Spatial and Temporal Wind Speed Variability: Case Study of Wolaita Sodo and Areka Area, Ethiopia

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Abstract
Study was conducted to assess spatial variability of wind speed for two sites (Areka and Sodo) and short- term wind speed variability for Areka site. The required wind speed data was obtained from Areka agricultural research center Meteorology station and Hawassa Meteorological Service Agency (AMSA.The collected data was analyzed by using MATLAB software. The five months primary data measured during day time at one hour interval was from Areka station for short-term temporal wind speed variability, as a result, short – term wind speed data indicates that increased pressure gradient causes greater wind speeds in the afternoons compared to early morning hours and evenings. Only during the early morning hours and evening, the wind speeds were less than average value and the deviations were lower than the remaining time. For spatial variability, five year wind speed data were obtained for Areka and Sodo sites and the two were compared. The data were analyzed using statistical analyses. Comparison of daytime measurement of five data points with 12 data points gave identical average wind speed distribution. Accordingly, when it comes to the statistical averaging there is no significant difference between the two since the two values were within statistical error from each other. Therefore; it is fair to assume there is no difference between the two. No significant spatial variability was obtained between Dubbo and Sodo sites. The study revealed that the areas have no abundant wind potential to produce energy. This is partly attributed to the level at which wind speed measurement was taken, 2 m, instead of the recommended 10 m height. Therefore, these particular sites are not ideal for grid connected applications.
Keywords: Wind speed, Wind data, and pressure gradien

INTRODUCTION

1.1 Background

Energy is one of the most significant elements for existence of life in the universe. Sun is the ultimate source of energy without which there could be no life on this planet. Energy can be harnessed into human usable form from various sources such as solar radiation, wind water nuclear reaction and many more. History tells us that economic prosperity of countries is highly dependent on the level of generation and utilization of energy. It is a pillar of economic growth.

Today the field of renewable energy is becoming one of the most preferable issues by many researchers with the main objective of exploiting abundant sources of energy effectively and efficiently in such a way that their use would cause no pollution to the environment and depletion of resources. Power generation from renewable resources especially from solar, wind, hydropower and biomass are expected to be much more important fields of study for the future for smooth transition from fossil fuels to other sustainable energy sources.

The journey to sustainable path of power generation would be successful if both developed as well as developing nations put emphasis on renewable energy resources like wind energy. Wind energy currently plays an important role in the energy supply in many areas of the world. Within the last 12 years, wind turbine technology has reached a very reliable and sophisticated level (Ackermann and Lennart, 2002).

Wind speed generally decreases as one moves from higher latitudes towards the equator. The energy transported to a higher altitude gets stronger as the latitude increases (i.e., as the area decreases flow of energy density increases). However, the local effects might be quite important. The presence of geographic structures such mountains and valleys have the tendency to curtail wind flow, create turbulence, and decrease wind speed. Flat lands and coastal areas on the other hand have elevated wind speeds.

Ethiopia being located near the equator, has limited wind resource potential. There are few promising windy areas in Ethiopia located alongside the Main East African Rift Valley, the north eastern escarpment of the country near Tigray regional state, and the eastern part of the country (near north east of the Somali Regional State).

1.2 Statement of the Problem

Measurements of wind speeds are usually made at long intervals (five times per day) due to various problems. The values obtained may not accurately represent actual wind speed distribution with respect to time. Hence, more information is required to link this average value read by meteorologists with the actual measurements made at shorter time intervals. There were limited wind speeds measuring stations in the country. This means, not all places that need wind turbine installation have wind speed data. Nearby stations have to be used in order to estimate the sutability of the area for wind power generator. However, the appropriateness of using such nearby station is not tested.

1.3 Objective of the Study

The general objective of this research was to study spatial and temporal variability of wind speed at Sodo and Areka area.

1.3.1 Specific objectives

1. To determine the variability of wind speed
2. To assess similarities/differences of wind speeds of two nearby stations (Areka and Sodo).

2. MATERIALS AND METHODS

2.1 Description of the Study Site

Wolaita zone, which covers an area of 4471.3 km^{2,} is one of the 13 zones and 8 special W*oreda* in South Nations Nationalities and Peoples Region (SNNPR) and situated 325 km away from Addis Ababa to the south. The geographical location of the Zone is 6.4-7.1^{0}N longitude and 37.4-38.2^{0}E latitude. The zone is classified into three agro-ecological zones, among them large proportion is *Woina-Dega* (middle altitude) which is about 56% of the area; the rest 35% and 9% is described as Kola (low altitude), and *Dega* (high altitude), respectively. The estimated average annual rainfall is 801 to 1600 mm. The rainfall in the Zone is characterized by bimodal distribution pattern and the main rainy season (*Meher*) is between June and end of September and (*Belg)* is from late February to late March/early April. The annual average temperature of the zone is 21.86°C. The altitude of the zone ranges from 501 to 2738 meter above sea level. It has two meteorological stations, Wolaita Sodo and Dubbo Meteorological Centers. (WZARDO, 2012).

This research was conducted in Wolaita zone, Areka area. The area is located 300 km south west of the capital, Addis Ababa along Hosanna road. This site has latitude and longitude of 7^{o}4'N 37^{o}42'E, respectively and an elevation of 1830 meters above sea level.

Sodo site is located at a distance of 35 km on the south east direction of Areka station and has latitude and longitude ranging between 06^o 49'17.6"N and 037^o 44'56.2"E, respectively and altitude of 1854 m.

2.2 Method of Data Gathering

Temporal component of this study was conducted on Areka station. Daily (12 hour) wind speed measurements were taken at intervals of one hour continuously for five months (February to Jun, 2015). Temporal variability of Areka site was selected to determine the variability of wind speed during day times. Wind speed measurements were taken at 2m height.

For the study of spatial variability, one other site (Sodo) was selected. Five year (2010 to 2014) data were used for this purpose. The data for Areka was taken from Areka Agricultural Research Center and that of Sodo was taken from National Meteorological Agency of Hawassa Branch. In this study, all the data that were obtained from the two sites (stations) were used for determining the spatial variability of the wind speeds. Wind speed measurements were taken five times daily at 6:00, 9:00, 12:00, 15:00, and 18:00 hours for five years. Besides being close to one another, the two sites have nearly the same altitude 1830 m and 1854 m. The reason for selection of Sodo site was to compare wind speed at the two locations and to assess if the data of one could be used for the other. Therefore, for this research, five years meteorological wind speed data of the two sites were used for comparison.

