EVALUATION OF WIND ENERGY POTENTIAL IN ZARIA METROPOLIS

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ABSTRACT

Meteorological data were acquired from the Nigerian College of Aviation Technology Zaria. The station is located at Longitude 07° 41' E, Latitude 11°08' N and elevation of 686 m above sea level. Diurnal wind speeds and directions were recorded with Wind Vane and Anemometer from 1995 through 2004. The readings were usually taken twice daily, at 10.00 am and 4.00 pm. A total of 6856 direction counts were recorded throughout the years. The north-easterly wind had 3050 direction counts, representing 44.5 %. Maximum wind speed of 2.35 m/s was obtained at a height of 2.5 m while 3.0 m/s was obtained at 10 m above the earth's surface, showing speed enhancement with height. The available wind power in the area was 16.46 w/s[2] but the maximum average extractable wind power per unit area was 9.76 w/m^{2}. It was also observed that dry season (High North-East (NE) wind period), normally ran from the months of November to February whereas the rainy season (High South-West (SW) wind period) ran from the months of May to September. In spite of the low available power, exploitations could be enhanced at higher level above the earth's surface. Maximum output was expected within the months of November and February when the dominant north-easterly wind was high and consistent.

Keywords: Wind, Extractible Energy, Speed, Power.

INTRODUCTION

The flow of air from a high atmospheric pressure to a low pressure area is one of the major initiator of wind. Thus, process of equalisation taking place between a region of rarefied air and one that is denser tends to initiate air flow/current (Brown,1962 and Fthenakis and Kim, 2009). Energy acquired from the wind is in the form of rotary, translational, or oscillatory mechanical motion (Cheremisnaff, 1978). In other words, wind results from the movement of air masses and arises primarily due to unequal heating of the earth's surfaces by the sun.

Air over oceans and lakes remains relatively cool during the day time (Fig. 1) since much of the sun's energy is consumed in the evaporation of water or is absorbed by the water itself as shown in Figure 2. On the land, air is heated more during the day, since land absorbs less sunlight than waters and evaporation is less. The heated air overland expands, becomes lighter and rises. The cooler, heavier air from over the water moves in to replace it. Local breezes on a shoreline are thus created in this way (Eldridge, 1979). These local seashore breezes reverse themselves during the night, since land cools more rapidly than water, and so does the air above it as shown in Figure 2. The warm air

that rises from the surface of the water is replaced by this cool air from over the land as it blows sea ward (Eldridges, 1979). Thus, the sea shore line becomes warmer at night. Similar breezes occur on mountain sides during the day as the heated air rises along the warm slopes that face the sum as shown in Figure 3. During the night, the relatively heavy cool air on the slope flows down into the valleys as shown in Figure 4 (Eldridges 1979). Thus, mountain sides (i.e. valley) are cooler at night.
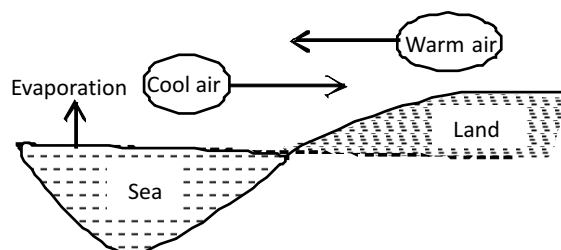

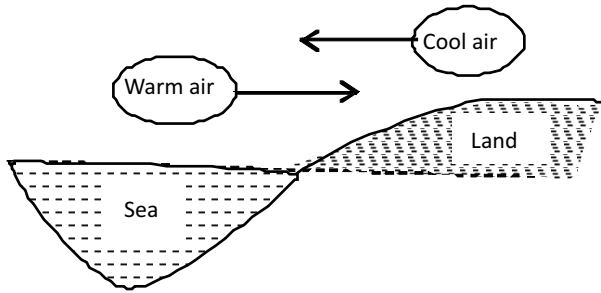Figure 1: Formation of Seashore Breeze during the Day Time

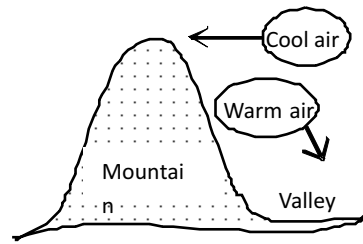Figure 2: Formation of Local Offshore Breeze During the Night Time

