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Assessment of wind energy potential in Nyala: South Darfur state, Sudan

Yousef A. Alsabah[1], Suliman A. Abadalla[2], Abdelrahman A. Elbadawi[2,3], Hassan H. Abuelhassan[2]

[1] Hajjah University, Faculty of Applied Science, Physics Department, Hajjah, Yemen
[2] Alneelain university, Faculty of Science and Technology, Physics Department, Khartoum, Sudan
[3] Future University, Faculty of Basic Studies and continuing learning

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ABSTRACT

Renewable energies constitute an excellent solution for both the increasing of energy consumption and environment problems. Among these energies, wind energy is very interesting, caring and attentiveness. Whereas, the wind energy is the subject of advanced research. In the development of wind turbine, the design of its different structures is very important. It will ensure: the robustness of the system, the energy efficiency, the optimal cost and the high reliability. In this paper, descriptive method was used for wind energy assessment in south Darfur state, where the wind speeds, atmospheric pressure and temperature were taken from Sudanese Meteorological Authority, statistically analyzed using statistical program as well as the seasonal distribution of wind speeds in the region. The results showed that the wind energy according to the analyzed data is too promised. The study confirmed that south Darfur state can be established wind energy farms in nowadays or in the future to generate electricity in order to solve the energy problems that the region has suffered throughout history of Sudan.

Corresponding Author:

Yousef A Alsabah,
Faculty of Applied Scienc, Physics Department,
Hajjah University,
Hajjah, Yemen.
Email: y.a.alsabah@gmail.com

1. INTRODUCTION

Electricity plays a very important role in the human life, and how to generate it by effective methods is an interested case for the scientists all over the world. Wind energy deployment through wind turbines has attracted global interest in recent years; for instance, according to the World Wind Energy Association the worldwide wind energy reached a capacity of 743 Giga watts in 2020 [1,2]. And, this capacity follows an increasing trend due to the high environmental and political impacts of the wind-energy production. Currently, most large wind turbines around the world are installed on land with sparse population and vast land. However, in many countries, most inhabitants are concentrated in places along coastlines where land is scarce and power is in high demand. A wind farm located offshore could experience wind speeds that are, on average, 90% greater than that over land. Today most wind energy comes from turbines- essentially giant windmills. The wind turns two or three of turbine's propeller-like blades around the turbines rotor. The rotor is connected to main shaft which spins a generate electricity [2]. Many African countries expect to see electricity demand expand rapidly in coming decades. Indeed these have become major issues for international policy. Otherwise Egypt succeeded in wind farm location, and it now produces electric power more than 550 megawatt in Gable alzait area [2, 3]. Also wind farm project in morocco and Namibia, and

Kenai, which means many developing and emerging economies substantial unexploited wind energy potential. Sudan government has considerable electric issues in nowadays, by giving wind turbines in northern state, and this research study the possibility to use wind energy to generate electric power in Darfur specially in Nyala one of important and crowded city in Darfur district In this research the data are given from Sudan metrological Authority Nyala station, includes wind speeds temperatures degree and atmospheric pressure from 2014 to 2020 covered all south Darfur state Arias and east of Mara Mountain [4,5].

South Darfur state covers an area of 127,3 km^2, it located in the west of Sudan in Darfur district, it occupies greater part of forest and green land, the animals and agricultures are the main stay of its inhabitants. The state capital is Nyala with coordinates 11.31N, 25.02E and altitude 3088m above sea level [6,7]. The significant of electricity is the spinal column of progressing, and development and it plays pivotal role to establish wide projects, like agricultural and industrial projects, then helps to stop the ethnic conflicts, and makes satiability in all the country and especially in Dar four district [7].

In addition to this, modern technology and new innovation may be emerging in some industrialized countries which will also lead to more energy. Solar power is one of the best renewable sources available because it's one cleanest source of energy. Solar power is the conversion of sunlight into electricity either directs by using photovoltaic or concentrated power [8, 9]. Hydropower or water power is power derived from the energy of falling water or fast running water which may be harnessed for useful purposes flowing water creates energy that can be captured and turned into electricity [9,10]. This is called hydroelectric power or hydropower. The most common type of hydroelectric power plant uses a dam on a river to Store water in reservoir [11,12].