2.3 Method of Data Analysis

The wind speed probability density distributions and the functions representing them mathematically are the main tools used in the wind related data assessment. Probability density functions (PDF) best describe the variation in wind speeds. Their use includes a wide range of applications, from the techniques used to identify the parameters of the distribution functions to the use of such functions for analyzing the wind speed data (Seguro and Lambert, 2000). Two of the commonly used functions for fitting measured wind speed probability distribution at a given location over a certain period of time are the Weibull and Rayleigh distributions. The Weibull probability distribution is a very accurate model in describing wind velocity variation as it conforms well to the observed long-term distribution of mean wind speeds for a range of sites (Rivera, 2008). The probability density function, $f(v)$, of the Weibull distribution is given by

$$f(v) = \frac{K}{C}\left(\frac{v}{C}\right)^{K-1} \exp\left[-\left(\frac{v}{C}\right)^{K}\right] \qquad (2.3.1)$$

where K is the Weibull shape factor, C is the scale factor (m/s) and v represents the wind speed (m/s). For a given average wind speed, a smaller shape factor indicates a relatively wide distribution of wind speeds around the average while a larger shape factor indicates a relatively narrow distribution of wind speeds around the average. For k = 2 the Weibull PDF is commonly known as the Rayleigh density function. The PDF in this case becomes

$$f(v) = \frac{2v}{C^2} \exp\left[-\left(\frac{v}{C}\right)^2\right] \quad (2.3.2)$$

There are a number of ways to calculate the Weibull parameters. Some of them are: probability plots, least square parameter estimation, maximum likelihood estimators, typical shape factors values, Justus Approximation, and the Quick Method (Ramos, 2005). These techniques give good results when sufficient data are available. An alternative way is to use typical shape factors values. The shape factor will normally range from 1 to 3. These typical values are known from experience and multiple observations of sites where wind speed measurements have been taken.

Table 1 Typical values for the shape factor

Types of Wind	Shape Factor K
Island Winds	1.5 to 2.5
Coastal Winds	2.5 to 3.5
Trade Winds	3 to 4

Source: (Rivera, 2008).
Once K is determined, the scale factor (C) can be calculated using the following equation.
Mathew (2006):

$$C = \frac{\bar{V}}{\Gamma\left(1+\frac{1}{K}\right)} \quad (2.3.3)$$

where $\bar{V}$ is the average wind speed (m/s) value and Γ is the gamma function (Mathew, 2006).
The average wind speed can be estimated using equation (3.4):

$$\bar{V} = \left(\frac{1}{n}\sum_{i=1}^{n} V_i^{\,m}\right)^{1/m} \quad (2.3.4)$$

Where V_i is the actual wind speed measurement at interval i, n is the total number of wind speed measurements, and m assumes the value of 1 for arithmetic mean, 2 for root mean square, and 3 for cubic root.
Better fit to the distribution curve is obtained for values of K ranging from 1.8 to 2.3. If Weibull K is not known, K = 2 is used for island sites, and 3 for coastal sites to get a first approximation.
For K = 2, C can be given as

$$C = \frac{\bar{v}}{\Gamma(1+1/2)} = \frac{\bar{v}}{\frac{1}{2}\Gamma\left(\frac{1}{2}\right)} \quad (2.3.5)$$

Since $\Gamma(n+1) = \int_0^\infty e^{-x} x^n \, dx = n\Gamma(n)$ implies $\Gamma(1) = 1$, $\Gamma(2) = 2$ and $\Gamma\left(\frac{1}{2}\right) = \sqrt{\pi}$
C becomes

$$C = \frac{\bar{v}}{\sqrt{\pi}/2} = \frac{2\bar{v}}{\sqrt{\pi}} \cong 1.129\,\bar{v}$$

And finally, Eq. (2.3.5) assumes the form of

$$f(v) = \frac{\pi v}{2\bar{v}^2} \exp\left[-\frac{\pi}{4}\left(\frac{v}{\bar{v}}\right)^2\right] \quad (2.3.6)$$

The data were analyzed using Microsoft excel and MATLAB software. Daily time averaged wind speed variability, monthly and yearly wind patterns were analyzed.

In order to achieve the first objective daytime of the five months were analyzed based on daytime mean speeds and variabilities over the five months.

In order to answer the second part of the objective the mean values and variability's of 12 data points obtained during daytime were compared with mean values of five data points (data recorded at 6:00, 9:00, 12:00, 15:00 and 18:00).

In order to achieve the third objectives daily five year wind data of Areka site was compared with Sodo site without making height correction. The two sites were compared in terms of their monthly and yearly mean wind speeds and the number of hours per day and number of days per year wind speed exceeded a certain critical value (mean value) for the two sites.

3. Results and Discussions

3.1 Temporal Wind Speed Variability

From five months wind speed data of Areka site, an hourly average wind speed values of each one hours, the daily average wind speed value of every day, the mean wind speed and standard deviation values of the five months were determined based on Excel spread sheet for the available wind speed variability of Areka site for daytimes.

It is essential to assess wind energy potential of a site before any wind energy based system could be set up. Study of wind velocity regime over a period of time in a locality can help to optimize the design of the wind energy conversion system by ensuring less energy generating costs (Wind power, 2002; Ulgen, 2002).