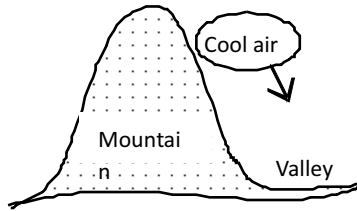Figure 3: Formation of Mountain Breeze During the Day Time

Figure 4: Formation of Valley Breeze

During the Night Time

Circulating planetary winds are likewise caused by the greater heating of the earth's surface near the equator than near the poles (Eldridge, 1979). This causes cold surface winds to blow from the poles to the equator to replace the hot air that rises in the tropics and moves in the upper atmosphere towards the poles (Fig. 5). However, the rotation of the Earth also affects these planetary winds, which makes-wind a much more complex phenomenon (Fig. 6). The inertia in the cold air moving near the surface towards the equator tends to twist it to the West, while the warm air moving in the upper atmosphere towards the poles tends to be turned to the East. This causes large counter clockwise circulation of the air around low pressure areas in the northern hemisphere, and clockwise circulation around such areas in the southern hemisphere. Since the Earth's axis of rotation is reclaimed at an angle of 23.5° to the plane in which it moves around the sun, seasonal variations in the heat received from the sun result in seasonal changes in the strength and direction of the winds at any given location on the Earth's surface (Eldridge 1979) and (Fauso *et al.*, 2012).
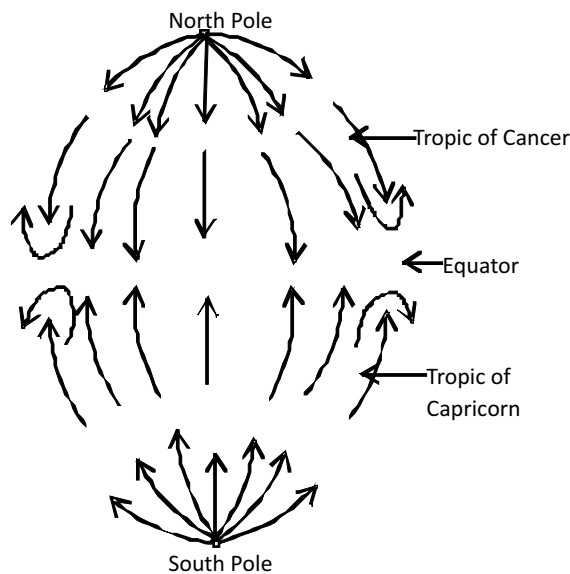

Figure 5: Hypothetical Wind Nature, Were the Earth not rotating

Polar Easterlies →

Prevailing Westerlies ←

Horse Latitude →

Northeast Trades ←

Doldrum →

Southeast Trades ←
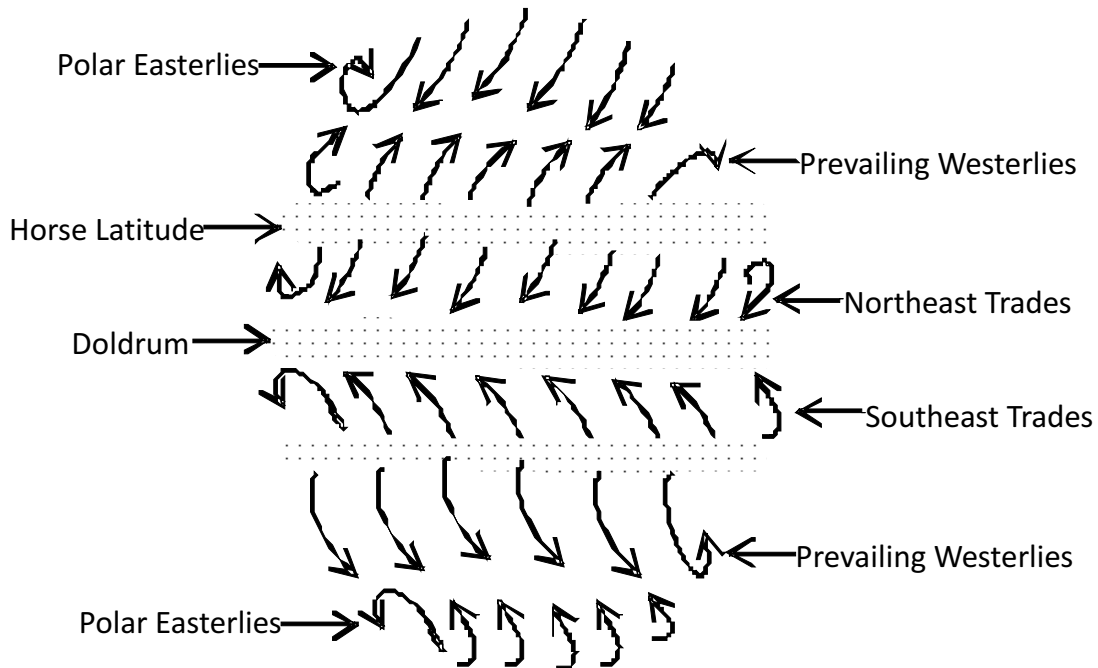
Prevailing Westerlies ←

