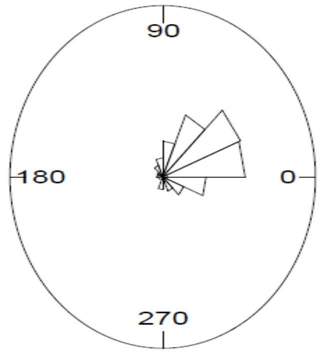
Table 2: Descriptive statistics of wind direction (in Degrees anticlockwise from East) and wind speed (in Km/hr) measured during evening (05:30 P.M.) for the four seasons for the five different meteorological stations of Assam

Stations	Characteristic	Variable	Seasons			
			Winter	Pre-monsoon	Monsoon	Post-monsoon
Dhubri	Wind direction	Circular Mean	99.37	115.50	126.01	118.52
		Circular Variance	0.33	0.48	0.32	0.31
	Wind speed	Mean	6.29	7.93	7.63	7.1
		Variance	8.49	17.64	17.76	32.69
Dibrugarh	Wind direction	Circular Mean	25.98	23.14	22.16	40.96
		Circular Variance	0.39	0.46	0.46	0.24
	Wind speed	Mean	8.73	10.68	8.84	8.63
		Variance	10.02	130.02	6.97	5.92
Guwahati	Wind direction	Circular Mean	65.33	20.13	-105.55	123.76
		Circular Variance	0.91	0.58	0.88	0.89
	Wind speed	Mean	6.07	9.20	8.54	6.59
		Variance	7.57	14.42	12.00	6.94
Silchar	Wind direction	Circular Mean	91.81	99.67	79.44	180
		Circular Variance	13.88	0.45	0.93	1
	Wind speed	Mean	4.55	6.41	8.13	4
		Variance	13.88	11.92	16.03	0
Tezpur	Wind direction	Circular Mean	17.54	31.81	152.58	13.82
		Circular Variance	0.43	0.41	0.89	0.43
	Wind speed	Mean	3.57	4.36	4.51	4.57
		Variance	1.82	3.02	3.43	5.39

Tables (1) and (2) show that except for Guwahati, the wind direction during both morning and evening seem to be the same on average for all the four seasons. A careful observation reveals that in Guwahati and hence, the central part of Assam, of which it is a representative, there is a shift in the pattern of wind flow from North-east direction in the morning to no specific direction in the evening. This indicates the occurrence of some atmospheric phenomenon which might be caus- ing this shift. During the evening, except for Dhubri and Dibrugarh stations, the average wind direction vary drastically across the four seasons while during the morning, for all the stations, it remains the same approximately. This indicates that possibly, there is no season-wise variation in the average wind direction during the morning. But the same cannot be concluded for the wind direction during the evening. The average wind speed, both during the morning and evening, is the highest for Dibrugarh station located in the East and lowest for Tezpur station located in the North of Assam. During the morning, for Guwahati-Winter season, Silchar-Monsoon season and Tezpur-Monsoon season, the mean and variance of the wind speed data are approximately the same. Thus, there is a fair amount of chance that the wind speed frequency distribution for these cases can be fitted well by the Gamma distribution. For Dibrugarh station, pre-monsoon season, the wind speed data during the evening is abnormally highly dispersed whereas the dispersion is zero for Silchar, Post-monsoon season. This points out to the interesting observation that the wind speed for all the days of this season had remained the same viz. 4 Km/hr. Furthermore, no general idea about any association between wind direction and wind speed can be derived from the tables. The linear-circular correlation between wind direction and wind speed will reveal the relationship between them, if any. Also, the question whether for each of the season, the average wind direction and average wind speed vary with respect to the stations, will be ad- dressed using the multi-sample non-parametric circular test and non-parametric Kruskal-Wallis Rank Sum Test respectively.

