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Appraisal of Wind Energy Potential in Zaria Metropolis

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Appraisal of Wind Energy Potential in Zaria Metropolis

Olatunji S [α] & Sanusi, Y.K.[σ]

Abstract - Daily wind speed and directions obtained using wind vane and anemometer for a period of ten years (1995-2004) were acquired from meteorological station located at longitude 07 º 41′ E and latitude 11º08′ W, altitude of 686 m in Nigerian college of aviation technolog Zaria. The readings were usually taken twice in a day, at 10.00 am and at 4.00 pm. The results showed a relative dominance of N-E. With 7251 direction counts recorded throughout the years N-E windhas3317 direction counts representing 45.75%, S-W 33.4%, N-W, 11.75% S-E 7.94% E, 0.68%; W, 0.30% S, 0.08% and N, 0.07%. The maximum wind speed of 3 m/s was obtained at a height of 10 m above the earth surface. There is an evidence of speed increase with height above the earth surface. The average extractable wind power per unit area wasnot less than 9 w/m^2 in the area . It was also observed that dry season (N-E wind period), normally runs from the month of November to February whereas the rainy season (S-W wind period), and runs from the month of May to September.

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I. Introduction

Wind was seen by a Greek philosophers-Anaximander as a current of air produced when air is stirred or melted by the sun (Brown, 1962)Atmospheric pressure varies from day to day and from place to place.So air flows from a high atmospheric pressure towards a low area.Thus, the process of equalisation taking place between a region of rarefied air and one that is denser tends to initiate air flow/current. Energy extracted from the wind is in the form of rotary, translational, or oscillatory mechanical motion (Cheremisnaff, 1978)

In consequence, wind results from the movement of air masses and arises primarily due to unequal heating of the earth's surfaces by the sun. The air over oceans and lakes remains relatively cool during the days since much of the sun's energy is consumed in the evaporating water or is absorbed by the water itself (Fig. 1) Over land, the 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 (Fig. 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 wormer at night. Similar breezes occur on mountain sides – during the day as the heated air rises along the warm slopes that face the sum (Fig. 3). During the night, the relatively heavy cool air on the slope flows down into the valleys (Fig. 4). (Eldridges 1979). Thus, mountain sides (valley) are cooler at night.

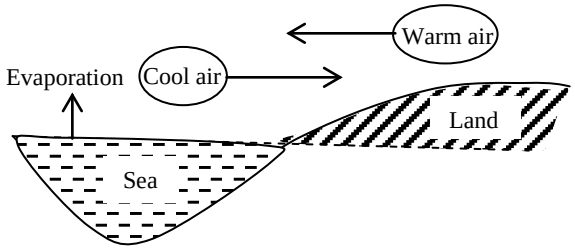

Figure 1 : Formation of Seashore Breeze during the Daytime

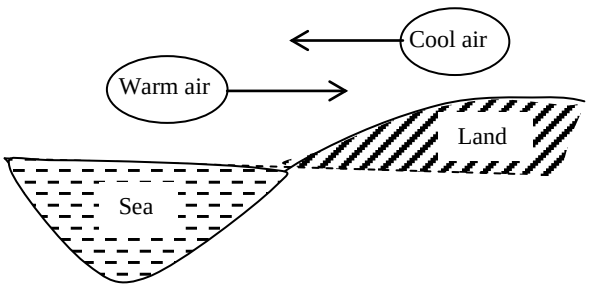

Figure 2 : Formation of Local Offshore Breeze during the Night time

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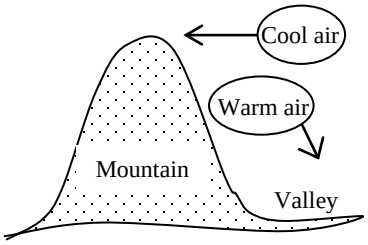

Figure 3 : Formation of Mountain Breeze During the Daytime

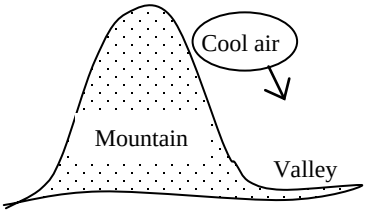

Figure 4 : Formation of Valley Breeze During the Night time

Circulating planetary winds are likewise caused by the greater heating of the earth's surface near the equator than near the poles. 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).