Polar Easterlies →

Figure 6: Effects of Earth's Rotation on the Wind Shape

In Zaria, Elegba *et al.*(1982) found that high average wind speed is observed during the months of November and December and low average wind speed during the months of January to October. It was also found that the long-term average wind speed for Zaria is 3.2 m/s. It was observed that wind speeds in the area are generally high between the months of November and June (Inglis, 1978 and Swena, 2000). This is important because irrigation periods fall between the months of November and March in the area. Measurement of wind speed with Wind mill can therefore be used index of water requirements.

MATERIALS AND METHODS

Site Location
Wind data were obtained from meteorological station situated on the global coordinates of Longitude 07° 41' E and Latitude $11^\circ 08'$ N, and at an altitude of 686 m above the sea level. The station is located in the Nigerian College of Aviation Technology, Zaria (Fig. 7). Daily wind speed and directions were acquired from Wind Vane and Anemometer for a period of ten years (1995-2004). The readings were usually taken twice in a day, at 10.00 am and at 4.00 pm. Average daily wind speeds for the duration of ten years were also collected over the specified epoch above. Ten year period is considered adequate for any peculiar climatological and seasonal variations (Elegba et *al.*, 1982).
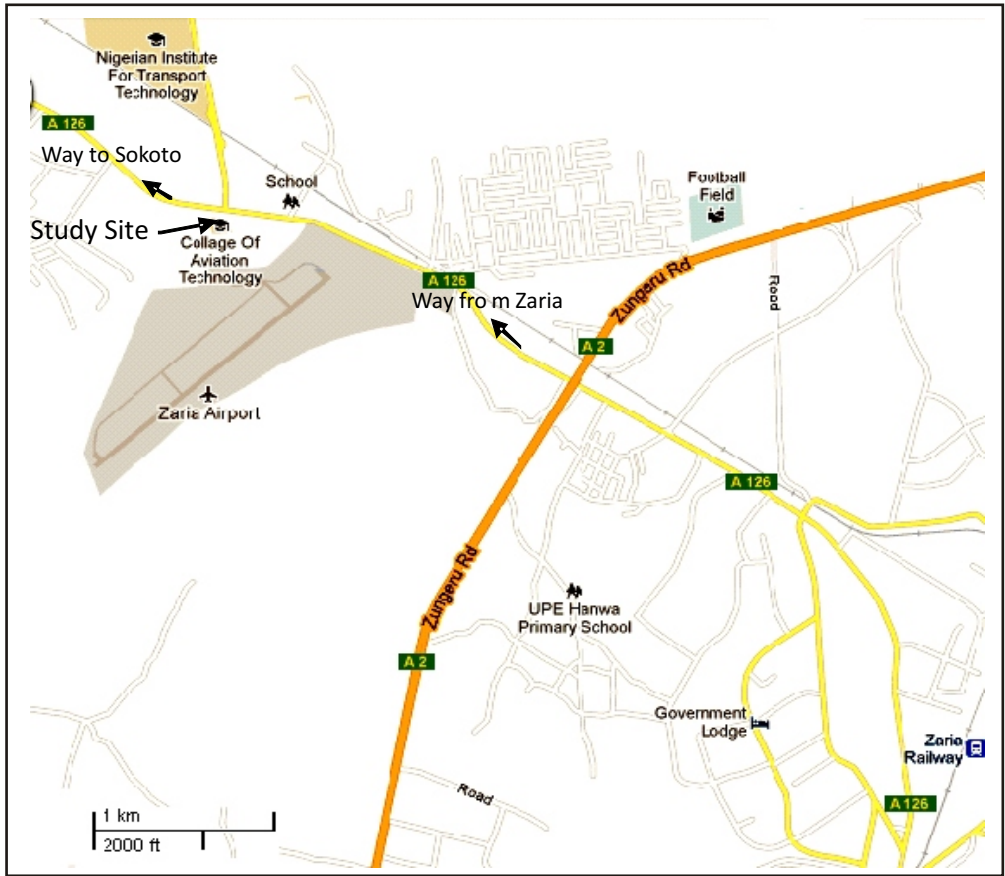
Figure 7: Location of the Study Site