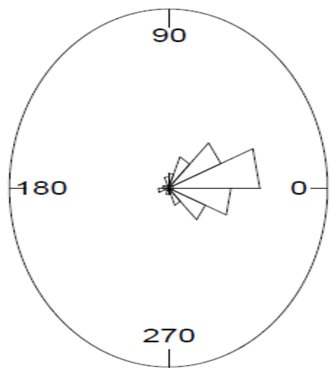
Rose diagrams:-

The rose diagrams of the average wind direction during morning and evening are displayed in the figures (1) and (2) respectively as shown below:



Note: Direction in 16 compass (in degree), i.e. 0 (360) → North, 90 → East, 180 → South, 270 → West.

Figure 1: Rose diagram of the daily wind direction measured during the morning, averaged over all the five stations



Note: Direction in 16 compass (in degree), i.e. 0 (360) → North, 90 → East, 180 → South, 270 → West.

Figure 2: Rose diagram of the daily wind direction measured during the evening, averaged over all the five stations

We observe from the above two figures that in Assam, on average, wind emanates from the North-east and the North North-east direction during the morning whereas during the evening, it emanates from North North-east direction. This shows the dominance of the North-east direction of wind flow in Assam.

Watson-wheeler multiple sample test to test the season-wise homogeneity of the different stations w.r.t the wind direction

For each season, for both morning and evening, we may frame our null hypothesis to be:
H_0: There is no significant difference amongst the stations with respect to the wind direction
The test statistic and *p*-value for each season is listed in Table (3) below:

Table 3: Watson-Wheeler Multiple Sample test statistic and *p*-value for each season, for both morning and evening

Season	**Time**	**Test statistic**	***p*-value**
Winter	Morning	22.398	0.00
	Evening	35.483	0.00
Pre-monsoon	Morning	46.941	0.00
	Evening	10.328	0.00
Monsoon	Morning	45.032	0.00
	Evening	35.483	0.00
Post-monsoon	Morning	38.591	0.00
	Evening	2.7734	0.00

We see that all the statistics are significant at 5% level of significance. Hence, we reject our null hypotheses for each season and conclude that there is a significant difference amongst the stations with respect to the wind direction, both during morning and evening.

Kruskal-Wallis rank sum test to test the season-wise homogeneity of the different stations with respect to the wind direction:-

For each season, for both morning and evening, we frame our null hypothesis as:

H_0: There is no significant difference amongst the stations with respect to the average wind speed.

The test statistic and *p*-value for each season is listed in table (4) below:

Table 4: Kruskal Wallis Rank Sum test statistic and *p*-value for each season, for both morning and evening

Season	Time	Test statistic	*p*-value
Winter	Morning	92.9542	0.00
	Evening	53.0281	0.00
Pre-monsoon	Morning	182.6323	0.00
	Evening	117.5651	0.00
Monsoon	Morning	171.4807	0.00
	Evening	153.3263	0.00
Post-monsoon	Morning	135.2692	0.00
	Evening	20.4179	0.00

We see that all the statistics are significant at 5% level of significance. Hence, we reject our null hypotheses for each season and conclude that there is a significant difference amongst the stations with respect to the wind speed, both during morning and evening.

Linear-linear correlation and circular-circular correlation:-

Table 5: Linear-linear correlation between wind speeds and circular-circular correlation between wind directions measured during morning and evening for the four seasons for the five different meteorological stations of Assam:

Stations	Characteristic	Variable	Seasons			
			Winter	Pre-monsoon	Monsoon	Post-monsoon
Dhubri	Wind direction	Correlation	0.524	0.827	0.278	-0.355
		p-value	0.00*	0.00*	0.00*	0.00*
	Wind speed	Correlation	0.386	0.339	0.410	0.048
		p-value	0.00*	0.00*	0.00*	0.52
Dibrugarh	Wind direction	Correlation	0.062	-0.297	0.750	0.469
		p-value	0.102	0.00*	0.00*	0.00*
	Wind speed	Correlation	0.474	0.034	0.050	0.123
		p-value	0.00*	0.48	0.43	0.10
Guwahati	Wind direction	Correlation	0.724	-0.308	-0.135	0.281
		p-value	0.00*	0.00*	0.05	0.00*
	Wind speed	Correlation	0.203	0.206	0.262	0.300
		p-value	0.00*	0.00*	0.00*	0.00*
Silchar	Wind direction	Correlation	0.487	0.368	-0.091	-0.542
		p-value	0.00*	0.00*	0.21	0.00*
	Wind speed	Correlation	0.033	0.122	0.037	Not available
		p-value	0.72	0.10	0.56	-
Tezpur	Wind direction	Correlation	0.225	0.258	0.182	0.353
		p-value	0.00*	0.00*	0.00*	0.00*
	Wind speed	Correlation	0.314	0.366	0.234	0.069
		p-value	0.00*	0.00*	0.00*	0.35