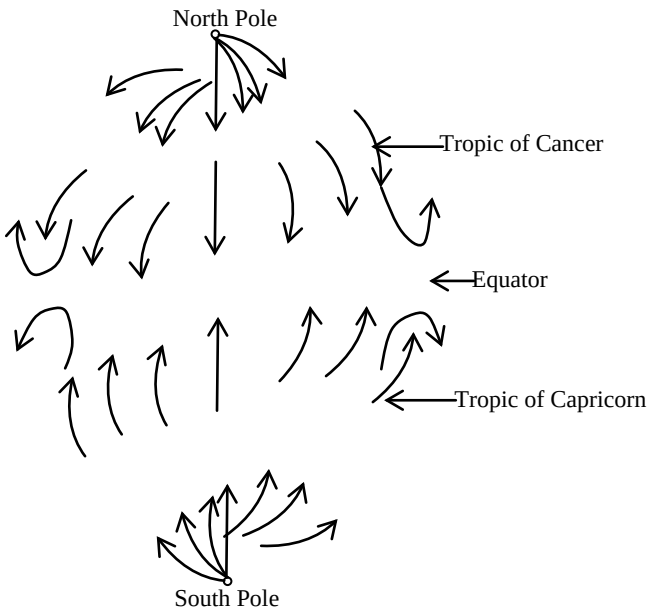

Figure 5 : Hypothetical Wind Nature, Were the Earth not rotating

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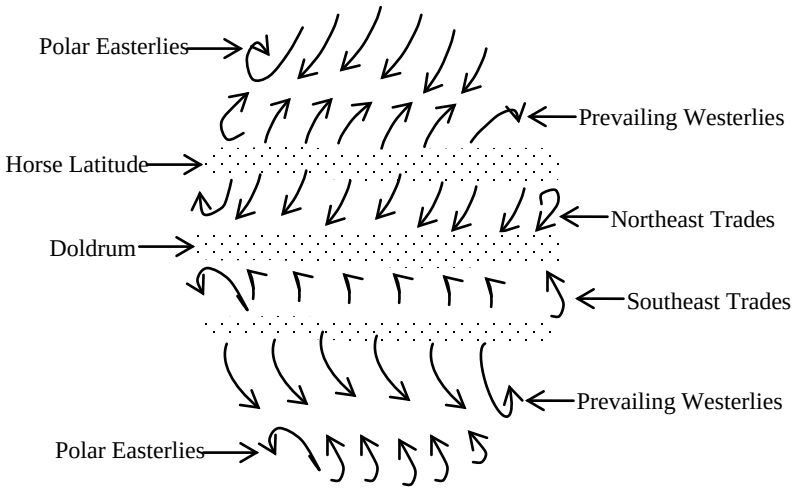

Figure 6 : Effects of Earth's Rotation on the Wind Shape

II. Related Literatures

In Zaria, Elegba, (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 3.2m/sec. It was observed that wind speeds in the area are generally high quantity between the months of November and June (Inglis,1978 and Swena, 2000) This is of very important significant because irrigation periods fall between the months of November and March in the area. Wind mills could therefore be used to advantage by matching the high water requirements with the high wind speeds in the period.

III. Materials and Methods

a) Instrumentation

The wind's direction was measured with wind vane. The vane or arrow points to the direction from which the wind is blowing so that wind is named from the direction it blows e.g. south-west wind blows from south-west direction. The wind vane is located in an exposed position on the field, at Nigerian College of Aviation Technology Zaria premises.

Anemometer was used to monitor the speed of windat a height of 2.5m above ground levelby calibrator on the support.

b) Theories

i. *Available Wind Energy*

The power available in a free flowing wind of a given cross – sectional area is given by

$$P_a = \frac{\rho V^3 A}{2} \quad (1)$$

Where $\rho = density, V = velocity\ and\ A = area$

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 is through their average available wind power per unit area (Justus, 1978). That is

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

ii. *Extractable Wind Energy*

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 extracted during the programme - Wind Energy Conversion Systemof U. S. A. in the year 2000 given by

$$P_e = \frac{C_p \rho V^3 A}{2} \quad (3)$$

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

iii. *Average Wind Speed*

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

$$\frac{V_H}{2.5} = \frac{V}{2.5} \quad (4)$$

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Where V_H = wind speed at a desired height and V = wind speed at reference height e.g. 2.5 m

iv. *Wind Energy Flux*

The available wind power per unit area is given as

For instance ρ = 1.16 kg/m^3 at 30°C (Dewinkel, I.E.S.; report 104)$\frac{P_a}{A} = 0.58V^3$, and assuming maximum machine efficiency, then $C_p = 0.593$ and