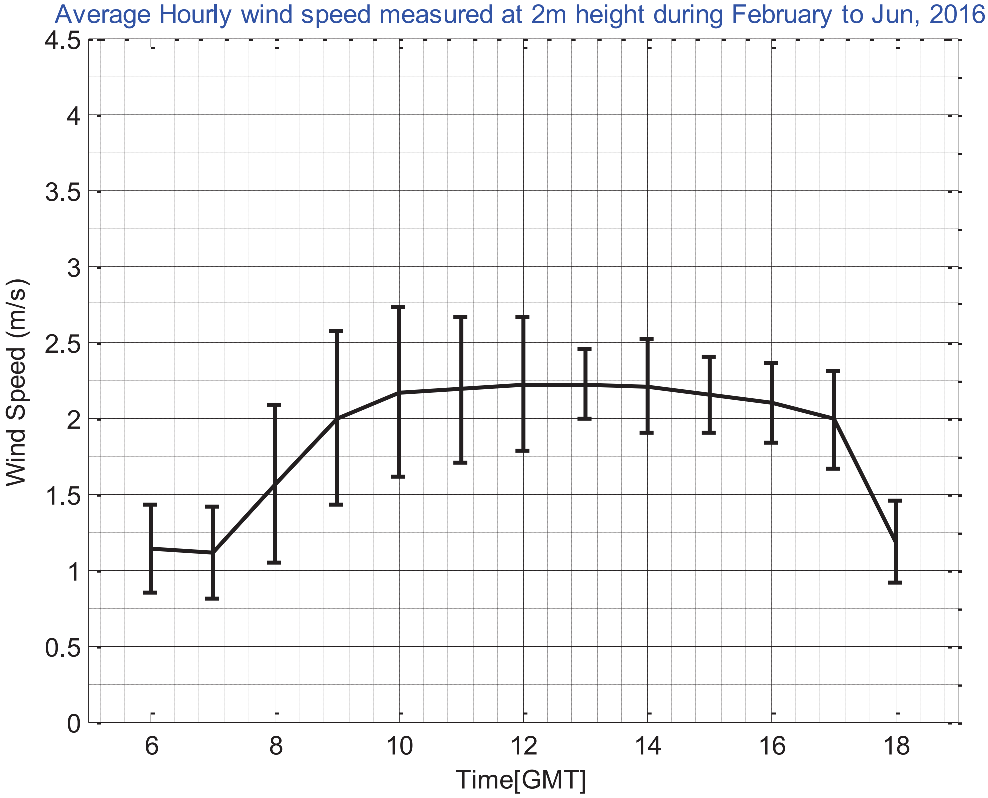

Figure 1. Five month (6 to 18) hourly average wind speeds measured at Areka site between February to Jun, 2016.

Wind velocity is generally recorded in a time-series format. At this site, wind speed was generally relatively low during morning hours and picked up after 0900. Peak wind speeds and maximum deviation were observed between 0900 and 1200. Thereafter, wind speeds and deviation remained nearly the same until 1700 and it fell after that. This is understandable since wind is dependent on the solar energy of an area and the terrain. As the soil warms and heats the earth surface, the temperature of the air close to the earth surface increases, thereby increasing pressure gradients. Increased pressure gradient causes greater wind speeds in the afternoons compared to early morning hours and evenings. Only during the early morning hours and evening the wind speeds were less than average value and the deviations were lower than the remaining time. As wind speed increases, the corresponding error also increases.

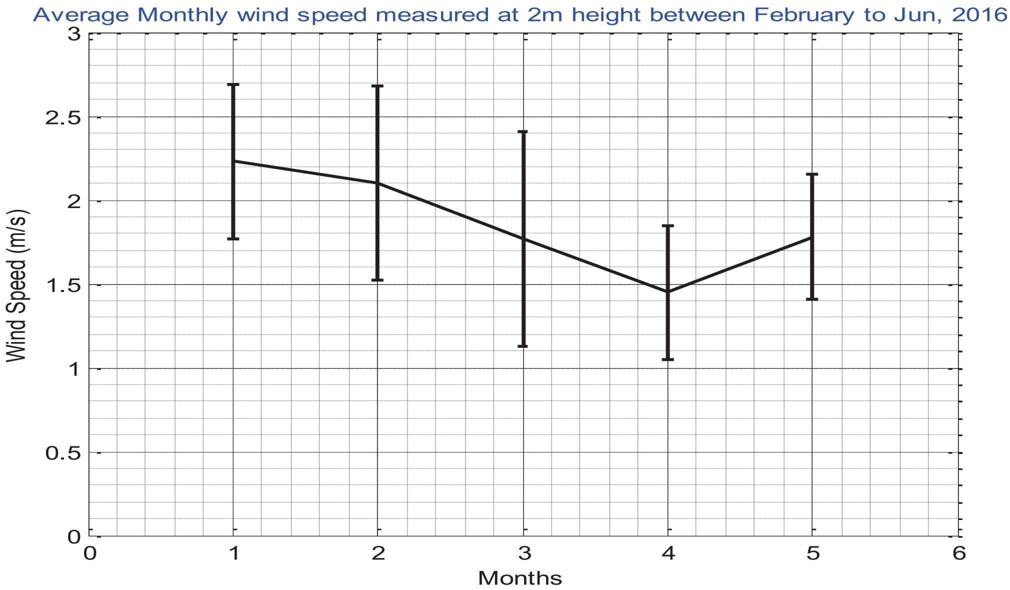

Figure3. Monthly average wind speeds during the months February to Jun, 2016 and their averages. The numbers 1-5 represent the months of the year 2016, number 1 representing February and the number 5 representing the month of Jun.

Figure 3 shows Average Monthly wind speed measured at 2m height between February to Jun, 2016 for each month. The available wind speed measured at Areka Meteorological Service office 2 meters station indicates that wind with minimum speeds occur between April-Jun, 2016. This may be due to change in wind pattern of the area or due to micro-change in the local terrain (growth of trees close to the station). While the maximum wind speeds which exceeds average values of five months occur between February and March with speeds 2.85 and 2.73 m/s, respectively. The values calculated over 5 months (February to Jun, 2016) indicate that mean wind speed is 1.86 m/s, minimum wind speed is 0.75m/s average standard deviation is 0.45m/s. Maximum deviations were observed between March and April while minimum deviation were observed between May and Jun.

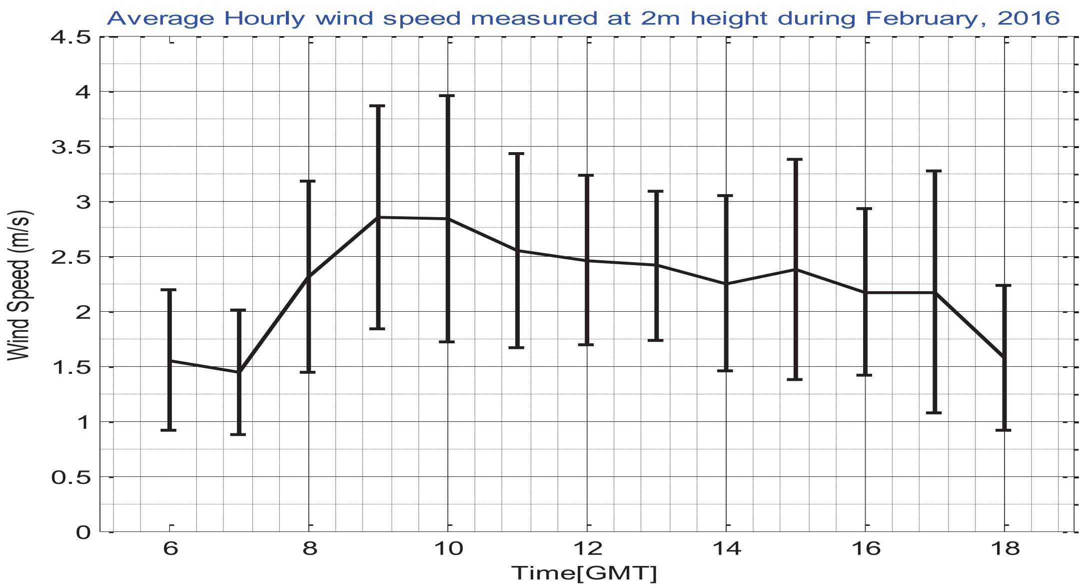

Figure 4. Wind speed variability within each hour plotted for the month February, 2016

