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Comparative Assessment of Wind Energy Resources Using NASA data and meteorological station Measurements: A Case Study of Sebha city, Libya.

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ABSTRACT: This paper aims to evaluate wind energy for Sebha region, by considering wind energy as one of the renewable energy sources. Annual data obtained from (NASA) as well as from the National Center of Meteorology were used through the years of (2000-2010). The Weibull distribution was used to analyze the data, the Weibull distribution elements of such as the scale factor, shape factor and wind shear are considered and by evaluate the probability density function and cumulative distribution function then the wind energy and power density for designated time determined. The comparison between the Weibull distribution according to the NASA and measured of meteorology station results reveal a reasonable agreement. also based on the results the suitable wind turbine that can be installed for Sebha conditions was selected.

Index terms: Wind energy, Wind turbine, Weibull distribution, Sebha city.

1. Introduction.

The growth in people and their life demand guide to the power requirement for all the stats. The now a day the power production mainly comes from the fossil fuel began to reduce because of the impeding on the environment and the limited of the fuel type depends on the underground mining .And Libya is one of the country that mainly uses the fossil fuel for production for the moment the demand of the power dramatically increased .So it's preferable to manage to use a renewable sources of energy [1]. The energy from the renewable sources as wind, solar, biomass and geothermal are available and its friendly to the environment with respect to the classical resources [2]. Wind energy has eminent itself among numerous renewable energy sources (RESs) due to its prominent advantages of safety, reliability, and scarcity of pollution [3].

The air streams flow from a place of high atmospheric pressure to one of low atmospheric pressure due to variations in atmospheric pressure between the two regions. Wind turbines use the movement of the air to create electrical

energy [4]. The power of wind may fulfill the considerable energy needs for any region, whatever they are local or far away, linked to the grid or standalone [5]. Throughout ages, the breeze has been used to propel ships and power windmills for crushing grain and pumps water [6]. In the context of climate, wind vitality has shown to be a clean invention with enormous potential for achieving these aims. Wind vitality is not harmful to the environment carbon-free, and permanent. This is why several nations plan to devote an amount of their energy budget to wind cultivate development ventures [7].

Jary et al. [8].Tobruk, Derna, Benghazi, Ajdabiya, Sirte, Misrata, and Tripoli are the seven locations along the Libyan coast that were they focus on this study. The information to be used is derived from meteorological data provided by meteoblue map. Data were analyzed from (2017-2020). The best power density ever was (148.65 W/m², 142.34 W/m² and 139.96 W/m²) respectively in Derna, Misrata and Tobruk.

Teyabeen et al. [9] Teyabeen and associates used wind speed data obtained from the city of Zuwara in 2007 to assess the wind power density on a monthly and annual basis using the Weibull function. At the interval of ten minutes, the wind speed was recorded at heights of (50-30-10 m) over sea level. The investigation's find that the wind speed for the aforementioned heights, the yearly normal is (4.51 m/s, 5.86 m/s, and 6.26 m/s) . At these heights, the typical yearly wind power density was (113.71 W/m², 204.19 W/m², and 243.48 W/m²) respectively.

El-Osta et al. [10] estimated the energy production and power density of various sizes of wind turbines using international standards (IEC) and assessed the wind resource at Hon City. They assessed meteorological information at various elevations (61,60,40,20 m) and examined wind data from April 2011 to March 2012 using Excel and computational models. According to the data, the Nordex N100-2500 turbine achieved a power factor of (42 %) and availability of (83.7 %) in the same area and month as the V112-3000 turbine, which produced the best power factor (42 %), prior to April.

Alfalahi et al.[11] They assessed wind resources at elevations of 10and 50 for nine sites located in the Green Mountain region of eastern Libya.These sites are Almerj, Eslenta, Shahat, Alhaniya, Alarqub, Alkuf, Albayadha, Qasrlibya, and Tulmetha. Wind speeds and directions were obtained over a long period from meteorological stations, along with hourly data from NASA. This data was analyzed to determine the energy produced by the wind. The results showed that the Shahat site was the best, followed by the Al-Kuf site. Therefore, it was proposed to establish a 2 MW wind farm at these locations, with a 250 kVA turbine selected.

Ahwide et al. [12] seven Libyan sites' wind characteristics were examined. These are Goterria, Al-Asaba, Al-Aziziya, Derna, Tarhuna, and Masalata. Every ten minutes, the direction and speed of the wind were recorded. The Weibull distribution function and the Excel application were used to assess energy production and wind direction at various levels over a period of one and a half years. Taking into account wind turbines with outputs between 1500 and 2000, it was demonstrated that every turbine utilized is beneficial. three locations. A project development could find Tarhuna, Derna, and Al-Maqroun to be economically feasible places for wind power plants. It is believed that Masalata and Al-Asaba are financially viable sites for the wind turbine project.

In this paper, the annual energy produced and the annual capacity density of the city of Sebha were evaluated at different altitudes using the Weibull function and the cumulative function.

1-1. Data description.

The data obtained from the National Center of Meteorology of Libya. And NASA power data [13]. The data were analyzed using the Excel and MATLAB programs.

1-2. Studying region.

The city of Sebha is located in the southwest of Libya, between latitude (27°02′20″) and longitude (14°25′35″E), and is about 800 kilometers away from the coastal city of Tripoli [14]. Figure (1) shows the location of the city of Sebha.

Figure (1) Location of Sebha city.