A wind turbine converts the kinetic energy from the wind to electrical energy. The power which can be extracted is proportional to the cube of the wind speed. There is, however, a theoretical limit to the power which can be extracted from the turbine. This is known as the Betz limit. This limit was derived by Betz to correspond to 59% of the maximum available power which can be extracted by the turbine [13,14].

Wind turbines are classified into two general types: horizontal axis and vertical axis. A horizontal axis machine has its blades rotating on an axis parallel to the ground. A vertical axis machine has its blades rotating on an axis perpendicular to the ground. There are a number of available designs for both and each type has certain advantages and disadvantages. However, compared with the horizontal axis type, very few vertical axis machines are available commerce [15,16].

Although vertical axis wind turbines have existed for centuries, they are not as common as their horizontal counterparts. The main reason for this is that they do not take advantage of the higher wind speeds at higher elevations above the ground as well as horizontal axis turbines [17,18].

A horizontal Axis Wind Turbine is the most common wind turbine design. In addition to being parallel to the ground, the axis of blade rotation is parallel to the wind flow. On a more homely front, the power of the wind is the rate of wind energy flow through an open window [19].

Wind energy depends on the amount of air (the volume of air in consideration), Speed of air (the magnitude of its velocity), Mass of air (related to its volume via density). Wind power quantifies the amount of wind energy flowing through an area of interest per unit time. In other words, wind power is the flux of wind energy through an area of interest. Flux is a fundamental concept in fluid mechanics, measuring the rate of flow of any quantity carried with the moving fluid, by definition normalized per unit area [20,21].

In general, flow is a vector quantify that can be oriented in any direction and only its component perpendicular to the area element is considered when quantifying the flux through that area.) The volume of air flowing through this area during unit time dt is given by the volume of The cylinder with cross-section area A and length U.dt i.e. The volume A.U.dt Therefore volume flow rate is AUU, the volume flux is U. The mass flow Rate is derived by multiplying the volume flow rate by the density of the Flow ρ and is equal to the mass of that cylinder divided by unit time

$$\frac{dm}{dt} = A.Udt \qquad 1$$

Wind energy by definition is the energy content of air flow due to its Motion. This type of energy is called the kinetic energy and is a function of Fluid's mass and velocity, given by

$$KE = \frac{1}{2}.m.u^2 \qquad 2$$

Wind power is the rate of kinetic energy flow. In derivation similar to the other flow rate quantities discussed earlier, the amount of kinetic energy flowing per unit time through a given area is equal to the kinetic energy content of the cylinder.

$$p = \frac{1}{2}\frac{dm}{dt} \qquad 3$$

The mass flow rate in equation (1) was substituted for air mass in Eq. (2). The Resultant equation for wind power is

$$p = \frac{1}{2}\, A.Udt \qquad 4$$

This is a fundamental equation in wind power analysis. It exhibits a highly nonlinear cubic dependence on wind speed. Whereby doubling the wind speed leads to eightfold increase in its available power. This explains why ambient wind speed is the major factor in considering wind energy. In Eq. (4). The power of the wind is a linear function of air density and as a result of the limited range of air density fluctuations; the density is of secondary Importance. The power dependence on the area implies a nonlinear quadratic dependence on the radius of a wind turbine swept area, highlighting the advantages of longer wind turbine blades. It is customary to normalize ambient wind power dividing by the area of interest; i.e., in terms of specific power flow. This leads to the definition of kinetic wind energy flux, known as the wind power density (WPD). Similarly, to the definitions of flux and flow rate above, wind energy flux is wind energy flow rate per unit area is given by:

$$\text{WPD} = \frac{p}{A} = \frac{1}{2}PU^2 \qquad 5$$

WPD is used to compare wind resources independent of wind turbine size and is the quantitative basis for the standard classification of wind Resource at the National Renewable Energy Laboratory (NREL) of the United States. Mean WPD has advantages over mean wind speed for comparing sites with different probability distribution skewers because of the cubic nonlinear dependence of wind power on wind speed And discussion there in). Further technical details of this classification system were originally introduced in typical values of wind power classes with the corresponding power densities and mean wind speeds are presented in Table 1 [8,22]