Figure 4 represents variability of wind speeds within the different hours of the month. Variability within each hour is almost the same for the 12 hours. This indicates uniformity in the variability of wind speed of the area. Highest wind speeds were recorded during the time 9:00 and 10:00 with wind speeds between 2.85 and 2.84 m/s respectively, moderate wind speeds were recorded during 800 and 1100 to 1700 with wind speeds ranging between 2.17 to 2.55 m/s and lowest wind speeds and deviation were recorded during 600 to 700 and 1800 or early morning and late afternoon with wind speeds ranging between 1.44to 1.57 m/s.

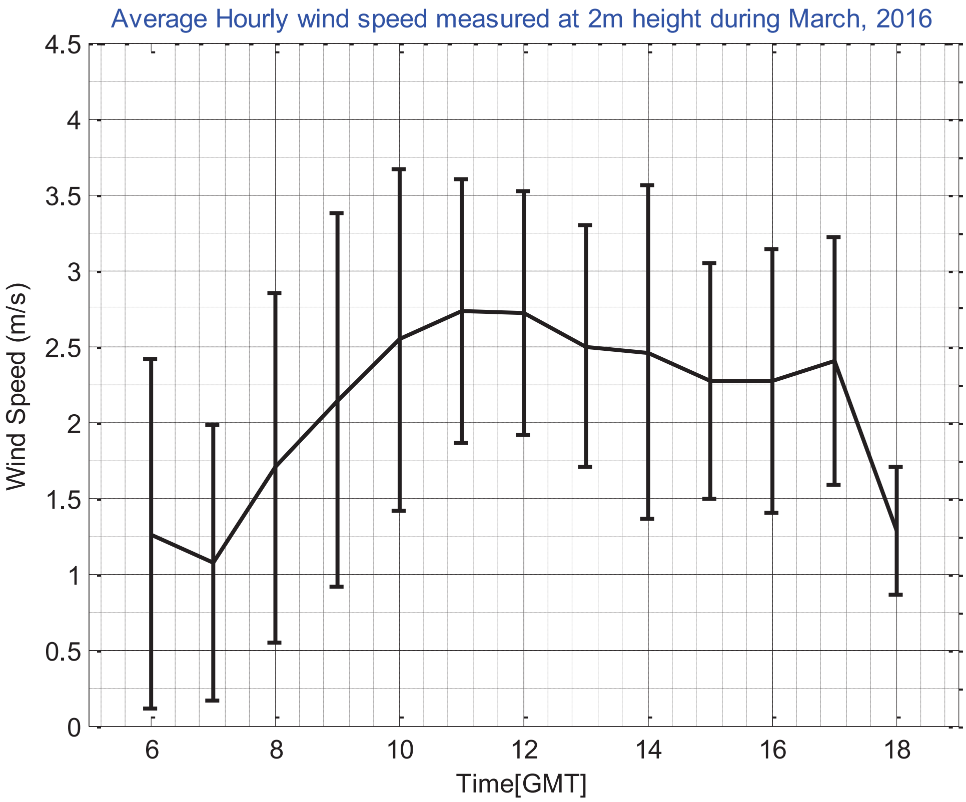

Figure 5. Wind speed variability within each hour plotted for the month March, 2016

As shown in figure 5, during day time of this month, high wind speeds were recorded between the time 1100 and 1200 of March with wind speeds between 2.73 and 2.72 m/s respectively, moderate wind speeds were recorded during 900,1000 and 1300 to 1700 with wind speeds ranging between 2.14 to 2.54m/s. For other remaining days, wind speeds were generally less than 1.3m/s. maximum deviation were obtained during the time 600,800,900,1000 and 1400 where as moderate deviation were obtained during 700, 1100to 1300,and 1500to 1700 and also minimum deviation was observed during 1800 only.

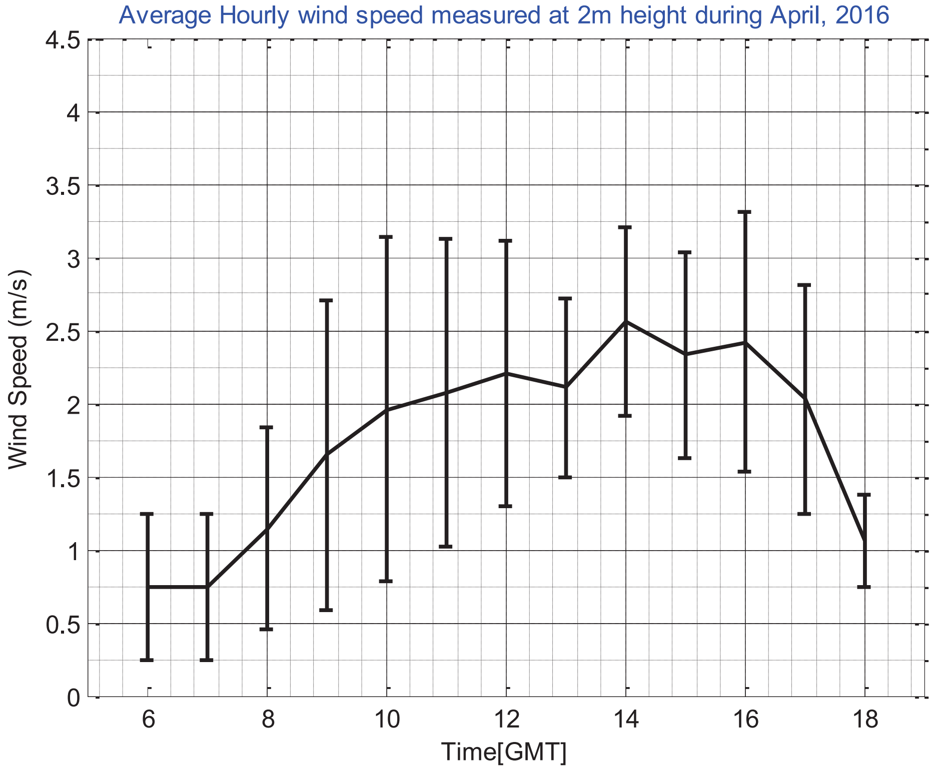

Figure 6. Wind speed variability within each hour plotted for the month April, 2016

As shown in figure 6, maximum wind speed occurred during 14:00 (late afternoon hour), minimum wind speed was recorded during 18:00(evening time), and the highest wind speeds were recorded between 11:00 to 17:00. Whereas, lowest Wind speeds shown between 6:00 to 8:00 and 18:00; moderate wind speeds were recorded during 9:00 and 10:00. The highest Wind speed variability obtained during 9:00 to 12:00, moderate Wind speed variability or deviation obtained during 8:00 and 13:00 to 17:00 and minimum deviation was obtained during 18:00.The time between 6:00 and 7:00, variability is relatively moderate.