2. Materials and method.

2.1 Weibull distribution.

Weibull distribution is a special case of Pierson class III distribution. In Weibull distribution, the variations in wind velocity are characterized by the two functions; (1) The probability density function and (2) The cumulative distribution function. The probability density function ($f(v)$) indicates the fraction of time (or probability) for which the wind is at a given velocity v. It is given by [15], [16].

$$f(v)=\frac{k}{c}\left(\frac{v}{c}\right)^{k-1}e^{-\left(\frac{v}{c}\right)^{k}} \quad (1)$$

$$F(v)=1-e^{-\left[\frac{\pi}{4}\left(\frac{v}{vm}\right)^{2}\right]} \quad (2)$$

2.2 Average wind speed.

One of the most important information on the wind spectra available at a location is its average velocity. In simple terms, the average velocity (v_m) is given by [15]

$$v_m = \left(\frac{\sum_{i=1}^{n} f_i v_i^3}{\sum_{i=1}^{n} f_i}\right)^{\frac{1}{3}} \quad (3)$$

2.3 Standard deviation.

One measure for the variability of velocities in a given set of wind data is the standard deviation (σ_v). Standard deviation tells us the deviation of individual velocities, The Standard deviation is given by [15].

$$\sigma_v = \sqrt{\frac{\sum_{i=1}^{n} f_i (v_i - v_m)^2}{\sum_{i=1}^{n} f_i}} \quad (4)$$

2.4 Extrapolation of wind speed.

Among wind speed extrapolation methods, the wind power law is the most widely used method. The wind power law can be given as [17-19].

$$v_2 = v_1 \left(\frac{h_2}{h_1}\right)^{\alpha} \quad (5)$$

where v_1 and v_2 are measured wind speed at height h_1 and h_2 respectively.

α is wind shear coefficient can be determined if wind speed measurement at two height is available and can be determined by the following equation [17], [18].

$$\alpha = \frac{ln(v_2/v_1)}{ln(h_2/h_1)} \quad (6)$$

In this study, wind shear coefficient value (0.2254) used for extrapolation wind speed at different hub height for Sebha city [20].

2.5 Standard deviation method.

This method used to determine shape factor (k) and scale factor (c).

The Weibull factors (k) and (c) estimated from the mean and standard deviation of wind data. K is determined by [15].

$$k = \left(\frac{\sigma_v}{v_m}\right)^{-1.090} \quad (7)$$

c was found using the expression [15].

$$c = \frac{v_m \, k^{2.6674}}{0.184 + 0.816 k^{2.73855}} \quad (8)$$

2.6 Weibull based approach.

we get energy density by using [15].

$$E_D = \frac{\rho a\, c^3}{2}\Gamma\left(\frac{3}{k}+1\right) \quad (9)$$

Energy available over a period (E_I) calculated by [15].

$$E_I = E_D\, T \quad (10)$$

where T is time period

Most frequent wind velocity calculated by [15],[21].

$$V_{FMax} = c\left(\frac{k-1}{k}\right)^{\frac{1}{k}} \quad (11)$$

The velocity contributing maximum energy to the regime ($V_{E\,Max}$). Energy per unit rotor area and time, contributed by a velocity V is [15],[21].

$$V_{E\,Max} = \frac{c(k+2)^{\frac{1}{k}}}{k^{\frac{1}{k}}} \quad (12)$$

3. Results and discussion.

The results of the analysis of data measured and obtained from NASA for Sebha city during (2000-2010) at height (10 m) are shown in tables (1) and (2), which show the annual Weibull variables, the average annual speed, the annual standard deviation, and the maximum possible wind speed, as well as the speed at which we obtain maximum energy, the annual wind power density, and the annual wind energy density

Table (1) Statistical Analysis for measured data at (10m).

Year	V_m (m/s)	σ_v	k	c	$V_{F\,max}$ (m/s)	$V_{E\,max}$ (m/s)	E_D (W/m^2)	E_I (Kwh/m^2)
2000	4.75	0.87	6.36	5.10	4.97	5.32	72.03	630.99
2001	4.97	0.85	6.87	5.30	5.18	5.50	80.58	705.92
2002	5.43	1.25	4.98	5.92	5.66	6.34	113.34	992.85
2003	5.81	0.75	9.25	6.07	6.00	6.20	111.94	980.56
2004	5.78	0.90	7.56	6.13	6.01	6.32	122.92	1076.76
2005	5.41	0.81	7.95	5.72	5.62	5.88	99.05	867.68
2006	5.15	0.98	6.10	5.54	5.38	5.81	92.62	811.36
2007	5.17	1.05	5.67	5.59	5.41	5.90	95.26	834.50
2008	5.35	0.70	9.22	5.60	5.53	5.72	87.95	770.40
2009	5.10	0.89	6.67	5.45	5.32	5.67	87.73	768.50
2010	5.22	0.93	6.85	5.58	5.45	5.81	94.40	826.92

Table (2) Statistical Analysis for NASA data at (10m).

Year	V_m (m/s)	σ_v	k	c	$V_{F\ max}$ (m/s)	$V_{E\ max}$ (m/s)	E_D (W/m^2)	E_I (Kwh/m^2)
2000	4.18	0.57	8.83	4.39	4.33	4.49	43.12	377.74
2001	4.06	0.57	8.55	4.26	4.20	4.37	40.11	351.36
2002	4.07	0.57	8.47	4.29	4.22	4.39	40.91	358.36
2003	4.34	0.40	13.25	4.42	4.39	4.47	24.15	211.58
2004	4.35	0.46	11.69	4.47	4.43	4.53	34.84	305.21
2005	4.34	0.46	11.65	4.47	4.43	4.53	35.06	307.16
2006	4.18	0.60	8.24	4.41	4.34	4.53	44.87	393.04
2007	4.18	0.58	8.55	4.39	4.33	4.50	43.89	384.48
2008	4.34	0.36	15.27	4.38	4.36	4.42	7.35	64.36
2009	4.16	0.46	10.98	4.29	4.26	4.36	34.09	298.60
2010	4.22	0.47	10.86	4.36	4.33	4.43	36.28	317.77

Regarding the average annual speed at the reference height (10 m), as shown in Figure (2), the maximum value for the average annual speed for the measured data was (5.808 m/s) during (2003) and the minimum value was (4.754 m/s) in (2000). As for the average speed for the obtained data from NASA, the maximum value for the average annual speed was (4.345 m/s) during (2004) and the minimum value was (4.055 m/s) in (2001).

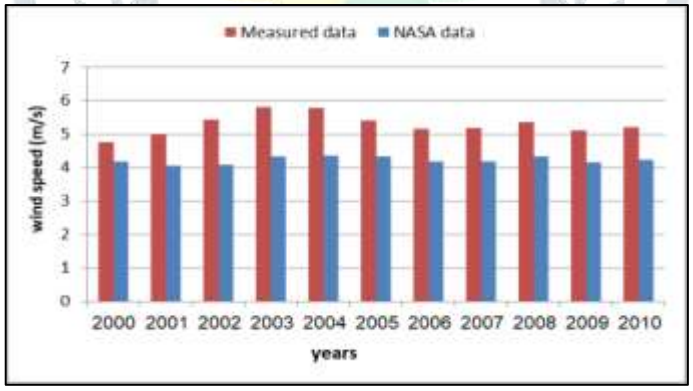

Figure (2) Annual wind speed at (10 m) for Measured and NASA data for Sebha city.