Instrumentation and Data Acquisitions

The adopted data were obtained exclusively with Wind Vane (Fig. 8) and Cup Anemometer (Fig. 9). For Wind direction data, the Vane points to the direction from which the wind is blowing so that the wind is named after the direction from which it blows e.g. South-West wind blows from South towards West direction. The action of force exerted by wind on Anemometer, registered as rotational speed on its support, determines the speed of the wind which is recorded by the calibrator on the support.
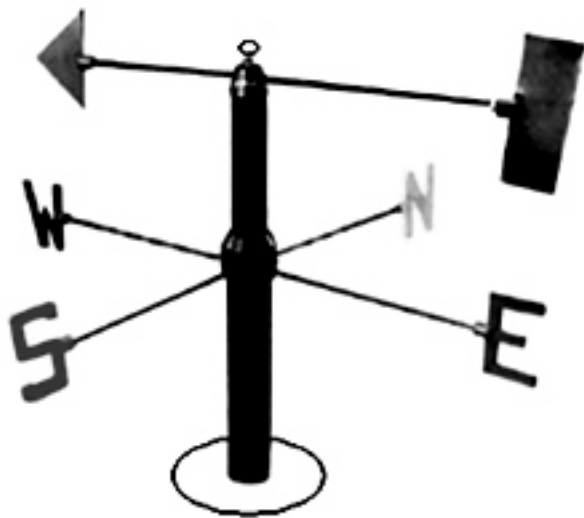

Figure 8: Wind Vane. (Encyclopaedia Britannica, 2012)

Figure 9: Cup Anemometer (Encyclopaedia Britannica, 2012)

Theory

The average value of the kinetic energy (E) in a moving wind can be expressed as:

$$E = \frac{1}{2}mv^2 \qquad (1)$$

Where m and v are mass and speed respectively. The power (P_a) available in a free flowing wind of a given cross - sectional area is given by the equation:

$$P_a = \frac{V^3 A}{2} \qquad (2)$$

Where and A are density and area respectively. All the available energy in the wind cannot be extracted because of the continuity constraint. It has been proved by Cheremisinaff (1978) that an ideal wind machine is capable of extracting only 59.3% of the energy available in the wind. One method of characterizing the potential wind energy of various sites of interest through the average available wind power per unit area (Justus, 1978) is by applying the equation:

$$\frac{P_a}{A} = \frac{V^3}{2} \qquad (3)$$

The amount of power which can be extracted from a wind stream depends on the available wind energy and on the operational characteristics of the wind machine. The average power (P_e) extracted during the programme - Wind Energy Conversion System of U. S. A. in the year 2000 is given by the equation:

$$P_e = \frac{c_p V^3 A}{2} \qquad (4)$$

Where (P_e) = extractable power and (C_p) is the power coefficient which is equal to 0.593 (Justus, 1978)