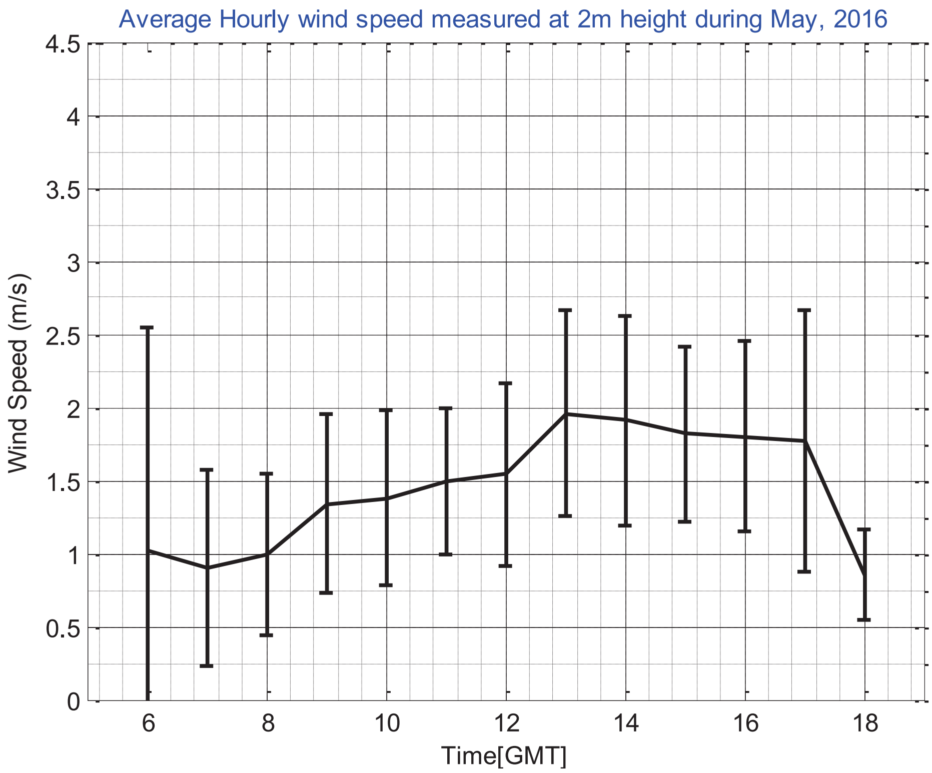

Figure 7. Wind speed variability within each hour plotted for the month May, 2016

As shown in figure 7, during day time of this month, maximum wind speed occurred during 13:00 (afternoon hour) which is 1.96 m/s lower than the average speed of five months with wind speed of 2.22 m/s. For other remaining 11 hours, wind speeds were generally less than 1.91m/s and ranging between 0.85 to 1.91m/s, these are the time where lowest wind speeds were recorded.

Accordingly, Figure7 represents variability of wind speeds within the different hours of the month; Variability within each hour is almost the same for 10 hours. This indicates uniformity in the variability of wind speed of the area. The highest and lowest deviation occurred during the time 6:00 and 18:00 or early morning and evening respectively. However, medium deviations occurred during the time between 7:00 to 17:00.

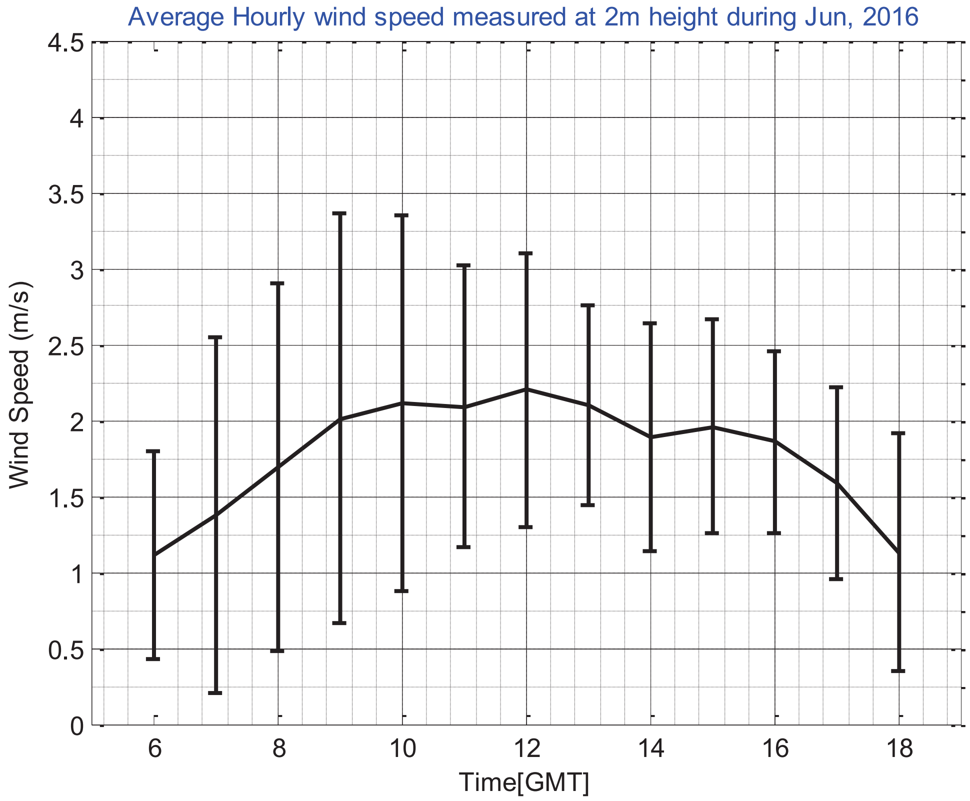

Figure 8. Wind speed variability within each hour plotted for the month Jun, 2016

As shown in figure 8, during day time of this month, maximum wind speed occurred during 12:00 which is 2.20 m/s nearly similar to the average speed of five months with wind speed 2.22 m/s, and the highest wind speed were recorded between 9:00 to 13:00. For other remaining 7 hours, wind speeds were generally less than the average wind speed of 2.20m/s and ranging between 1.11 to 1.96m/s, these are the time where lowest wind speeds were recorded.