As shown in Figure (3), at the reference height (10 m) we note that the maximum value of the most frequently average annual speed of the measured data is (6.013 m/s) during (2004), While the minimum value is (4.965 m/s) during year (2000). According to NASA data, the maximum value of the most frequent average annual speed is (4.434 m/s) during (2004) while the minimum value is (4.201 m/s) in (2001).

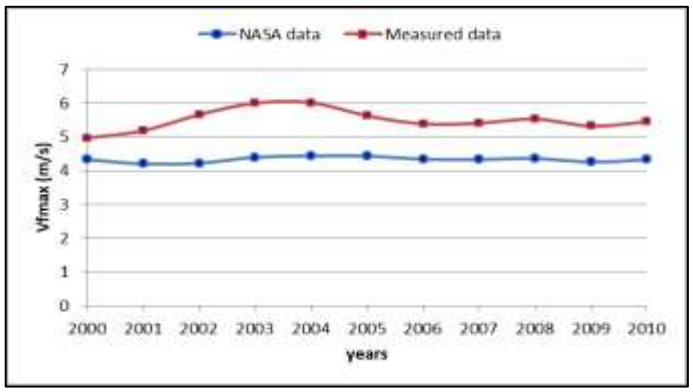

Figure (3) Annual most frequent wind speed at (10 m) for Measured and NASA data for Sebha city.

As shown in Figure (4), at the reference height (10 m), it was found that the maximum value for the speed providing the maximum energy is (6.337 m/s) during (2002) for the measured data, and the minimum value was (5.324 m/s) in (2000). As for the data obtained from NASA, the maximum value for the speed producing the maximum energy is (4.529 m/s) during (2004), while the smallest value is (4.360 m/s) in (2009).

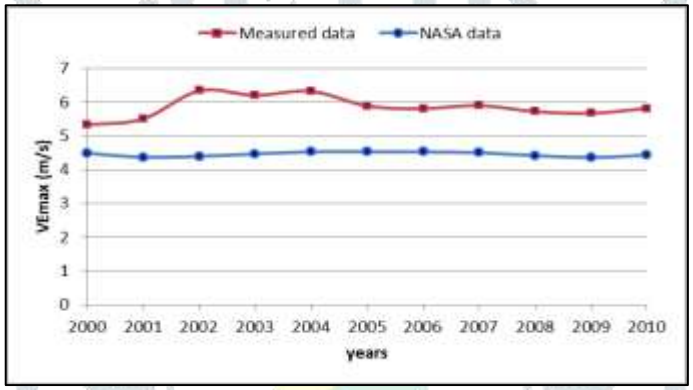

Figure (4) Annual wind speed contributing maximum energy at (10 m) for Measured and NASA data for Sebha city.

As shown in Figure (5), at the reference height (10 m), The maximum value of the wind power density for the measured data is (122.917 W/m^2) during (2004) and the minimum value of the power density is (72.030 W/m^2) in (2000) As for the data obtained from NASA, it was The maximum value of wind power density is (44.867 W/m^2) during (2006) and the minimum value of wind power density is (7.347 W/m^2) in (2008).

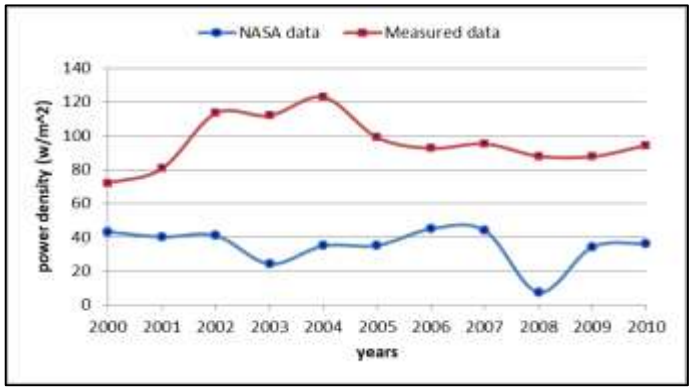

Figure (5) wind power density at (10 m) for Measured and NASA data for Sebha city.

In Figure (6), for the measured data, it was found that the maximum value of wind energy density is (1076.760 Kwh/m^2) during (2004) and the minimum value is (630.985 Kwh/m^2) in (2000). As for the data obtained from NASA, that the maximum value of wind energy density is (393.040 Kwh/m^2) during (2006). The minimum value was (64.364 Kwh/m^2) in (2008).

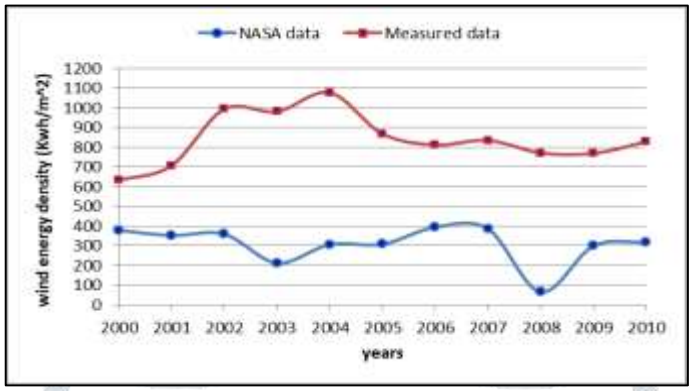

Figure (6) Wind energy density at (10 m) for Measured and NASA data for Sebha city.

Table (3) and (4) shows annual Weibull variables, the average annual speed, the annual standard deviation, and the maximum possible wind speed, as well as the speed at which we obtain maximum energy, the annual wind power density, and the annual wind energy density for measured and NASA data at (50 m).

Table (3) statistical analysis for measured data at (50m) for Sebha city.