The monthly and yearly average wind speeds are converted from 2.5 m height to 10 m height using the equation:

$$\frac{V_H}{2.5} = \frac{V}{2.5} \qquad (5)$$

Where V_H = wind speed at a desired height and V = wind speed at reference height e.g. 2.5 m Conclusively, available wind power per unit area in

equation 3, given that density = 1.16 kg/m^3 and the temperature t = 30°C, is given by the equation:

$$\frac{Pa}{A} = 0.58V^3 \qquad (6)$$

Also, assuming maximum machine efficiency in equation 4 so that C_p = 0.593 (Dewinkel, I.E.S.; report 104, 1985) then extractable power per unit area is given by equation:

$$\frac{Pe}{A} = 0.3344V^3 \qquad (7)$$

RESULTS AND DISCUSSION

Wind Speed and Power

The wind speed of 2 m/sec is considered to be the minimum threshold value for any meaningful small scale wind power application (Elegba *et al.*, 1982). At 2.5 m height the overall average speed is 1.68 m/s with the highest value of 2.35 m/s occurring in July as shown in Table 1. But at 10 m height, the overall average is 2.10 m/s as shown in Tables 2 and 3. This shows therefore that speed is enhanced by an altitude increase. Maximum average speed of 3 m/s is observed from the month of January through July and low average wind speed period is observed from August to December as shown in Figure 10.

Figure 11 shows fairly steady wind speed from 1995 to 1999 after which it fluctuates. There is more than 9 W/m^2 extractable wind power per unit area in the metropolis as shown in Figure 12. Table 4 shows that highest average power per unit area of 16.46 W/m^2 occurs in May but 9.76 W/m^2 power per unit area is extractable in the same month as shown in Table 5.

Table 1: Wind Speed for 1995 - 2004 at Height 2.5 m above the Earth's Surface

Months	1995 (m/s)	1996 (m/s)	1997 (m/s)	1998 (m/s)	1999 (m/s)	2000 (m/s)	2001 (m/s)	2002 (m/s)	2003 (m/s)	2004 (m/s)	Average (m/s)
Jan.	1.25	1.50	1.83	1.47	2.93	1.59	1.65	1.59	1.35	1.47	1.70
Feb.	1.25	1.90	1.94	1.75	2.01	1.66	2.29	1.42	1.26	1.60	1.71
Mar	1.53	1.78	1.53	1.88	2.28	1.72	2.15	1.54	1.74	1.92	1.82
Apr	2.04	1.92	2.19	2.32	1.79	2.14	1.72	2.38	2.01	2.16	1.81
May.	2.16	2.60	2.08	2.39	2.78	2.61	2.94	2.40	2.28	2.13	2.07
Jun.	1.84	2.32	2.24	2.28	2.67	2.42	2.74	2.80	2.00	2.15	2.35
Jul	1.49	1.67	2.03	1.94	2.16	1.86	2.03	2.39	1.82	1.98	1.94
Aug	1.53	1.30	1.47	1.53	1.35	1.66	1.59	1.56	1.26	1.61	1.49
Sep	1.14	1.60	1.32	1.22	1.13	1.04	1.27	1.36	1.14	1.30	1.20
Oct	0.84	1.12	1.02	1.17	1.09	0.71	096	0.95	1.00	0.80	0.97
Nov	099	1.17	1.64	1.30	0.86	1.01	0.98	1.09	0.91	0.93	1.09
Dec.	1.53	1.64	1.31	1.61	1.05	1.61	1.67	1.65	1.15	1.20	1.44
Average	1.50	1.67	1.72	1.74	1.84	1.67	1.83	1.76	1.49	1.61	

Table 2: Monthly Average Wind Speed for 1995 - 2004 at Height 10 m above the Earth's Surface

Months	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Average
Speed (m/s)	2.12	2.13	2.25	2.58	3.05	2.93	2.42	1.86	1.50	1.21	1.36	1.80	2.10