Figure8 also represents variability of wind speeds within the different hours of the month; Variability within each hour is almost the same except for 7:00 to 10:00 hours. This indicates uniformity in the variability of wind speed of the area and the highest deviations were occurred during the time between 7:00 to 10:00, respectively. However, for the remaining other different hours medium deviations were occurred.

Assessment of the Differences between 5 against 12 Data Points

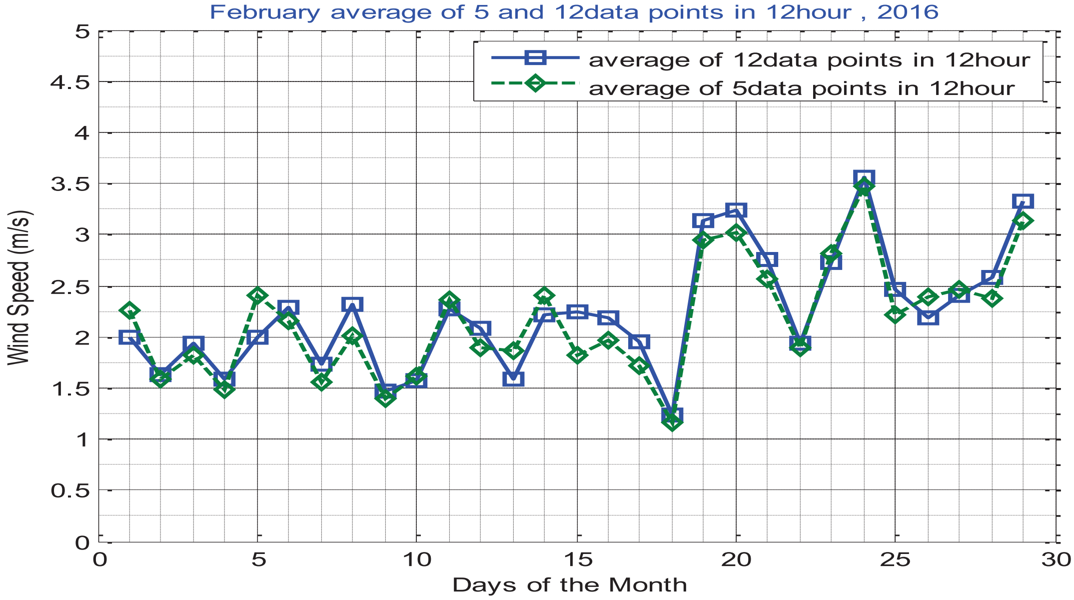

Figure 9 5 and 12 data points measured at Areka site between February 1 and 29, respectively, 2016).

Figure 9 and Appendix figure 3 shows that both five and twelve data points give the same representation and slightly higher value of the 12 hour wind speed average than the five data points used for the same duration. Accordingly, when it comes to the statistical averaging there is no significant difference between the two since the two values are within statistical error from each other as shown in Table 1. Based on Table 2, the average, maximum, minimum and Standard deviations wind speeds occurred for both data sets on the same dates, have nearly the same value. According to these results, the daily mean wind speed values of the 12 data points and five data points have none significant differences, which implies that the meteorological data collection time that is five times per day was better represented.

Table2 Data statistics of daytime averaged (values of 12 data points and 5 data points) wind speeds measured at Areka site between February to Jun, 2015.

Data statistics	Daytime wind speed (m/s) (12 data points over 12 hours)	Daytime wind speed (m/s) (5 data points over 12 hours)
Minimum	1.45	1.31
Maximum	2.23	2.16
Mean	1.86	1.74
Median	1.78	1.68
S.D	0.31	0.32

3.2 Spatial Variability of Wind Speed

Daily mean wind speed values and standard deviations for each month and for all of the five years are presented in Appendix F and G for each site (Areka and Sodo), for the years 2010-2014. As indicated in the Appendix F, the trends of the daily means for five years were similar. Most of the daily wind speed values were between 1.52 m/s and 1.59 m/s, while only a few were over 1.60 m/s and under 1.50 m/s. For January, the days at which the wind speed greater than the mean were recorded in the days 2, 3, 4, 7, 8, 11, 12, 13, 23, 24, 25, 26, 28, and 29 which are 18 in number. For other days, wind speeds were generally less than the mean. Similar argumentation leads us to tabulate the number of the days of each month for the whole years that the wind speeds were above, below or equal to the mean.

Table 3. Monthly average wind speeds and standard deviations, 2010-2014 for both sites measured at 2 m height