Year	V_m (m/s)	σ_v	k	c	$V_{F\ max}$ (m/s)	$V_{E\ max}$ (m/s)	E_D (W/m^2)	E_I (Kwh/m^2)
2000	6.82	1.25	6.36	7.32	7.13	7.64	212.95	1865.42
2001	7.13	1.22	6.87	7.61	7.44	7.90	238.24	2086.94
2002	7.80	1.79	4.98	8.50	8.12	9.10	335.07	2935.21
2003	8.34	1.08	9.25	8.72	8.61	8.90	330.92	2898.90
2004	8.29	1.30	7.56	8.79	8.63	9.07	363.39	3183.29
2005	7.77	1.16	7.95	8.21	8.07	8.45	292.83	2565.18
2006	7.40	1.41	6.10	7.96	7.73	8.34	273.82	2398.67
2007	7.43	1.51	5.67	8.03	7.76	8.47	281.63	2467.06
2008	7.68	1.00	9.22	8.04	7.94	8.21	260.00	2277.59
2009	7.32	1.28	6.67	7.82	7.64	8.14	259.35	2271.94
2010	7.49	1.33	6.58	8.02	7.82	8.35	279.07	2444.66

Table (4) statistical analysis for NASA data at (50m) for Sebha city.

Year	V_m (m/s)	σ_v	k	c	$V_{F\ max}$ (m/s)	$V_{E\ max}$ (m/s)	E_D (W/m^2)	E_I (Kwh/m^2)
2000	6.01	0.81	8.83	6.30	6.22	6.45	128.04	1121.60
2001	5.83	0.81	8.55	6.13	6.04	6.28	119.09	1043.27
2002	5.86	0.83	8.47	6.16	6.07	6.32	121.47	1064.06
2003	6.23	0.58	13.25	6.35	6.32	6.42	71.716	628.23
2004	6.25	0.65	11.69	6.42	6.37	6.51	103.45	906.23
2005	6.24	0.66	11.65	6.42	6.37	6.51	104.11	912.02
2006	6.01	0.87	8.24	6.33	6.24	6.50	133.22	1167.03
2007	6.01	0.84	8.55	6.31	6.22	6.47	130.32	1141.60
2008	6.24	0.51	15.27	6.29	6.27	6.35	21.82	191.11
2009	5.97	0.66	10.98	6.17	6.12	6.27	101.21	886.62
2010	6.07	0.68	10.86	6.27	6.22	6.37	107.71	943.53

Regarding the average annual speed at height (50 m), as shown in Figure (7), the maximum value for the average annual speed for the measured data was (8.337 m/s) during (2003) and the minimum value was (6.823 m/s) in (2000). As for the average speed for the obtained data from NASA, the maximum value for the average annual speed was (6.236 m/s) during (2004) and the minimum value was (5.819 m/s) in (2001).

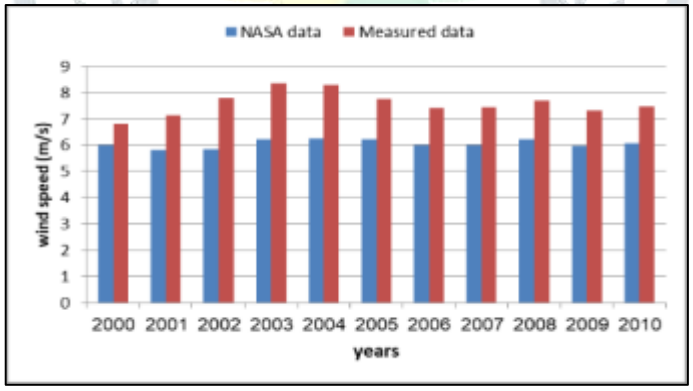

Figure (7) Annual wind speed at (50 m) for Measured and NASA data for Sebha city.

As shown in Figure (8), at height (50 m). The maximum value of the most frequently average annual speed of the measured data is (8.630 m/s) during (2004), While the minimum value is (7.126 m/s) in (2000). According to NASA data, the maximum value of the most frequent average annual speed is (6.374 m/s) during (2004) while the minimum value is (6.038 m/s) in (2001).

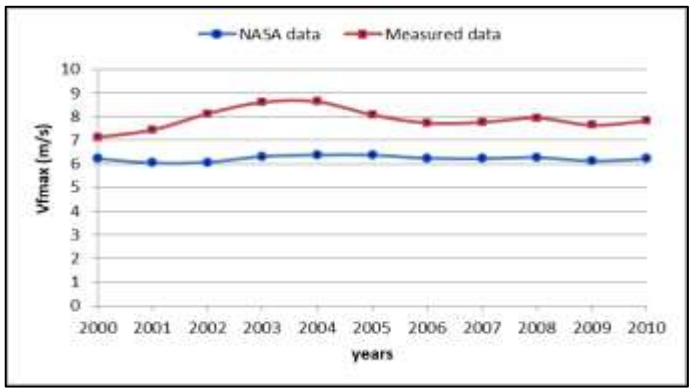

Figure (8) Annual most frequent wind speed at (50 m) for Measured and NASA data for Sebha city.

As shown in Figure (9), at height (50 m), it was found that the maximum value for the speed providing the maximum energy is (9.095 m/s) during (2002) for the measured data, and the minimum value was (7.642 m/s) in (2000). As forthe data obtained from NASA, the maximum value for the speed producing the maximum energy is (6.510 m/s) during (2004), while the minimum value is (6.267m/s) in (2009).

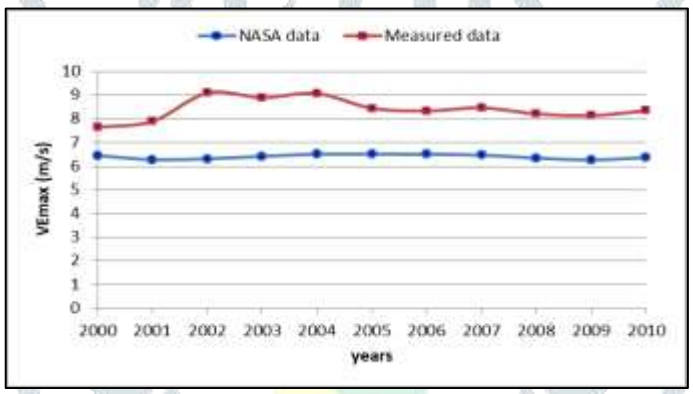

Figure (9) Annual wind speed contributing maximum energy at (50 m) for Measured and NASA data for Sebha city.