$$\frac{P_e}{A} = 0.3344\, V^3.$$

c) Data Acquisition

Data was obtained from meteorological stationlocated at longitude 07° 41′E and latitude 11°08′W, and at an altitude of 686m in Nigerian college of aviation technolog Zaria.Daily wind speed and directions obtained from wind vane and anemometerfora period of ten years (1995-2004) were acquired. The readings are usually taken twice in a day, at 10.00am and at 4.00 pm. Average daily wind speeds for duration of ten years were collected for Zaria, 1995-2004 inclusive. Ten year period is considered adequate for any peculiar climatological and seasonal variations as recommended by (Ishaku 1982)

IV. Results and Discussions

a) Wind Speed

Wind speed of 2m/sec is considered to be the minimum threshold speed for any meaningful small scale wind power application (Elegba *et.al.*, 1982). Average wind speed in the area is enhanced by the altitude increase (Tables 1-3) The maximum average wind speed of 3 m/s was observed from the month of January through Julyand low average wind speed period is observed from August to December (Fig. 7) The fact that high average wind speed period is observed between January to July is of domestic and economic important. This is because it is the period when irrigation is carried out and supply of domestic water from other sources is low.

The variation of wind speed over the years is not much pronounced. It can be seen in figure 8 that wind speed was fairly steady from 1995 to 1999 after which if fluctuates. The average wind speed over the ten years was seen to be 2.1 m/s (Table 3) There exists 9 W/m^2 extractable wind power per unit area in the metropolis (Fig. 9)

Table 1 : Wind Speed for 1995 - 2004 at 2.5 m Height

	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 at 10m Height

Month	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 : Yearly Average Wind Speed at 10m Height

Year	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

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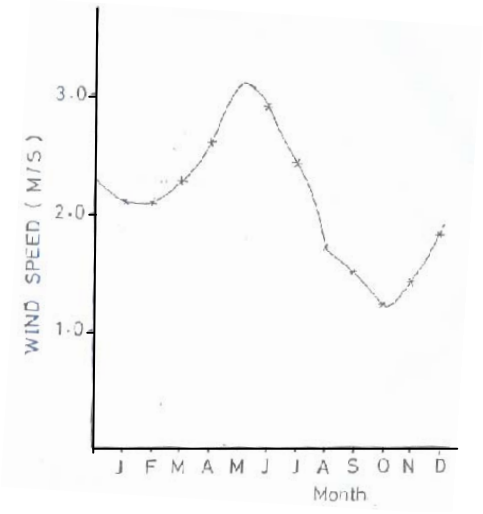

Figure 7 : Monthly Average Wind Speed Distribution

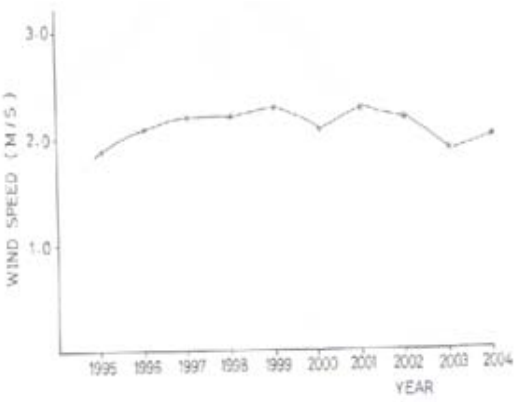

Figure 8 : Yearly Average Wind Speed Distribution

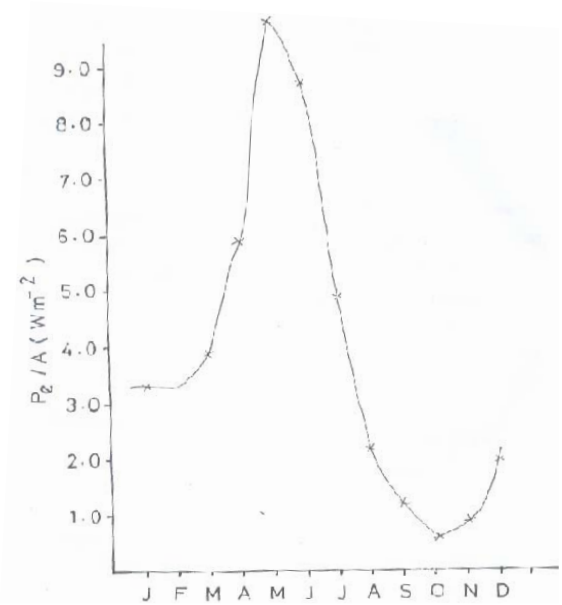

Figure 9 : Extractible Wind Power perunit Area Distribution

Table 4 : Monthly Extractable Wind Power per Unit Area Wind Directions

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Pa(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

Month	Jan.	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Pe/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

b) Wind Directions

In order to prepare table 6, the wind direction data for each month and for each of the prevailing directions are counted (direction count) over the period under study. To plot a graph of monthly and yearly (Figures 10 and 11) total direction count for each month and for each wind direction over the period Table 6a-b are summed up to obtain table 7 and table 8.