The wind power, a measure of the energy available in wind, is given by

$$PW = \frac{1}{2}A\rho V^3 \qquad 6$$

Where ρ is the air density taken as 1.225 kg/m^3, A is the cross section of the area through which it flows (swept area of turbine blade) in m2 and V is the velocity of the wind. It is computationally easier to work with wind power density, which is simply given by computationally easier to work with wind power density which is simply given by

$$P = \frac{1}{2}\,\rho V^3 \qquad 7$$

From equations 6 and 7, it is clear that wind energy can be estimated directly from empirical data by using the sample mean value and from Weibull model mean value of wind speed, V. P in equation 7 gives the power available from the wind. Theoretically, only 59% of this power is extractable but practically it is only possible to extract 30%. Hence, the practically extractable power is approximately given by: [9,23]

$$PE = 0.1V^3 \qquad 8$$

The design goal for VAWTs is no different than for HAWTs: to maximize Power production. The most general way of expressing the efficiency of the System toward this goal is through the power coefficient, CP, which is defined as

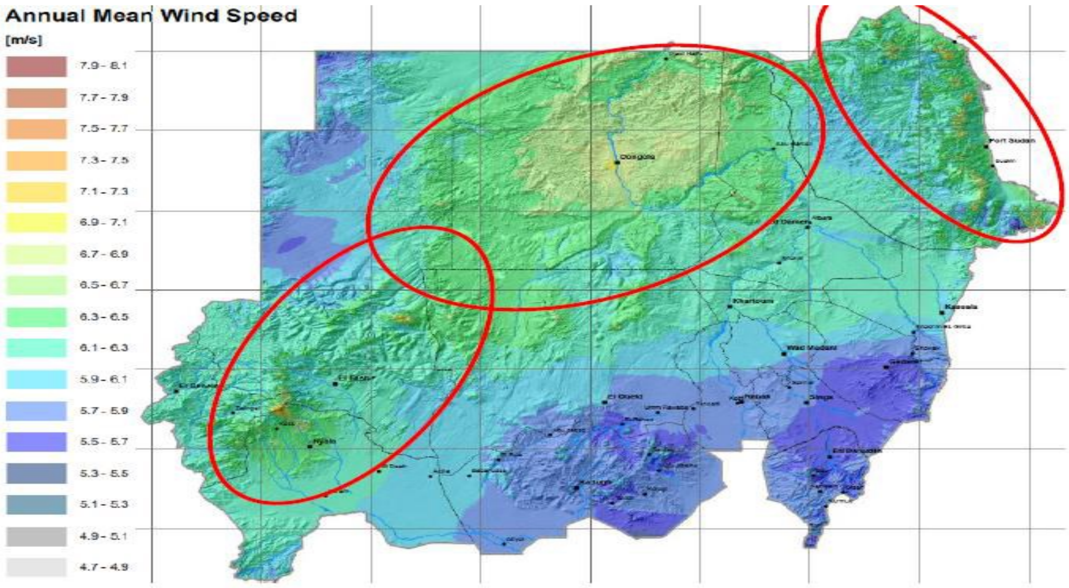
$$CP = \frac{P}{\frac{1}{2}\,PU^2A} \qquad 9$$

Where P is the power produced by the wind turbine, ρ is the density of the air, U is the free stream velocity, and A is the cross-sectional area of the wind Turbine this is the same equation used in calculating the efficiency of a HAWT however the cross-sectional area is calculated slightly differently. Rather than using the area of the disk swept by the blades, one generally uses the diameter of the rotors multiplied by the length of the rotor blades, As with HAWTs, many engineers strive to increase the power coefficient of any design, as this parameter represents the overall efficiency of a wind turbine [24,25].

2. Methodology

A wind measurement campaign was started in Northern Sudan in 2002 in order to identify areas of high wind energy potential and investigate the feasibility of electrical power generation by wind energy. Subsequent wind measurements have focused on other areas of high potential. A number of studies confirm that Sudan has considerable wind energy resources, with annual average wind speeds in selected locations in the range of 7-8 m/s, particularly in North State, north of latitude 12° N and along the Nile valley. In total, there is a potential of 5,000 MW of utility-scale wind energy generation in Sudan. The principal sites for wind energy have been identified as the central northern part of Sudan with Dongola at its center; and the Red Sea region, with Port Sudan as its major city. And South Darfur state Nyala. [10].