As shown in Figure (10), at height (50 m), The maximum value of the wind power density for the measured data is (363.388 W/m^2) during (2004) and the minimum value of the power density is (212.947 W/m^2) in (2000) As for the data obtained from NASA, it was The maximum value of wind power density is (133.222 W/m^2) during (2006) and the minimum value of wind power density is (21.816 W/m^2) in a year (2008).

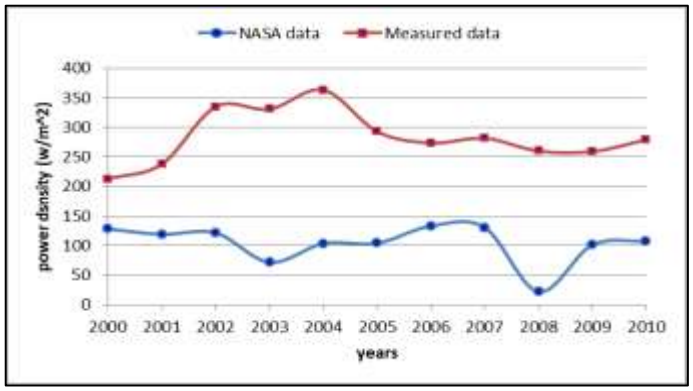

Figure (10) wind power density at (50 m) for Measured and NASA data for Sebha city.

Figure (11) shows that the maximum value of wind energy density for measured data is (3183.284 Kwh/m^2) during (2004) and minimum value is (1865.416 Kwh/m^2) in (2000). According to NASA statistics, the maximum wind energy density (1167.026 Kwh/m^2) was recorded in (2006). The minimum value is (191.111 Kwh/m^2) in (2008).

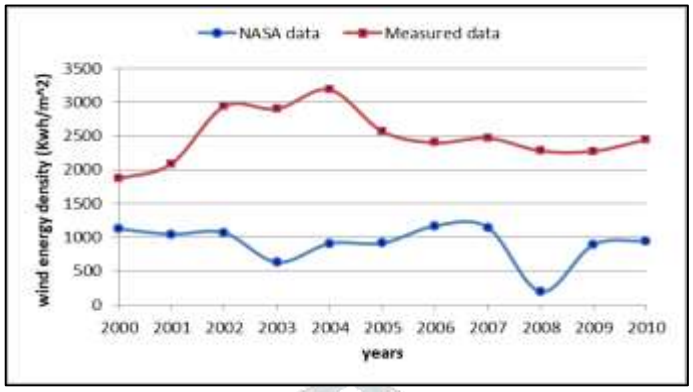

Figure (11) Wind energy density at (50 m) for Measured and NASA data for Sebha city.

Table (5) and (6) shows annual Weibull variables, the average annual speed, the annual standard deviation, and the maximum possible wind speed, as well as the speed at which we obtain maximum energy, the annual wind power density, and the annual wind energy density for measured and NASA data at (75 m).

Table (5) statistical analysis for measured data at (75m) for Sebha city.

Year	V_m (m/s)	σ_v	k	c	$V_{F\,max}$ (m/s)	$V_{E\,max}$ (m/s)	E_D (W/m^2)	E_I (Kwh/m^2)
2000	7.47	1.37	6.36	8.02	7.81	8.37	279.81	2451.17
2001	7.81	1.33	6.87	8.34	8.15	8.65	313.04	2742.25
2002	8.54	1.96	4.98	9.31	8.90	9.96	440.28	3856.89
2003	9.13	1.19	9.25	9.55	9.43	9.75	434.84	3809.16
2004	9.08	1.42	7.56	9.63	9.45	9.94	477.50	4182.86
2005	8.51	1.27	7.95	8.99	8.84	9.25	384.78	3370.66
2006	8.10	1.54	6.10	8.72	8.46	9.13	359.80	3151.87
2007	8.13	1.66	5.67	8.79	8.50	9.27	370.06	3241.74
2008	8.42	1.10	9.22	8.80	8.69	8.99	341.64	2992.77
2009	8.01	1.41	6.67	8.57	8.36	8.91	340.79	2985.34
2010	8.20	1.46	6.58	8.78	8.56	9.14	366.70	3212.29

Table (6) statistical analysis for NASA data at (75m) for Sebha city.

Year	V_m (m/s)	σ_v	k	c	$V_{F\ max}$ (m/s)	$V_{E\ max}$ (m/s)	E_D (W/m^2)	E_I (Kwh/m^2)
2000	6.58	0.89	8.83	6.91	6.81	7.07	168.43	1475.40
2001	6.39	0.89	8.55	6.71	6.62	6.88	156.67	1372.35
2002	6.42	0.90	8.47	6.75	6.65	6.92	159.79	1399.70
2003	6.83	0.64	13.25	6.96	6.92	7.03	94.34	826.40
2004	6.84	0.72	11.69	7.04	6.98	7.13	136.09	1192.09
2005	6.83	0.72	11.56	7.04	6.98	7.13	136.95	1199.71
2006	6.59	0.95	8.24	6.94	6.83	7.13	175.25	1535.16
2007	6.58	0.92	8.55	6.92	6.82	7.09	171.43	1501.72
2008	6.83	0.56	15.27	6.90	6.87	6.95	28.70	251.40
2009	6.55	0.73	10.98	6.76	6.70	6.87	133.14	1166.29
2010	6.65	0.75	10.86	6.87	6.81	6.98	141.68	1241.16

Regarding the average annual speed at height (75 m), as shown in Figure (12), the maximum value for the average annual speed for the measured data was (9.131 m/s) during (2003) and the minimum value was (7.473 m/s) in (2000). As for the average speed for the obtained data from NASA, the maximum value for the average annual speed was (6.830 m/s) during (2004) and the minimum value was (6.374 m/s) in (2001).