Note: * indicates that the *p*-value is significant at 5% level of significance

From the above table, we observe that during the post-monsoon season, for all the stations except Guwahati, the wind directions are coming out to be significantly correlated whereas the wind speeds are not. Some of the correlations between wind directions are found to be negative, indicating that a increase in wind direction during morning corresponds to a decrease in wind direction during evening for those cases. All the correlations between the wind speeds are found to be positive, indicating that increase in wind speed during morning corresponds to a increase in wind speed during evening. For half of the cases, a significant correlation between wind directions corresponds to a significant correlation between wind speeds. For the other half, it does not. Thus, we get no idea about the general pattern of association between wind direction and wind speed of the study areas, as indicated by the descriptive statistics.

Linear-circular correlation and regression:-

Table (6) shows the linear-circular correlation between the wind speed-direction for the five meteorological stations for all the four seasons:

Table 6: Linear-circular correlation between wind speed and wind direction measured during morning (08:30 A.M.) and evening (05:30 P.M.) for the four seasons of the five different meteorological stations of Assam

Stations	Characteristic	Variable	Seasons			
			Winter	**Pre-monsoon**	**Monsoon**	**Post-monsoon**
Dhubri	Morning	r^2	0.07	0.11	0.07*	0.12
		p-value	0.154	0.00*	0.00*	0.00*
	Evening	r^2	0.68	0.01	0.10	0.12
		p-value	0.104	0.802	0.014*	0.319
Dibrugarh	Morning	r^2	0.03	0.001	0.05	0.10
		p-value	0.506	0.926	0.017*	0.00*
	Evening	r^2	0.14	0.025	0.08	0.21
		p-value	0.242	0.290	0.00*	0.156
Guwahati	Morning	r^2	0.02	0.05	0.09	0.03
		p-value	0.648	0.036*	0.00*	0.475
	Evening	r^2	0.007	0.014	0.002	0.02
		p-value	0.826	0.353	0.813	0.669
Silchar	Morning	r^2	0.06	0.07	0.024	0.009
		p-value	0.166	0.026*	0.344	0.733
	Evening	r^2	0.21	0.03	0.40	Not available
		p-value	0.104	0.439	0.00*	-
Tezpur	Morning	r^2	0.09	0.102	0.03	0.006
		p-value	0.271	0.00*	0.286	0.789
	Evening	r^2	0.03	0.02	0.05	0.441
		p-value	0.825	0.623	0.430	0.234

Note: * indicates that the *p*-value is significant at 5% level of significance

For the cases for which the multiple correlation coefficients have come out to be significant, we fit multiple linear regression models to them.

Table (7) lists the multiple regression model diagnostics for the significant cases and the *p*-values for the test of significance of the estimated regression coefficients:

Table 7: Multiple regression diagnostics

Stations	Season	Time	Regression diagnostics			
			Coefficients	**Value**	**Standard Error**	***p*-value**
Dhubri	Pre-monsoon	Morning	Intercept	5.9904	0.7771	0.000*
			cos θ	-2.8396	0.9762	0.004*
			sin θ	2.5592	0.8215	0.002*
	Monsoon	Morning	Intercept	4.7500	0.7366	0.000*
			cos θ	-1.6545	0.7598	0.031*
			sin θ	2.3798	0.7250	0.001*
		Evening	Intercept	5.6219	0.9863	0.000*
			cos θ	-1.7549	1.4232	0.221
			sin θ	2.3957	0.8073	0.004*
	Post-monsoon	Morning	Intercept	4.637	1.285	0.000*
			cos θ	-3.820	0.975	0.000*
			sin θ	2.783	1.339	0.040*
Dibrugarh	Monsoon	Morning	Intercept	8.6045	0.2417	0.000*
			cos θ	0.9625	0.3474	0.006*
			sin θ	-0.3610	0.2912	0.217
		Evening	Intercept	8.3246	0.2726	0.000*
			cos θ	0.6523	0.3806	0.089
			sin θ	0.9363	0.3127	0.003*
	Post-monsoon	Morning	Intercept	7.4674	0.5208	0.000*
			cos θ	1.1347	0.7057	0.111
			sin θ	1.1998	0.4391	0.007*
Guwahati	Pre-monsoon	Morning	Intercept	8.6667	0.4370	0.000*
			cos θ	0.9466	0.5815	0.106
			sin θ	0.9328	0.5869	0.114
	Monsoon	Morning	Intercept	7.6132	0.2756	0.000*
			cos θ	0.6833	0.4238	0.109
			sin θ	1.0216	0.3846	0.009*
Silchar	Pre-monsoon	Morning	Intercept	6.2035	0.4714	0.000*
			cos θ	0.6985	0.7759	0.370
			sin θ	-1.3353	0.5203	0.011*
	Monsoon	Evening	Intercept	8.2816	0.4735	0.000*
			cos θ	2.1808	1.6976	0.206
			sin θ	-2.6752	0.4993	0.000*
Tezpur	Pre-monsoon	Morning	Intercept	4.5553	0.3363	0.000*
			cos θ	-0.8674	0.4555	0.060
			sin θ	1.1843	0.3819	0.003*

Note: * indicates that the *p*-value is significant at 5% level of significance

Figures (3) and (4) depict the regression models fitted to the above data, where X represents the response, C represents the $\cos\theta$-axis and S represents the $\sin\theta$-axis:

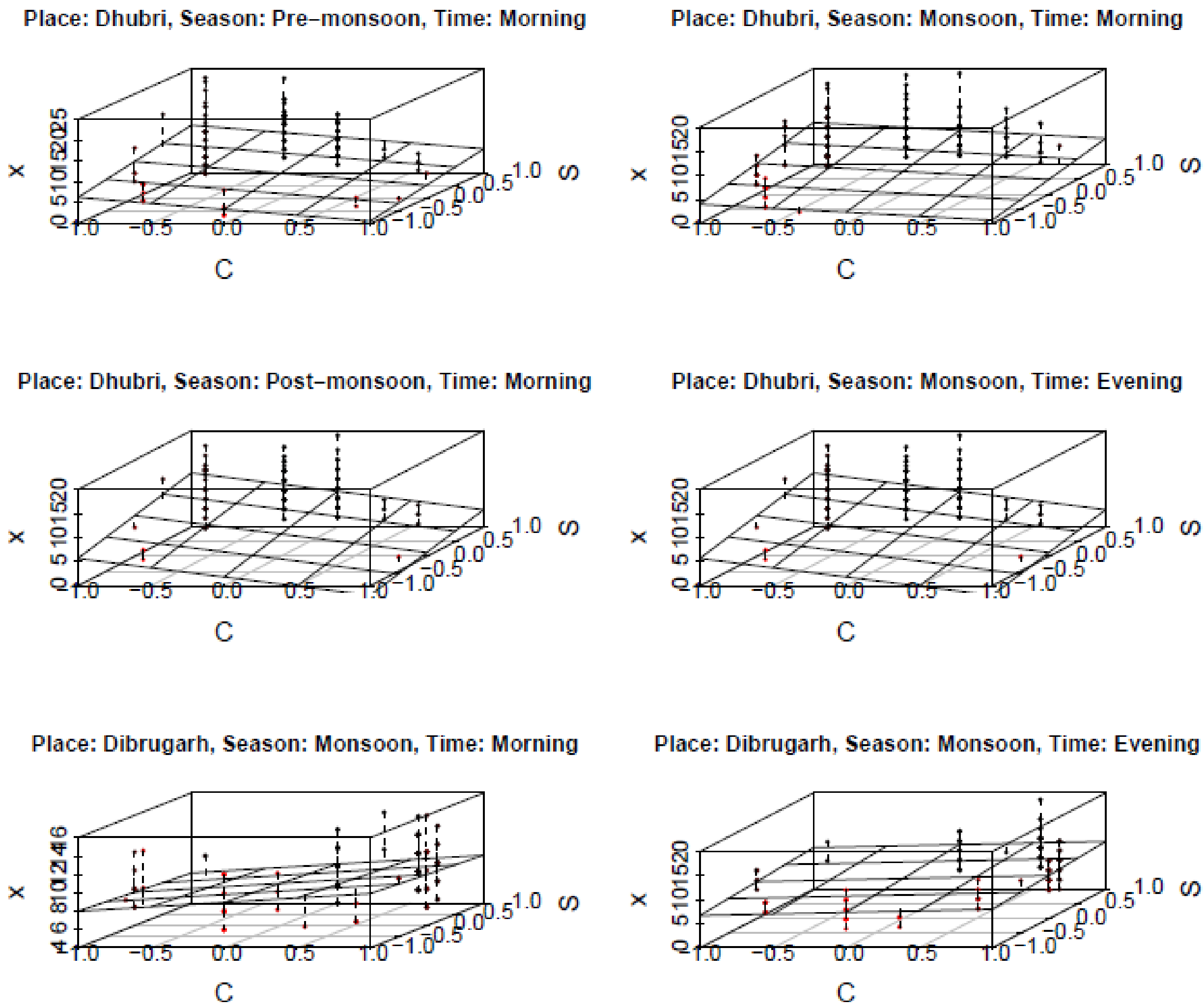


Figure 3: Fitted multiple linear regression models

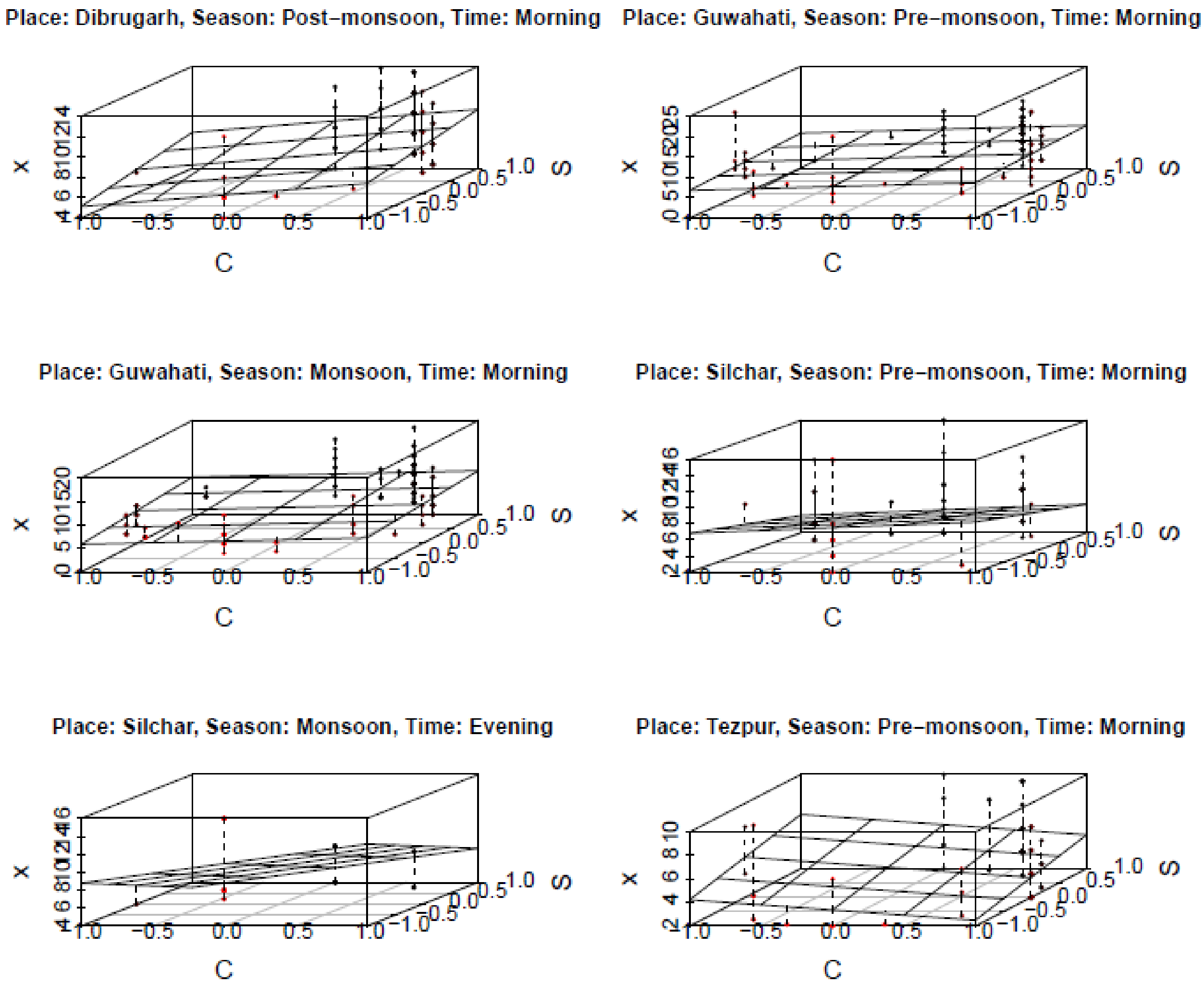


Figure 4: Fitted multiple linear regression models

From the first subfigure in figure 3, corresponding to Dhubri, pre-monsoon season (morning), it is clear that X is negatively associated with the component $\cos\theta$ whereas it is positively associated with the component $\sin\theta$ as the plane is positively inclined towards the $\sin\theta$-axis and negatively inclined towards the $\cos\theta$-axis. The other sub-figures under 3 and 4 can similarly be interpreted.

Conclusion:-

The study aims to analyse the pattern of wind direction and speed measured during both morning and evening and its various inter-relationships for the five meteorological stations of Assam viz. Dhubri, Dibrugarh, Guwahati, Silchar and Tezpur. The central part of Assam represented by Guwahati experiences a shift in the wind direction pattern from morning to evening. The study revealed that in Assam, on average, the wind direction emanates from north-east direction during both morning and evening. Although the mean wind direction during morning does not vary across seasons for each place, the Watson-Wheeler test has shown the places to significantly vary for every season, during both morning and evening with respect to the wind direction. The wind speed on average varies across the places for different seasons during both morning and evening. The wind speed during morning and evening for the places located in the north-western part of Assam is found to be significantly positively correlated. The association between wind speed and direction is found to be positive for all the places for post-monsoon season and for winter, they are found to be non-significant. The places (and seasons) for which there is a significant association between wind speed and direction, there is a chance of sediment re-suspension and increase in various kinds of bacteria as indicated by the studies carried out by Krstulovic and Solic (1991), Smith et al. (1999) and

Roslev et al. (2008). An analysis of water quality of the water bodies located in the vicinity of these stations with reference to the wind direction and speed may form a possible future scope of the present study.

Acknowledgement:-

The authors would like to thank the Department of Science and Technology (DST), New Delhi, India for providing financial assistance through Innovation in Science Pursuit for Inspired Research (INSPIRE) programme to Miss Sahana Bhattacharjee in the Department of Statistics, Gauhati University, Guwahati, India.

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