The Darfur region is characterized variation and diversity in terrain. In the north of it the desert is interspersed with valleys and group of hills that receive small amount of rain. Sometimes not more than ten inches this helped the growth of grasses suitable for breeding animals. As for the central part of Darfur it consists of mountains and sandy areas on the eastern and western sides and is exposed to relatively large amount of rain ranging in diameter from 12 inches to 25 inches above jabel Mara. As for southern section it is characterized by a lot of rain which helps the spread of tall weeds that are suitable raising livestock. The average temperature is between 25 and 35degrees.The region extends from the desert in the north to the poor savannah in the south one of the important mountain Africa found in Darfur Jebel Mara which has heights of 3088 m where the most fertile Darfur lands are located. The region is also divided administratively into five states. **[11]**



Picture 1 Calculated annual average wind speeds at 50 m height in Sudan (Red ovals show areas with the highest potential.24 At 60 m height, the winds speeds in Dongola, Nyala and the Red Sea region are 7.2, 7.9, and 7.0 m/s, respectively.

2 -1 The data:

The data was on the monthly wind speed obtained from the Sudanese Meteorological Authority from Nyala state at hub height of 10 meters. The period covered by the data was 2014 to 2021 the data are shown in table1 [12].

Table 1 wind speed in m/s

year	*JAN*	*FEB*	*MAR*	*APR*	*MA*	*JUN*	*JUL*	*AU*	*SE*	*OC*	*NO*	*DE*
2014	940.0	932.2	936.9	936.4	936.6	937.9	938.8	939.1	939.0	938.8	939.7	940.6
2015	942.2	938.1	937.1	938.6	937.2	937.8	938.9	938.8	938.6	938.5	939.7	943.9
2016	942.8	940.5	936.8	936.3	937.8	938.4	938.4	938.8	939.2	937.5	938.6	940.6
2017	939.4	940.4	937.5	936.6	937.1	937.8	938.5	938.2	938.7	938.0	939.2	939.7
2018	941.7	936.6	936.8	936.8	935.9	938.1	938.7	939.3	938.0	938.0	939.0	941.3
2019	939.9	939.2	938.5	936.5	935.8	938.1	938.2	939.3	938.4	938.2	938.5	940.9
2020	942.5	941.8	938.0	937.5	938.4	937.8	937.5	938.5	938.5	938.4	940.0	940.0

Table 2 The availability of abundant sunshine throughout the year. It is well known that wind energy is derivable from solar energy.

year	*Jan*	*Feb*	*March*	*April*	*May*	*June*	*July*	*August*	*Sep*	*Oct*	*Nov*	*Dec*
2014	3.0	4.0	3.5	3.0	3.0	3.0	3.5	3.0	2.0	3.0	3.5	4.0
2015	3.0	4.0	4.5	5.0	3.0	3.5	3.0	2.5	2.5	3.5	3.5	4.5
2016	4.0	4.0	4.0	3.0	2.5	3.0	3.0	2.0	1.5	2.0	3.0	4.0
2017	3.5	4.5	3.0	3.5	2.5	2.5	2.5	2.0	1.5	2.0	3.0	3.5
2018	4.0	3.5	3.0	3.0	2.0	2.5	2.5	2.0	2.0	2.0	3.0	3.0
2019	2.5	1.0	3.5	3.0	2.0	2.0	2.5	2.0	2.0	1.5	3.0	4.0
2020	4.0	5.5	2.0	4.5	1.5	3.0	4.0	3.0	2.5	3.0	4.0	4.5

2 -2 The annual average of temperatures degrees

The temperature increases into 40 centigrade in May in summer and it lows down in winter about 14 centigrade in December. Table 3 Maximum annual temperatures (Centigrade).

Hence, the availability of abundant sunshine gives an indication of the wind energy potential of Nyala. A recorded yearly average wind speed of m/s is further confirms, this. What remains is an expository study of the wind characteristics of Nyala to highlight the salient features of it.