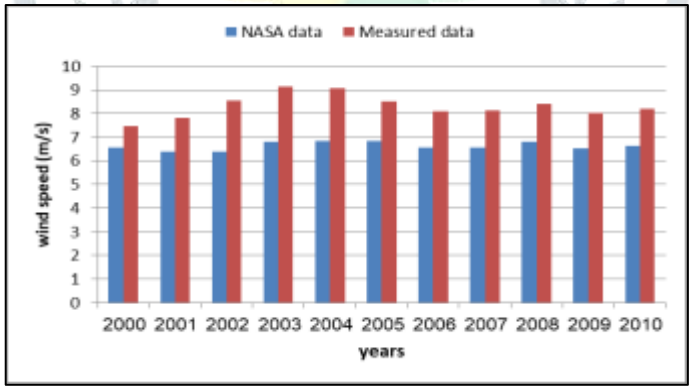

Figure (12) Annual wind speed at (75 m) for Measured and NASA data for Sebha city.

As shown in Figure (13), at height (75 m). The maximum value of the most frequently average annual speed of the measured data is (9.453 m/s) during (2004), While the minimum value is (7.805 m/s) in (2000). According to NASA data, the maximum value of the most frequent average annual speed is (6.984 m/s) during (2004) while the minimum value is (6.616 m/s) in (2001).

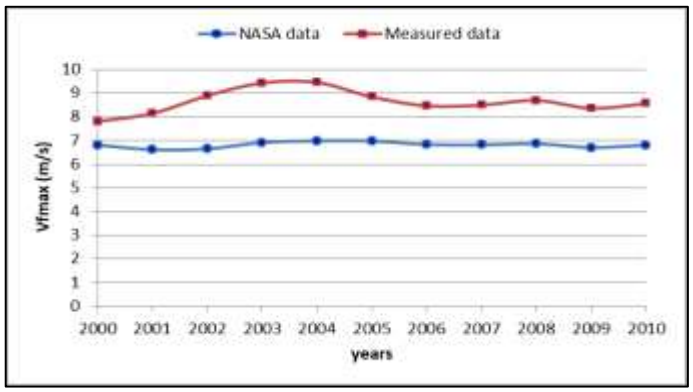

Figure (13) Annual most frequent wind speed at (75 m) for Measured and NASA data for Sebha city.

As shown in Figure (14), at height (75 m), the maximum value for the speed providing the maximum energy is (9.962 m/s) during (2002) for the measured data, and the minimum value was (8.370 m/s) in (2000). As for the data obtainedfrom NASA, the maximum value for the speed producing the maximum energy is (7.133 m/s) during (2004), while the minimum value is (6.866 m/s) in (2009).

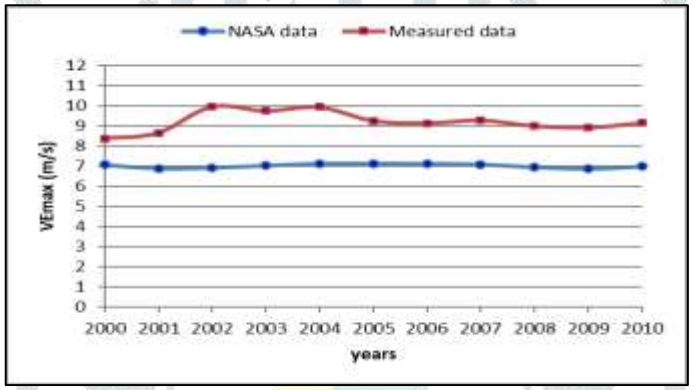

Figure (14) Annual wind speed contributing maximum energy at (75 m) for Measured and NASA data for Sebha city.

In Figure (15), at height (75m), The maximum value of the wind power density for the measured data is (477.495 W/m^2) during (2004) and the minimum value of the power density is (279.813 W/m^2) in (2000) As for the data obtained from NASA, it was The maximum value of wind power density is (175.246 W/m^2) during (2006) and the minimum value of wind power density is (28.698 W/m^2) in (2008) .

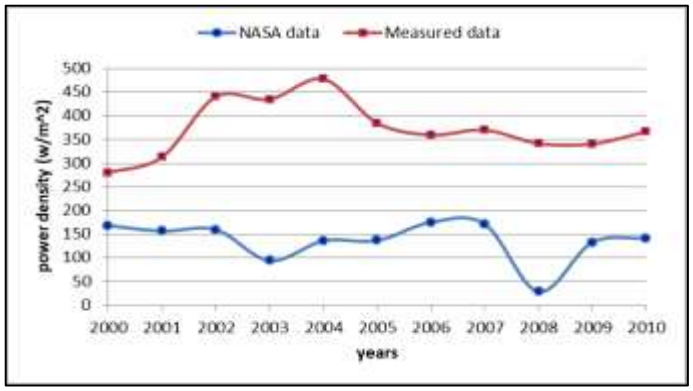

Figure (15) wind power density at (75 m) for Measured and NASA data for Sebha city.

In Figure (16), for the measured data, the maximum value of wind energy density is (4182.856 Kwh/m^2) during (2004) and the minimum value is (2451.168 Kwh/m^2) in (2000) As for the data obtained from NASA, the maximum value of wind energy density is (1535.159Kwh/m^2) during (2006). The minimum value was (251.396 Kwh/m^2) in (2008).

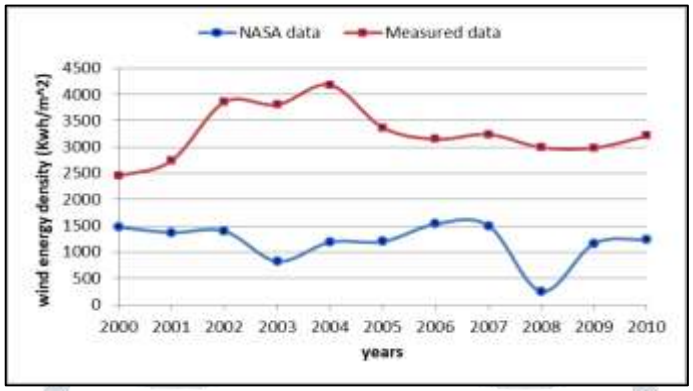

Figure (16) Wind energy density at (75 m) for Measured and NASA data for Sebha city.

Table (7) and (8) shows annual Weibull variables, the average annual speed, the annual standard deviation, and the maximum possible wind speed, as well as the speed at which we obtain maximum energy, the annual wind power density, and the annual wind energy density for measured and NASA data at (100 m).