Throughout the ten years under study, the NE wind direction is found to be the most predominant

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(3317 counts, 47.75%) out of 7251 counts recorded for the period. This is then followed by the SW wind direction (2424direction counts, representing 33.43%)

Figure 10 shows that NE wind direction count dominates over all other wind directions and the fact that NE wind is cold and dry wind reveals the tropical nature of Zaria. Hence, NE wind is predominant wind in Zaria.

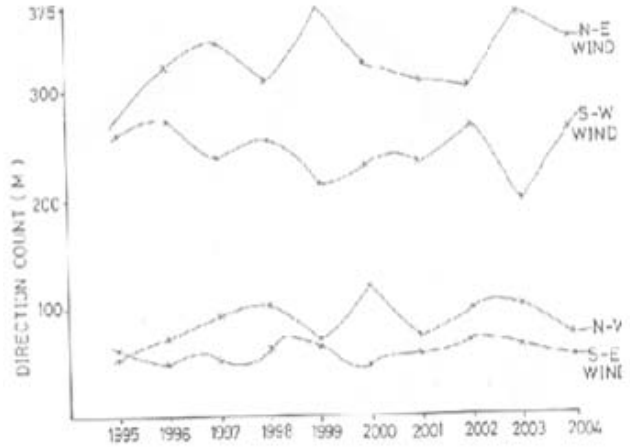

Figure 10 : Yearly Total Direction Count Distribution

c) Direction Count Distribution

When the sun heats the air molecules on the surface of the earth, theygain kinetic energy and move upward with higher kinetic energy (higher direction counts) and lower potential energy until maximum kinetic energy is attained. At this point, the molecules start to drift downward with increasing potential energy and decreasing kinetic energy (lower direction count) until maximum potential energy is attained. The process continues as confirmedin figure 11.This agrees with the assertion that atmospheric heating is converted into average kinetic energy during the rising of masses of warm air Hidy (1967) Further, since wind direction is velocity dependent, it can be seen from fig.11 that the higher the direction count, the higher the kinetic energy and the lower the potential energy and vice – versa. This implies that all the crests in fig. 11 represent points of maximum kinetic energy and all the troughs represent points of maximum potential energy.

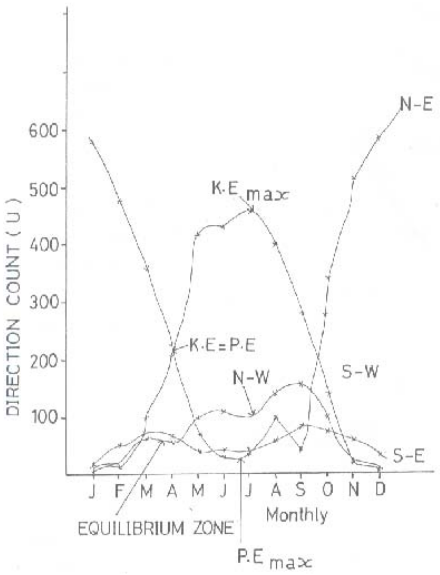

Figure 11 : Monthly Total Direction Count Distribution

The NE wind is characterised by dry and cold naturewhileSW wind ischaracterisedby wet and warm nature. This can be seen from fig. 11 in that NE wind has maximum potential energy. But along the paths of motion of these two winds, there is a point where the kinetic energy of one wind is equal to the potential energy of the other wind (equilibrium point). These pointsare where the effects of these two winds are mixed; thisliegenerally between the month of February and May, so also between September and November (Fig. 11) These points where the SW wind (warm) slips over the NE wind (cold) are the points of interchange of energy.

Hidy (1967) stated that rising of warm air and sinking of cold airis a direct circulation that heads to the release of potential energy to the kinetic energy of fluid motion. He furthered that when cool air over takes warmers air and drifts underneath it, a cold front develops; warm air slipping over retreating cold air gives rise to a warm front.