Table 3: Annual Average Wind Speed at 10 m Height above the Earth's Surface

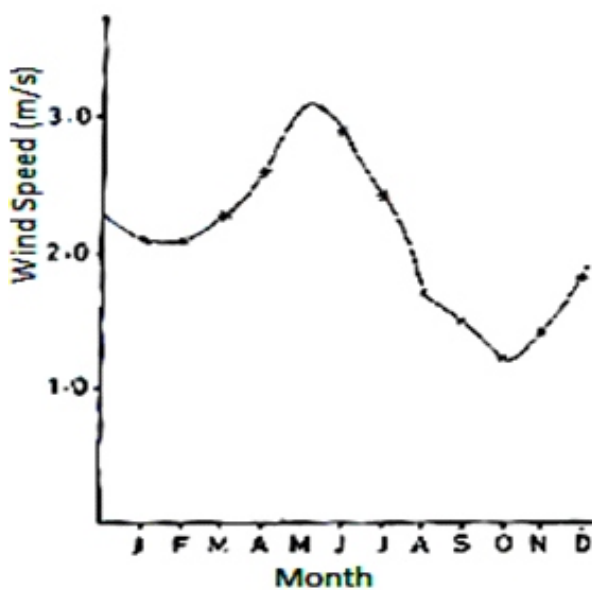| Years	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	Average
Speed (m/s)	1.87	2.08	2.15	2.17	2.30	2.08	2.28	2.20	1.86	2.01	2.10

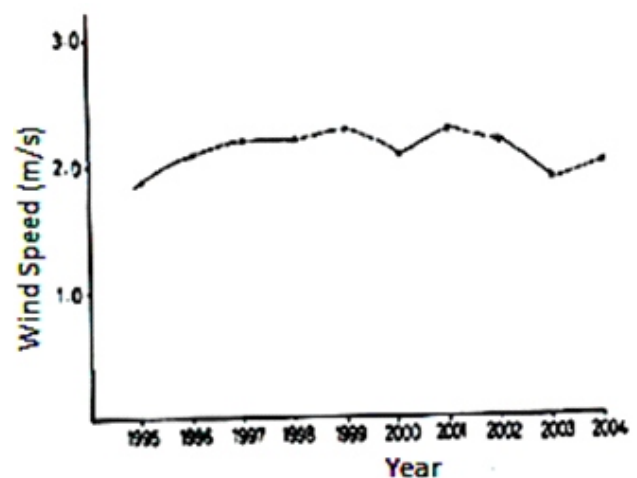Figure 10: Monthly Average Wind Speed Distribution

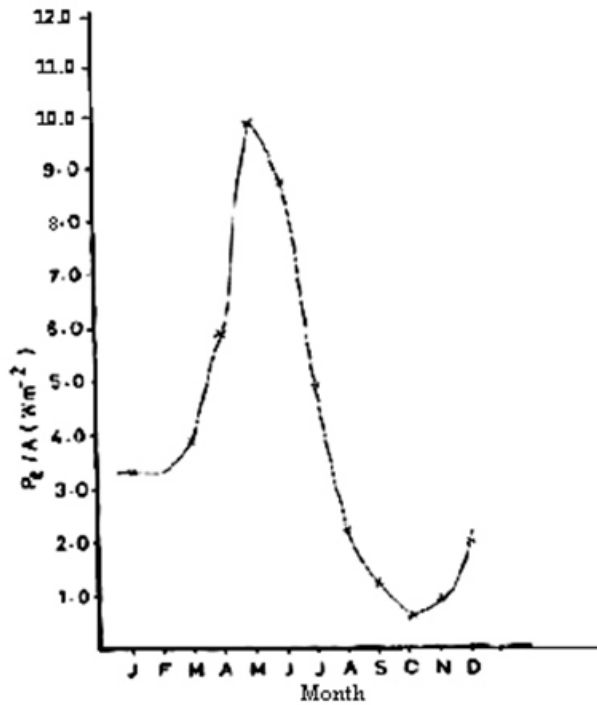Figure 11: Yearly Average Wind Speed Distribution

Figure 12: Extractible Wind Power Per Unit Area Distribution

Table 4: Monthly Available Wind Power per unit Area for 1995-2004

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
$P_a(W/m^2)$	5.53	5.60	6.61	9.96	16.46	14.59	8.22	3.73	1.96	1.03	1.46	3.38

Table 5: Monthly Extractable Wind Power per unit Area for 1995-2004

Months	Jan.	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P_e/m^2	3.28	3.32	3.92	5.91	9.76	8.65	4.88	2.21	1.16	0.61	0.87	2.00

Wind Directions and Direction Count Distributions

The average wind direction count characteristic plots for the years and months considered are shown in Figures 10 and 11 as presented in Tables 6 and 7.