Table 3 temperature degree

Month	JA	FE	MAR	APR	MAY	JUN	JUL	AU	SEP	OC	NO	DE
2014	31.6	32.8	38.2	39.4	39.3	38.3	35.5	31.5	33.1	35.2	34.4	32.3
2015	29.9	35.0	38.1	37.6	39.7	39.1	36.9	33.3	34.9	34.4	33.9	27.4
2016	28.2	32.7	39.4	39.6	39.7	37.7	34.0	31.9	33.7	36.2	35.4	31.4
2017	38.4	31.3	37.3	39.0	39.6	36.9	34.3	31.7	33.7	36.4	33.8	31.9
2018	27.7	36.3	37.7	38.7	39.6	36.1	34.1	32.4	34.4	36.7	34.4	30.4
2019	33.5	34.0	36.8	39.6	40.6	36.7	34.1	31.7	33.4	32.6	34.5	31.3
2020	28.7	31.8	37.8	39.9	39.4	38.6	33.5	30.7	32.9	36.0	33.9	33.3

3. The data analysis

Seasonal, monthly and annual distribution of daily and monthly wind speed. ***Seasonal distribution***, *the w*inter begins from November and continuously to February, where the directions of the wind speeds is from north to northeast of the region and the range of wind speeds between from 3 into 5.5 meter per second, which is the highest wind speeds throughout the year at a height of ten meters from the surface of the earth.

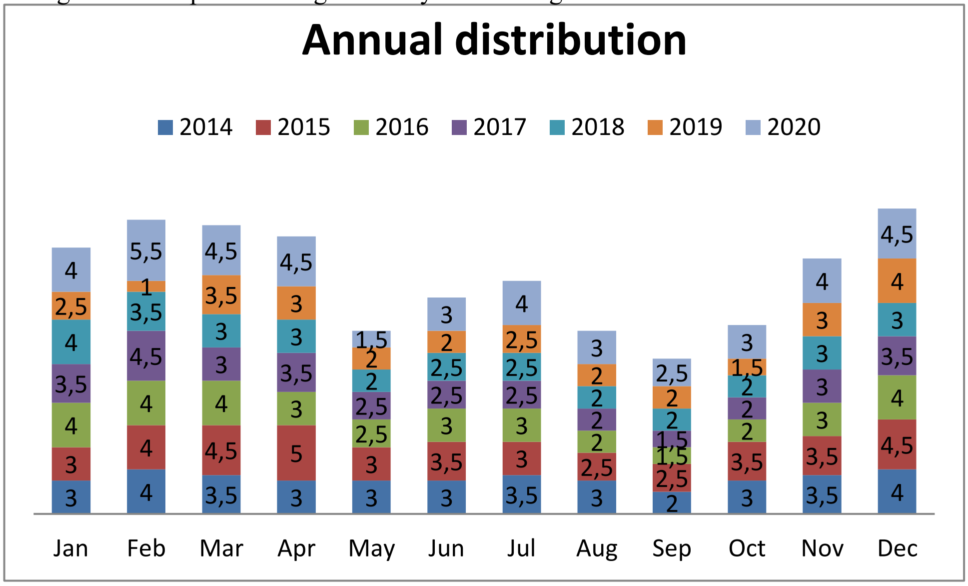
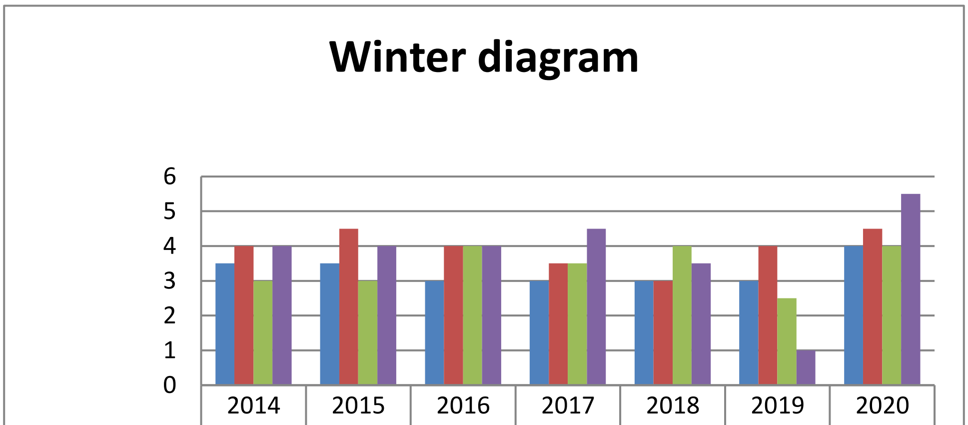