The nature of fig. 11 confirmed that when the NE wind (cold) slips over the SW wind (warm) cold front develops. This cold front generally stretched from the month of October to March. Also,when the SW wind (warm) slips over NE wind (cold) warm front develops. This warm front generally stretches from the month of April to September. Coincidentally, April-September marks the wet/rainy session, October-March marks the dry and coldest (hazy) period; and partly March - April usually witness extremelyhot weather.

Distribution of wind direction monthly directing count is shown in table 6a-j.

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Table 6a : 1995 Monthly Directing Count

1995		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
WIND DIRECTION COUNT	NW	0	0	0	3	14	66	2	9	7	8	5	0
	NE	60	46	30	3	2	4	4	4	7	18	37	27
	SW	0	0	1	6	42	46	52	46	37	23	5	0
	SE	0	0	0	0	4	4	3	3	9	13	12	5
	N	0	0	0	0	0	0	0	0	0	1	0	0
	W	0	0	0	0	0	0	0	0	0	0	0	0
	S	0	0	0	0	0	0	1	0	0	0	0	0
	E	2	10	23	0	0	0	0	0	0	0	0	0

Table 6b : 1996 Monthly Directing Count

1996		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
WIND DIRECTION COUNT	NW	0	1	2	6	8	5	7	9	16	12	3	1
	NE	57	54	33	20	1	1	3	6	11	23	54	57
	SW	0	1	12	24	50	57	3	38	25	22	1	0
	SE	5	0	8	5	2	1	47	4	6	5	2	4
	N	0	0	0	1	0	0	4	0	1	0	0	0
	W	0	0	0	1	1	2	0	3	1	0	0	0
	S	0	0	0	0	0	0	1	2	0	0	0	0
	E	0	2	7	2	0	0	0	0	0	0	0	0

Table 6c : 1997 Monthly Directing Count

1997		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
WIND DIRECTION COUNT	NW	2	2	7	5	12	12	9	16	18	7	0	2
	NE	59	52	45	22	4	0	0	1	7	34	58	60
	SW	0	0	2	23	45	45	50	40	30	14	0	0
	SE	1	2	8	20	3	3	3	5	5	7	2	0
	N	0	0	0	0	0	0	0	0	0	0	0	0
	W	0	0	0	0	0	0	0	0	0	0	0	0
	S	0	0	0	0	0	0	0	0	0	0	0	0
	E	0	0	0	0	0	0	0	0	0	0	0	0

Table 6d : 1998 Monthly Directing Count

1998		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
WIND DIRECTION COUNT	NW	0	1	7	17	12	16	9	12	14	13	1	1
	NE	60	42	45	19	3	3	2	2	16	21	48	58
	SW	2	3	4	31	43	38	46	43	23	21	0	1
	SE	0	10	6	3	4	3	5	5	7	7	11	2
	N	0	0	0	0	0	0	0	0	0	0	0	0
	W	0	0	0	0	0	0	0	0	0	0	0	0
	S	0	0	0	0	0	0	0	0	0	0	0	0
	E	0	0	0	0	0	0	0	0	0	0	0	0

Table 6e : 1999 Monthly Directing Count

1999		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
WIND DIRECTION COUNT	NW	0	1	4	1	7	12	9	17	18	4	1	0
	NE	62	44	43	32	8	2	4	2	12	51	56	59
	SW	0	1	7	11	45	37	44	38	22	4	1	1
	SE	0	10	0	16	2	9	5	4	8	3	2	2
	N	0	0	0	0	0	0	0	0	0	0	0	0
	W	0	0	0	0	0	0	0	0	0	0	0	0
	S	0	0	0	0	0	0	0	0	0	0	0	0
	E	0	0	0	0	0	0	0	0	0	0	0	0

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Table 6f : 2000 Monthly Directing Count

2000		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
WIND DIRECTION COUNT	NW	2	6	10	7	12	16	12	19	18	15	0	0
	NE	59	48	35	20	20	5	6	2	2	27	50	60
	SW	0	1	12	31	41	35	37	31	31	18	0	0
	SE	1	3	5	0	5	2	5	7	7	2	8	1
	N	0	0	0	0	0	0	0	0	0	0	1	0
	W	0	0	0	1	3	2	2	2	2	0	0	0
	S	0	0	0	0	0	0	0	0	0	0	0	0
	E	0	0	0	1	0	0	0	0	0	0	0	1