SITEs	Months	2014		2013		2012		2011		2010		AVERAGE	
		Av. Wind speed (m/s)	STDEV	Av. Wind speed (m/s)	STDEV	Av. Wind speed (m/s)	STDEV	Av. Wind speed (m/s)	STDEV	Av. Wind speed (m/s)	STDEV	Av. Wind speed (m/s)	STDEV
Areka	J	1.82	0.58	1.82	0.59	1.66	0.52	2.01	0.71	1.46	0.44	1.75	0.57
	F	2.16	0.69	1.66	0.61	2.21	0.74	2.32	0.7	1.33	0.45	1.94	0.64
	M	2.06	0.81	1.31	0.51	2.12	0.74	2.19	0.81	1.62	0.67	1.86	0.71
	A	1.64	0.62	1.63	0.62	1.18	0.5	1.75	0.83	1.46	0.64	1.53	0.64
	M	1.48	0.60	1.25	0.43	1.05	0.45	1.31	0.45	1.35	0.57	1.29	0.50
	J	1.21	0.54	1.34	0.45	1.73	0.56	1.08	0.36	1.12	0.51	1.30	0.48
	J	1.17	0.54	1.15	0.42	1.58	0.46	0.83	0.41	1.22	0.52	1.19	0.47
	A	1.15	0.5	0.83	0.43	1.55	0.48	0.95	0.43	1.32	0.62	1.16	0.49
	S	1.39	0.64	1.14	0.54	1.46	0.52	0.95	0.49	1.30	0.61	1.25	0.56
	O	1.72	0.77	1.53	0.69	1.62	0.64	1.29	0.65	1.78	0.89	1.59	0.73
	N	1.42	0.63	1.85	0.8	1.72	0.62	0.61	0.61	2.36	0.98	1.59	0.73
	D	1.8	0.66	1.76	0.58	1.52	0.53	1.83	0.69	2.3	0.75	1.84	0.64
	YEARLY	1.59	0.63	1.44	0.56	1.62	0.56	1.43	0.60	1.55	0.64	1.52	0.60
SODO	J	1.77	0.80	1.62	0.75	1.69	0.84	2.31	0.86	1.51	0.81	1.78	0.81
	F	2.41	1.27	1.52	0.89	2.09	0.83	2.57	1.17	1.49	0.80	2.02	0.99
	M	2.00	0.83	1.75	0.83	2.04	0.95	2.24	1.14	1.93	1.00	1.99	0.95
	A	1.85	0.90	1.37	0.72	1.87	1.11	1.90	1.10	1.60	0.85	1.72	0.94
	M	1.47	0.84	1.20	0.79	1.67	0.94	1.69	0.90	1.35	0.85	1.47	0.86
	J	1.35	0.72	1.30	0.82	1.55	0.80	1.58	0.77	1.05	0.66	1.37	0.75
	J	1.15	0.54	1.20	0.73	1.37	0.57	1.35	0.92	1.20	0.76	1.25	0.71
	A	1.10	0.61	1.34	0.79	1.24	0.67	1.16	0.67	1.19	0.81	1.20	0.71
	S	1.24	0.68	1.24	0.63	1.13	0.58	1.11	0.65	1.14	0.70	1.17	0.65
	O	1.77	0.69	1.34	0.75	1.61	0.75	1.18	0.67	1.70	0.93	1.52	0.76
	N	1.51	0.70	1.84	0.90	2.14	1.09	1.75	0.96	2.61	1.18	1.97	0.97
	D	2.05	0.80	1.70	0.80	1.52	0.77	1.81	0.93	2.76	1.23	1.97	0.90
	YEARLY	1.64	0.78	1.45	0.78	1.66	0.82	1.72	0.90	1.63	0.88	1.62	0.83

The monthly average wind speed values and the standard deviations from the data obtained for the overall and individual five years for each sites are presented in above Table (4.6).

- **For Areka Site:**

For the five years, the average wind speed is only 1.52 m/s. The minimum wind speed for all the five years is 1.19 m/s, which occurred in the months of July, while the maximum was 1.94 m/s in February.

- **For Sodo Site:**

For the five years, the average wind speed is only 1.62 m/s. The minimum wind speed for all the five years is 1.17 m/s, which occurred in the months of September, while the maximum was 2.02 m/s in February.

In appendix figure A, the average monthly wind speeds measured at 2 m height during each year with the average of the five years for Areka are depicted. In 2010, maximum deviations were observed in the months of October and November. November is also a month with maximum wind speed.

In 2011 between the months January to April there were very high wind speed variations and high wind speeds, whereas during other months both variations and wind speeds were low. In 2012, during the months of February and March very high wind speed variations were observed, whereas during the months of April and June very low wind speed variations were observed and the other months' variations were moderate. . In 2013, maximum deviation was observed in the months of November. It is also a month with maximum wind speed, whereas the other months' variations were moderate. In 2014, during the months of February, March and October there were very high wind speed variations and high wind speeds, whereas the other months' variations were moderate.

A more elaborate pattern is observed from the average. During the months October to March very high wind speed variations and high wind speeds were observed, whereas the other months had moderate values of both

In appendix figure B, the average monthly wind speeds measured at 2 m height during each year with the average of the five years for Sodo are depicted. In 2010, maximum deviations were observed in the months of November and October. They are also the months' with maximum wind speeds, whereas the other months' variations were moderate.

In 2011 between the months February to April there were high wind speed variations and high wind speeds, whereas during other months both variations and wind speeds were moderate. In 2012, during the month of November high wind speed variation was observed, whereas the other months' variations were moderate. In 2013 between the months November to March there were high wind speed variations and high wind speeds, whereas during other months both variations and wind speeds were moderate. In 2014, maximum deviation was observed in the month of November. It is also a month with maximum wind speed, whereas the other months' variations were moderate.

A more elaborate pattern is observed from the average. During the months November to February very high wind speed variations and high wind speeds were observed, whereas the other months had low values of both.

Table 4 The number of days at which the mean values of each month was greater, less or equal to daily variability of five years for each two site (Areka and Sodo), respectively

Site		J	F	M	A	M	J	J	A	S	O	N	D	Sum
Areka	Number of days greater than mean	18	13	14	17	15	18	16	12	18	15	14	14	184
	Number of days less than mean	13	16	17	12	16	11	14	17	9	15	15	16	171
	Number of days Equal to mean	----	----	----	1	----	1	1	2	3	1	1	1	11
	Total number of days For Areka site	31	29	31	30	31	30	31	31	30	31	30	31	366
Sodo	Number of day greater than mean	15	13	15	15	16	17	15	16	14	14	18	14	182
	Number of day less than mean	16	15	15	15	15	12	15	15	12	17	12	15	174
	Number of day Equal to mean	---	1	1	---	----	1	1	---	4	---	---	2	10
	Total number of days For Sodo site	31	29	31	30	31	30	31	31	30	31	30	31	366

Out of 366 days the numbers of days greater than the mean wind speed at Areka site were 184, less than, for 171 days and equal to, for 11 days.

As indicated in the Appendix B, the daily mean wind speeds, standard deviation, minimum and maximum values for Sodo site were evaluated for five years, 2010-2014. The trends of the daily means for five years were similar. Most of the daily wind speeds were between 1.58 m/s and 1.65 m/s, while only a few were over 1.70 m/s and under 1.55 m/s.

Over the five years, the days at which the wind speed above, below or equal to the mean value of each month between January to December were summarized in Appendix B. Similar argument leads us to tabulate the number of the days of each month for five years that the wind speeds were above, below or equal to the mean (Table 4).

Out of 366 days the numbers of days greater than the mean wind speed at Sodo were 182 (184 for Areka), less than, for 173 days (171 for Areka) and equal to, for 10 days (11 for Areka).