Throughout the span of years under study, the NE wind direction appeared predominantly with direction counts of 3050 which is 44.5 % of the whole count values. The lowest of all is the SE wind which is 7.7 % as shown in Table 6. Figure 13 shows dominant feature of the NE wind over all other wind directions and the fact that NE wind is cold and dry wind reveals the tropical nature of Zaria. Hence, the NE wind is predominant wind in Zaria.

Table 6: Yearly Total Wind Direction Counts

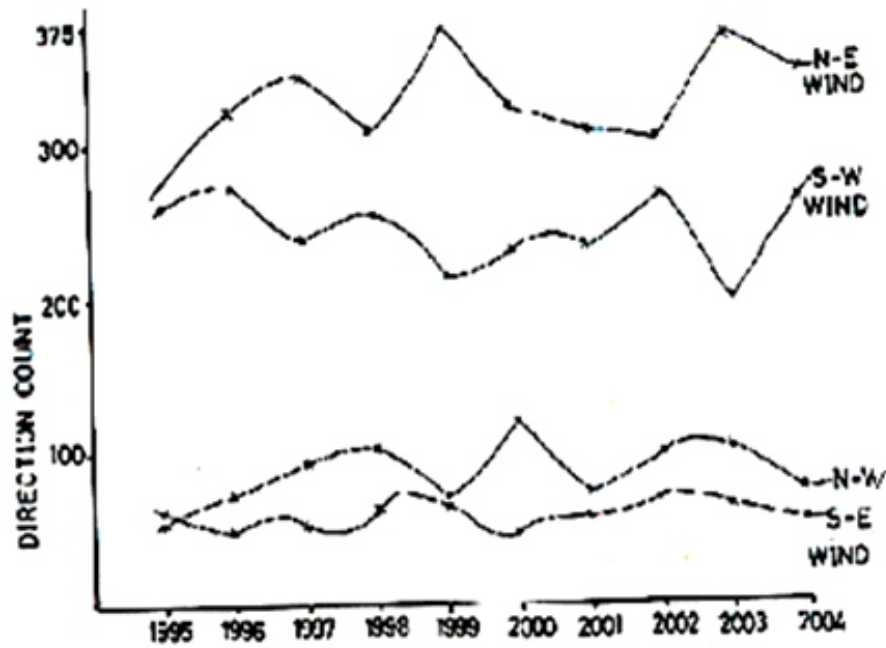| WIND DIRECTION COUNTS	Year	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	Total	%
	NE	272	320	342	209	375	219	300	300	369	344	3050	44.5
	SE	61	46	51	63	69	46	56	67	64	53	530	7.7
	NW	54	70	92	103	74	117	72	97	100	73	852	12.4
	SW	258	271	239	255	212	223	232	266	197	261	2424	34.4

Figure 13: Yearly Total Direction Count Distributions

'The average direction counts for each specific month in all the years studied are shown in Table 7. The NE direction has the highest total counts of 3317 which represents 45.75 %. Also, NE wind is prominent around the months of November, December and January. The latter could account for the approach of harmattan session as the NE wind is characteristically dry and cold (Hidy, 1967) Meanwhile, the SW wind is prominent in May, June and July as shown in Table 7. The latter could account for the approach of rain season that is common around that period as the SW wind is characteristically wet and warm (Hidy, 1967)

Table 7: Monthly Total Wind Direction Counts for 1995-2004

		Jan	Feb	Mar	Apr	Mar	Ju	Jul	Au	Se	Oc	Nov	Dec	TOTAL	%
	NE	582	479	359	224	62	28	29	97	32	333	513	580	3317	45.75
	E	2	12	30	3	0	0	0	0	0	0	0	1	49	0.68
	SE	19	46	70	63	33	37	34	55	79	60	53	27	576	7.94
	S	0	0	0	0	0	0	2	3	0	0	1	0	6	0.08
	SW	6	12	96	206	418	423	457	386	271	131	14	4	2424	33.43
	W	0	11	0	2	4	4	3	5	3	1	0	0	22	0.30
	NW	11	17	65	52	97	108	95	133	154	95	17	8	852	11.75
	N	0	0	0	1	0	0	0	1	1	0	2	0	5	0.07
Total		620	566	620	551	614	600	620	620	600	620	600	620	72510	100