Figure 2 Seasonal, monthly and annual distribution of daily and monthly wind speed



	2014	2015	2016	2017	2018	2019	2020
November	3,5	3,5	3	3	3	3	4
December	4	4,5	4	3,5	3	4	4,5
January	3	3	4	3,5	4	2,5	4
February	4	4	4	4,5	3,5	1	5,5

Figure3 wind distribution in winter.

The average wind speeds in winter is 3.5 m/s and the highest wind speed is 5.5 m/s in 2020. This average wind speed was covered seven years ago from 2014 to 2020 that means there were stability in wind speeding. The summer season begins in March and ends with beginning of autumn and in June when the winds blow and inflate from northeastern direction accompanied by dust and their speeds are very high with high temperatures table 1 shows the average of wind speeds, monthly. Figure 4 shows the wind distributions in summer. The average of wind speeds in summer is 3.1 m/s which is covered the same period as winter.

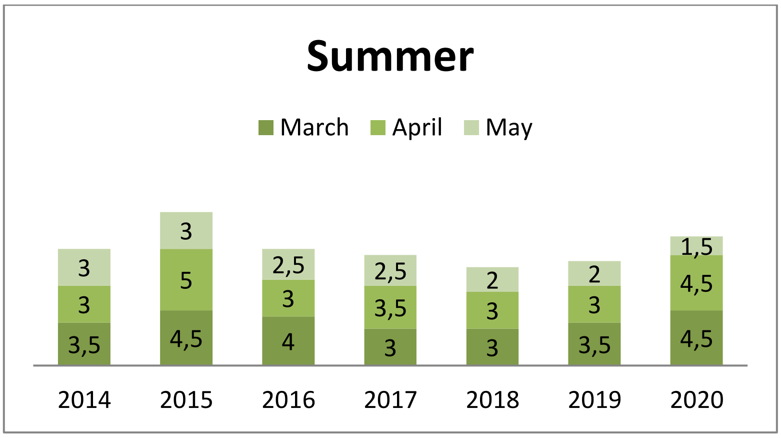


Figure4 wind distributions in summer

By the ends of summer autumn will begins from June to the ends of October. The directions of monsoon wind speeds change sometimes from south to southwest. In autumn wind speeds will be the lowest at all season of the year in the region and its range is between 1.5 into 3.5 meters per second. Accompanied degrees, are relatively in the average of temperatures. Figure 5 shows the average of the monthly wind speeds. The average wind speeds in autumn in seven years ago, was 2.5 m/s where in this season the temperature is low and wind direction turns into south and southwest.