Table (7) statistical analysis for measured data at (100 m) for Sebha city.

Year	V_m (m/s)	σ_v	k	c	$V_{F\ max}$ (m/s)	$V_{E\ max}$ (m/s)	E_D (W/m^2)	E_I (Kwh/m^2)
2000	7.97	1.46	6.36	8.55	8.33	8.93	339.64	2975.22
2001	8.33	1.42	6.87	8.89	8.69	9.23	379.97	3328.54
2002	9.11	2.09	4.98	9.93	9.49	10.63	534.42	4681.48
2003	9.74	1.26	9.25	10.18	10.06	10.40	527.80	4623.55
2004	9.69	1.52	7.57	10.27	10.08	10.60	579.58	5077.14
2005	9.08	1.36	7.95	9.59	9.43	9.87	467.04	4091.30
2006	8.64	1.65	6.10	9.30	9.03	9.74	436.73	3825.73
2007	8.68	1.77	5.67	9.38	9.06	9.89	449.18	3934.81
2008	8.98	1.17	9.22	9.39	9.27	9.59	414.68	3632.61
2009	8.55	1.50	6.67	9.14	8.92	9.51	413.65	3623.60
2010	8.75	1.55	6.58	9.36	9.13	9.75	445.10	3899.07

Table (8) statistical analysis for NASA data at (100 m) for Sebha city.

Year	V_m (m/s)	σ_v	k	c	$V_{F\ max}$ (m/s)	$V_{E\ max}$ (m/s)	E_D (W/m^2)	E_I (Kwh/m^2)
2000	7.01	0.95	8.83	7.35	7.25	7.53	203.33	1781.13
2001	6.80	0.95	8.55	7.15	7.05	7.33	189.12	1656.73
2002	6.83	0.96	8.47	7.19	7.08	7.37	192.89	1689.74
2003	7.27	0.68	13.25	7.41	7.37	7.49	113.89	997.64
2004	7.29	0.76	11.69	7.49	7.44	7.60	164.28	1439.11
2005	7.28	0.77	11.65	7.49	7.43	7.59	165.33	1448.30
2006	7.01	1.01	8.24	7.39	7.28	7.59	211.56	1853.26
2007	7.01	0.98	8.55	7.37	7.26	7.55	206.95	1812.89
2008	7.28	0.60	15.27	7.34	7.31	7.40	34.64	303.489
2009	6.97	0.77	10.98	7.20	7.14	7.31	160.73	1407.97
2010	7.08	0.79	10.86	7.32	7.25	7.43	171.04	1498.35

Regarding the average annual speed at (100 m), as shown in Figure (17), the maximum value for the average annual speed for the measured data was (9.740 m/s) during (2003) and the minimum value was (7.972 m/s) in (2000). As for the average speed for the obtained data from NASA, the maximum value for the average annual speed was (7.286 m/s) during (2004) and the minimum value was (6.799 m/s) in (2001).

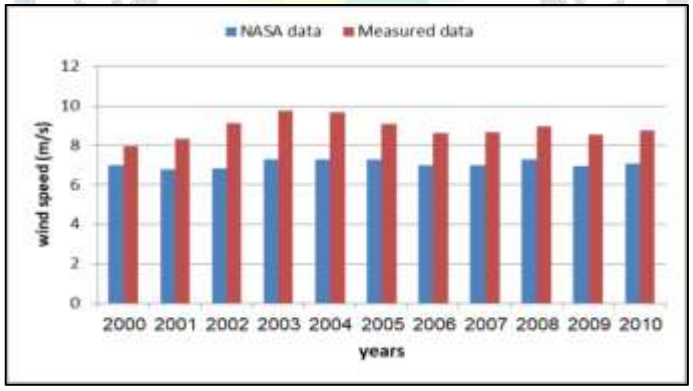

Figure (17) Annual wind speed at (100 m) for Measured and NASA data for Sebha city.

As shown in Figure (18), at height (100 m). The maximum value of the most frequently average annual speed of the measured data is (10.083 m/s) during (2004), While the minimum value is (8.325 m/s) in (2000). According to NASA data, the maximum value of the most frequent average annual speed is (7.436 m/s) during (2004) while the minimum value is (7.045 m/s) in (2001).

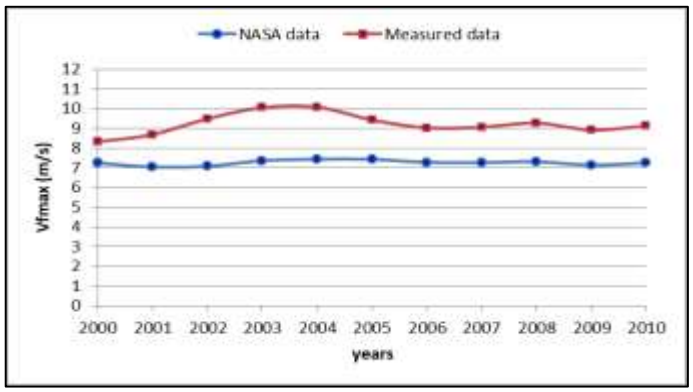

Figure (18) Annual most frequent wind speed at (100 m) for Measured and NASA data for Sebha city.

As shown in Figure (19), at height (100 m), the maximum value for the speed providing the maximum energy is (10.627 m/s) during (2002) for the measured data, and the minimum value was (8.928 m/s) in (2000). As for the data obtained from NASA, the largest value for the speed producing the maximum energy is (7.595 m/s) during (2004), while the smallest value is (7.311 m/s) in (2009).

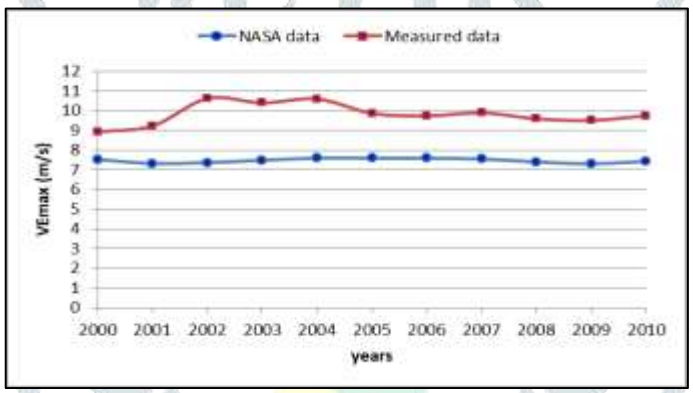

Figure (19) Annual wind speed contributing maximum energy at (100 m) for Measured and NASA data for Sebha city.