Figure 14 shows the monthly average direction count distribution for each wind direction. Hidy (1967) affirmed that atmospheric heating is converted into average kinetic energy during the rising of masses of warm air since wind direction is velocity dependent. Thus, it can be deduced from Figure 14 that higher direction count corresponds to high kinetic energy and low potential energy and vice versa. This implies that all the crests in Figure 14 represent points of maximum kinetic energy and all the troughs represent points of maximum potential energy.
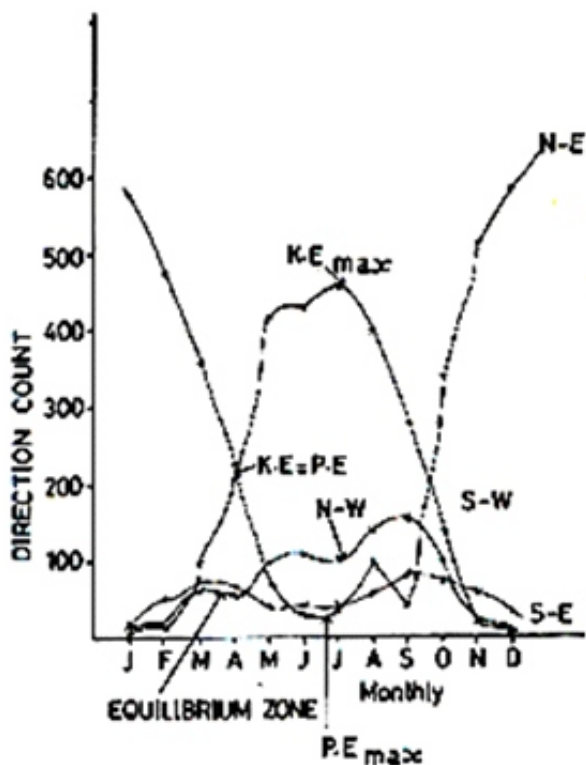
Figure 14: Monthly Total Direction Count Distribution

Along the paths of motion of these two winds, there is an equilibrium point where the kinetic energy of one wind is equal to the potential energy of the other wind. These points are where the effects of these two winds are mixed which lie generally between the month of February and May, and between September and November as shown in Figure 14. These points, where the SW wind (i.e. warm wind) slip over the NE wind (i.e. cold wind), are the points of interchange of energy (Elegba *et al*. 1982) and (Darwishs and Sayigh, 1987).

CONCLUSION

Using the available wind data acquired from observatory in the Nigerian College of Aviation Technology, Zaria, an assessment of wind energy potential in Zaria was accomplished. This was aimed at gaining an in sight into the feasibility of harnessing wind energy in Zaria for various developmental purposes.
Average wind speed of 1.68 m/s at 2.5 m height, with the highest instantaneous value of 2.35 m/s occurring in July, was obtained. At 10 m height the average speed increased to 2.10 m/s. Maximum average speed of 3 m/s was observed from January through July and low average wind speed period was observed from August to

December. This shows that speed is enhanced by the altitude increase. Though, the average annual wind speed in Zaria metropolis obtained here is not very high, it can still be harnessed for wind power generation. Some wind machines (e.g. one designed by U.S.C. NIG.L.T.D) have a start up wind speed of 1.5m/s. Further, the highest average power per unit area of $16.46\,W/m^2$ occurs in May but $9.76\,W/m^2$ power per unit area is extractable in the same month

The NE wind direction dominates other directions because out of 6856 direction counts that have been recorded throughout the years NE wind accounted for 3050 direction counts, which represents 44.5 %. The SE wind has the lowest counts of 7.7 %. It was also observed that dry season (NE wind period), normally runs from the month of November to February and marked by high NE direction counts within these months. Rainy season (SW wind period) runs from the month of May to September and marked by high SW direction counts within these months as well.

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