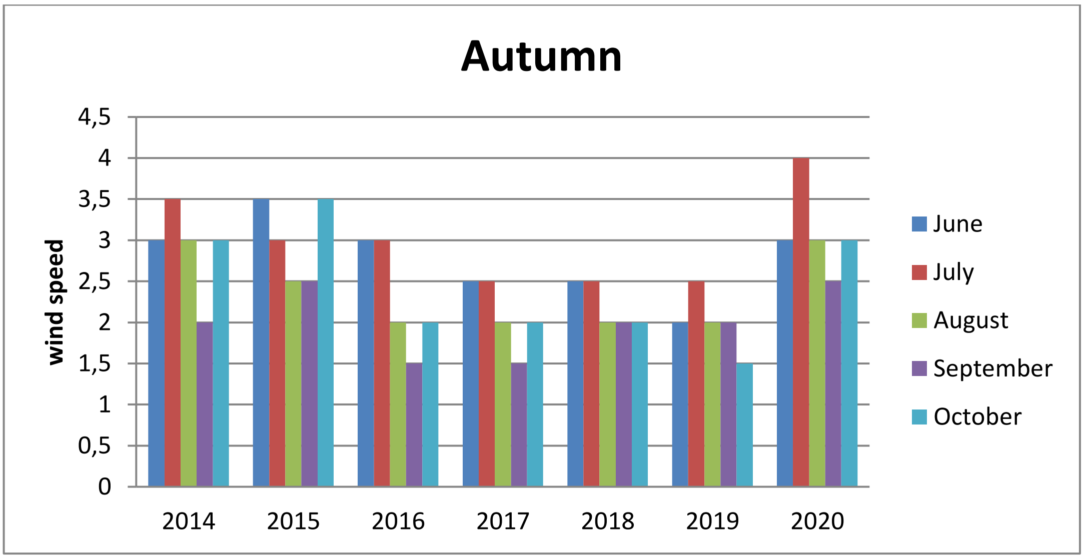


Figure 5. the average monthly wind speeds

Using the law of energy to convert the wind speed from a height of ten meters to the required heights and determine the difference between the distance of the anemometer and the turbine.

$$aV_2 = V_1 \frac{h_2}{h_1} \qquad 9$$

Where V_1 is the known wind speed at a hub height of h_1, V_2 is the wind speed to be determined for a specified hub height h_2. We assume the a is coefficient depend on stability of air and it range between 0.05 to 0.5 V_1 = 2.86 the minimum monthly average wind speed value for Nyala. At h_1 = 10 m and the wind speed was calculated at specified hub heights of h_2 = 30, 50, 70, 90, 110, 130 and 150 m, and these are tabulated in table 4.

Table 4 Estimated Average Wind Speed at Specified Hub Heights in Nyala.

Hub heights (m)	10	30	50	70	90	110	130
Sample estimate (m)	2.86	4.29	7.15	10	12.8	15.7	18.5
Model estimate (m)	3.1	4.65	7.75	10.85	13.95	17	20.1

4. Discussion

From table 1 it is clear that the wind is available throughout the years and the lowest wind speeds were annually in the autumn; specially the moths of august and September. The highest wind speeds were in the winter and summer season. Table 2 indicates that the atmospheric pressure is relatively stable. The state rises from sea level by 655m and the annual wind directions are northeast and south to southwest in the fall. Table 3 illustrates the maximum temperatures throughout the years sometimes reaches 40 degrees Celsius as the maximum rises of temperature. The temperature rises in March, April and May and decreases in the middle of the fall season. From the analyzing wind speeds, it was found that the wind increases by the increasing of temperature degrees and move from warm regions to the col one.

Figures 1, 2, 3 and 4 show the annual and seasonal distribution of wind speeds. The values of the flowing averages were found, the average wind speeds in the summer is 3.1m/s. The average wind speed in the fall season is 2.5m/s. The average wind speed in winter is 3.5m/s, and the average annual wind speeds is 3m/s. All of these speeds and averages are in height of ten meters and this is the height of metrological anemometer in the state.

From Picture1 the map of Sudan which shows the areas where the wind speeds increase annually, and hence energy farm can be established to generate electricity. It shows that wind speeds in the height of 50 m is higher than 7m/s and table 6 explains these facts theoretically using law of energies and calculated the difference between the higher of anemometer and estimated values of wind turbine.

5. Conclusion

The analysis of wind speed data has clearly shows that; wind energy has a great potential in Nyala. From the computation of the wind speed at hub heights in the range of 50 m to 130 m was investigated. It is a well-known fact that wind energy derives from solar energy. This was easily noticed here as the monthly data on temperature is strongly. This implies that high values of temperature associate with high values of wind speed. Coupling a wind turbine of swept area of 100km^2 into this environment can easily generate 300MW of electricity. And this amount of electricity enough to solve all the problem of energy in Darfur District. Consequently, there is the possibility of generating higher wattages of electricity in South Darfur State. Exploitation of wind energy potential is not yet popular with the Government. It is hoped that with the results of this paper represent an indicator to the government so as to begin develop the impetus to look in this direction of alternative source of an eco-friendly electricity generation.

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