Table 6g : 2001 Monthly Directing Count

2001		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
WIND0 DIRECTION COUNT	NW	4	0	6	2	12	7	11	12	11	6	0	1
	NE	55	55	28	36	5	3	5	6	13	45	55	6
	SW	3	0	22	13	44	35	44	34	21	4	2	1
	SE	0	1	6	9	1	5	1	9	15	7	2	0
	N	0	0	0	0	0	0	0	0	0	0	0	0
	W	0	0	0	0	0	0	0	0	0	0	0	0
	S	0	0	0	0	0	0	1	1	0	0	0	0
	E	0	0	0	0	0	0	0	0	0	0	1	0

Table 6h : 2002 Monthly Directing Count

2002		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
WIND DIRECTION COUNT	NW	1	2	0	6	7	5	18	11	19	14	6	0
	NE	54	47	26	18	7	2	1	3	9	30	44	59
	SW	0	2	16	30	43	47	40	41	29	12	4	0
	SE	7	5	10	6	5	6	3	7	3	6	6	3
	N	0	0	0	0	0	0	0	0	0	0	0	0
	W	0	0	0	0	0	0	0	0	0	0	0	0
	S	0	0	0	0	0	0	0	0	0	0	0	0
	E	0	0	0	0	0	0	0	0	0	0	0	0

Table 6i : 2003 Monthly Directing Count

2003		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
WIND DIRECTION COUNT	NW	1	4	13	4	4	15	11	13	21	14	0	0
	NE	59	41	32	47	19	7	2	6	7	35	57	57
	SW	0	1	11	3	36	37	45	34	21	8	0	1
	SE	2	10	6	6	3	1	4	9	11	5	3	4
	N	0	0	0	0	0	0	0	0	0	0	0	0
	W	0	0	0	0	0	0	0	0	0	0	0	0
	S	0	0	0	0	0	0	0	0	0	0	0	0
	E	0	0	0	0	0	0	0	0	0	0	0	0

Table 6j : 2004 Monthly Directing Count

2004		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
WIND DIRECTION COUNT	NW	1	0	8	1	9	14	7	15	12	2	1	3
	NE	57	50	42	17	12	1	2	1	8	49	53	52
	SW	1	3	7	34	39	42	52	44	32	5	1	1
	SE	3	5	9	8	2	3	1	2	8	5	5	6
	N	0	0	0	0	0	0	0	0	0	0	0	0
	W	0	0	0	0	0	0	0	0	0	1	0	0
	S	0	0	0	0	0	0	0	0	0	0	0	0
	E	0	0	0	0	0	0	0	0	0	0	0	0

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Table 7 : Yearly Total Wind Direction Count

WIND DIRECTION COUNT	Year	1995	1996	1997	1998	1999	200	2001	2002	2003	2004
	N-E	272	320	342	209	375	219	300	300	369	344
	S-E	61	46	51	63	69	46	56	67	64	53
	N-W	54	70	92	103	74	117	72	97	100	73
	S-W	258	271	239	255	212	233	232	266	197	261

Table 8 : Monthly Total Wind Direction Count

WIND DIRECTION COUNT		Ja	Fe	Ma	Apr	Ma	Ju	Jul	Au	Se	Oc	Nov	De	TOTAL	%
	N-E	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
	S-E	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
	S-W	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
	N-W	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

V. Conclusion

The fact that wind parameters vary with seasons and topography of the side considered, a careful assessment of wind energy potential in Zaria was carried out with wind data obtained therefore. This is in order to have an in sight into the feasibility of harnessing wind energy in Zaria for various developmental purposes. There is a relative dominance of N-E wind direction. This is because out of 7251 direction counts that have been recorded throughout the years N-E wind accountedfor 3317 direction counts, which represent 45.75%. Others are:S-W 33.4%, N-W, 11.75% S-E 7.94% E, 0.68%; W, 0.30% S, 0.08% and N, 0.07%. It was also observed that dry season (N-E wind period), normally runs from the month of November to February whereas the rainy season (S-W wind period), runs from the month of May to September. The maximum wind speed of 3 m/s was obtained at a height of 10 m above the earth surface. There is an evidence of speed increase with height above the earth surface. The average extractable wind power per unit area was not less than 9 w/m^2 in the area.

Though average annual wind speed in Zaria metropolis (2.1 m/s) is not very high, butcan still be harnessed for wind power generation, though at high altitudes as the result here depicts positive dependence of speed on altitude. This is because 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.

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