Table 5 Time variability of the wind speeds of two sites (Areka and Sodo) over five years

Timely variability of five years for Areka site							Timely variability of five years for Sodo site					
Years	6:00	9:00	12:00	15:00	18:00	Avg	6:00	9:00	12:00	15:00	18:00	Avg
2010	1.10	1.99	1.90	1.72	1.43	1.63	1.20	2.10	1.90	1.56	1.00	1.55
2011	1.46	2.04	1.89	1.81	1.39	1.72	1.16	2.02	1.83	1.45	1.09	1.51
2012	1.20	2.07	1.88	1.85	1.30	1.66	1.11	1.98	1.77	1.42	1.08	1.47
2013	0.95	1.84	1.69	1.64	1.13	1.45	1.21	2.09	1.85	1.57	1.36	1.62
2014	1.12	1.92	1.87	1.76	1.29	1.59	1.14	1.89	1.71	1.38	1.09	1.44
Avg	1.16	1.97	1.85	1.76	1.31	1.61	1.16	2.01	1.81	1.48	1.12	1.52
S.D	0.19	0.09	0.09	0.08	0.11	0.10	0.04	0.09	0.07	0.08	0.14	0.07

At both sites high wind speeds were observed between 9:00-12:00 hours, moderate wind speeds around 1500 and low at 0600 and 1800. Correlation between the two sites shows a fairly reasonable regression coefficient indicating similarities between the two sites (Figure 9).

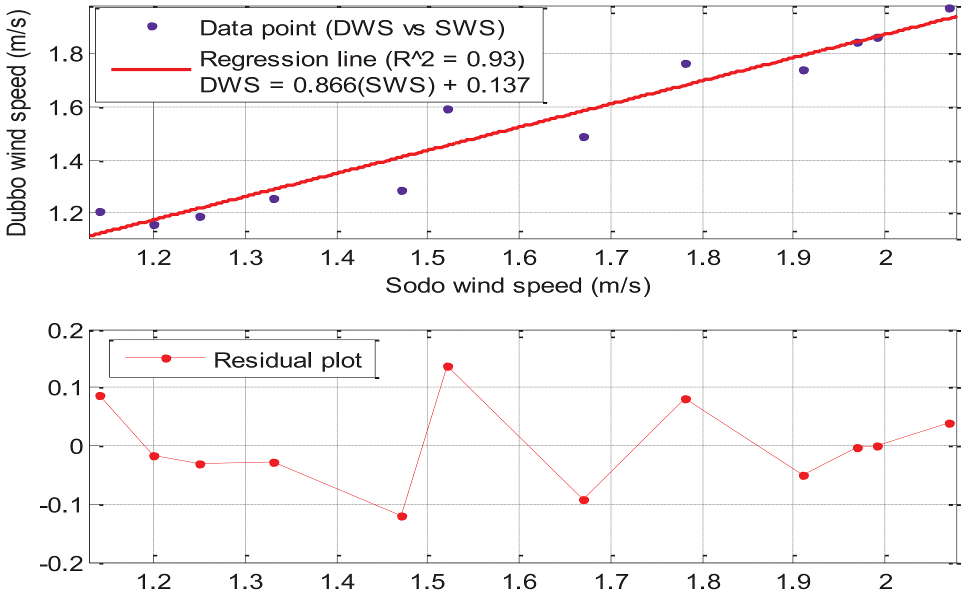

Figure 9 Linear regression line fitted between wind speeds of Areka and Sodo sites. AWS and SWS stand for Areka and Sodo wind speeds, respectively

Table 6 Differences between wind speeds at Sodo and Areka sites

Average wind speed	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Avg
Sodo	1.78	2.07	1.99	1.67	1.47	1.33	1.25	1.20	1.14	1.52	1.91	1.97	1.62
Areka	1.76	1.97	1.86	1.49	1.29	1.26	1.19	1.16	1.21	1.59	1.74	1.84	1.53
Difference	0.02	0.10	0.13	0.18	0.18	0.07	0.06	0.04	-0.07	0.07	0.17	0.13	0.08
Average of the two	1.77	2.02	1.93	1.58	1.38	1.30	1.22	1.18	1.18	1.56	1.83	1.91	1.57
Percent error	1.1	5.0	6.8	11.4	13.0	5.4	4.9	3.4	6.0	4.5	9.3	6.8	4.7

Table 7 Data statistics of wind averaged wind speeds of Sodo and Areka sites

Data statistics	**Sodo wind speed (m/s)**	**Areka wind speed (m/s)**
Minimum	1.14	1.16
Maximum	2.07	1.97
Mean	1.61	1.53
Median	1.60	1.54
Mode	1.14	1.16
Standard deviation	0.34	0.30
Range	0.93	0.81

As depicted in Figure. 9, there is strong positive correlation between the wind speeds of the two sites with large R^2 value of 0.93. The fitted line has slope of 0.865, which is nearly close to one. The intercept (0.137) is also fairly close to zero. Table 6 indicates percent errors of the two sites with respect to their average wind speeds for all the twelve months. Maximum error of 13% was observed in May whereas the minimum percent error of 1.1% was observed in January. The average for all the months is about 5%. Except for the two months (April and May), the two sites are identical within an error of 10%.

CONCLUSIONS

Conclusions

In the present study, short term temporal wind speed variability of Areka site and spatial wind speed variability of two locations (Areka and Sodo) have been analyzed. The most important outcomes of the study can be summarized as follows:

- ❖ In assessing daily wind speed variation, the result showed that over the five months February and March daytime wind speed was generally higher than the average wind speed and April to Jun have lowest average wind speed were recorded compared with the average wind speeds.
- ❖ Both five and twelve data points give the same representation and slightly higher value of the 12 hour

wind speed average than the five data points used for the same duration. Accordingly, when it comes to the statistical averaging there is no significant difference between the two since the two values were within statistical error from each other. Therefore; it is fair to assume there is no difference between the two.

- As far as spatial variability is concerned, it is fair to assume that the two data obtained at Areka and at Sodo ended in giving nearly identical results and hence could be considered to be equivalent. Both Areka and Sodo site wind data profile, presents poor wind characteristics. This is shown by low monthly and yearly mean wind speed values for the whole year. The yearly average wind speed values of Areka was 1.52m/s and Sodo was 1.62m/s measured at 2 meter heights for the whole five years.
- Wind speed and direction data were very important tools for wind farm site selection and establishment. However, according to this study wind speed distribution was poor in quality and distribution. As a result, the study area has low wind potential. Therefore, these particular sites are not ideal for grid connected applications. However, since this study was conducted by taking five months wind speed data and analyzed, further study will be given due emphasis on long period of wind speed data for remarkable recommendation.

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