In Figure (20), at height (100 m), The maximum value of the wind power density for the measured data is (579.582 W/m^2) during (2004) and the lowest value of the power density is (339.637 W/m^2) in (2000) As for the data obtained from NASA, it was The maximum value of wind power density is (211.559 W/m^2) during (2006) and the minimum value of wind power density is (34.644 W/m^2) in (2008).

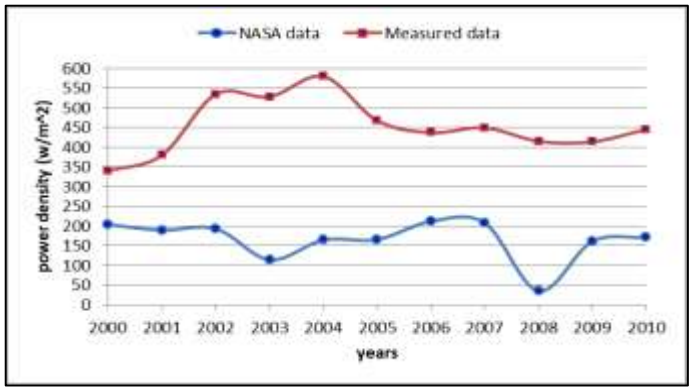

Figure (20) wind power density at (100 m) for Measured and NASA data for Sebha city.

In Figure (21), for the measured data at (100 m), the maximum value of wind energy density is (5077.140 Kwh/m^2) during (2004) and the minimum value is (2975.222 Kwh/m^2) in (2000) As for the data obtained from NASA, the maximum value of wind energy density is (1853.262 Kwh/m^2) during (2006). The lowest value was (303.489 Kwh/m^2) in (2008).

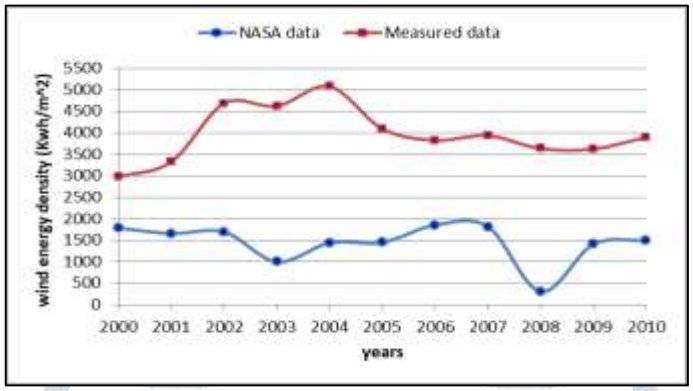

Figure (21) Wind energy density at (100 m) for Measured and NASA data for Sebha city.

3.1 Histogram and Weibull distribution.

As shown in Figure (22), for the data measured at a height of (10 m), the maximum frequency wind speed in the city of Sebha in the years studied is (4.5 m/s) with a probability of (0.757), Then (4.62 m/s) with a probability of (0.705), then (4m/s) with a probability of (0.631), then (3.9 m/s) with a probability of (0.591), then (3.5 m/s) with probability (0.265), then (3m/s) with probability (0.101) and the minimum frequency wind speed is (5.2 m/s) with probability (0.03). The Speed (6 m/s and above) These have no frequency and no probability.

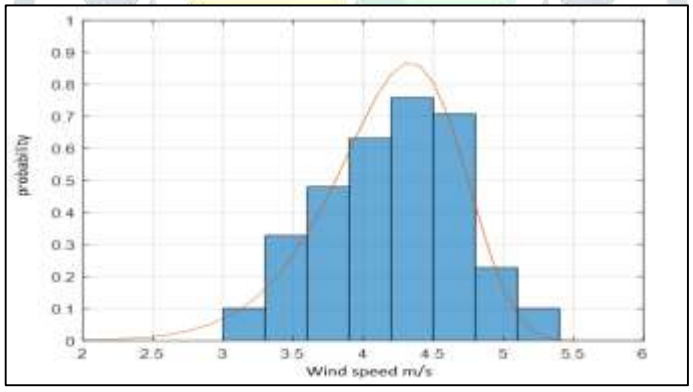

Figure (22) Histogram and Weibull distribution for measured data at (10 m) for Sebha city

In figure (23) for NASA data, the maximum frequency speed is (5.2 m/s) with a probability of (0.411), then (5.6 m/s) with a probability of (0.363), then (4.9 m/s) with a probability of (0.354), then (6.2 m/s) with a probability of (0.312), then (4.2 m/s) with a probability of (0.191), then (3.9 m/s) with a probability of (0.133), then (6.8 m/s) with a probability of (0.111), and the lowest reciprocating speed was (3.0 m/s) with a probability of (0.03), while the speed (8 m/s and above), as it has no frequency and probability

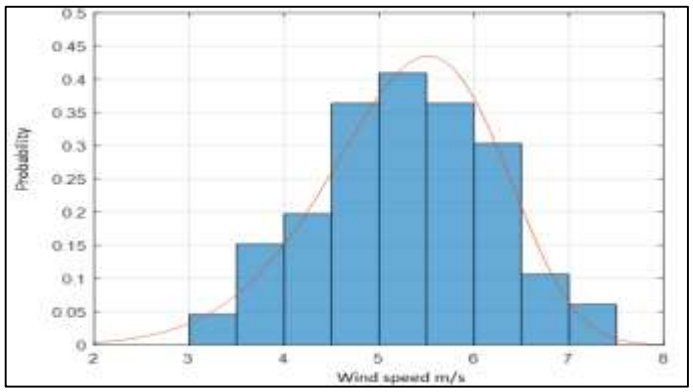

Figure (23) Histogram and Weibull distribution for NASA data at (10 m) for Sebha city.

Figure (24) depicts the cumulative probability distribution of wind speed for both the measured data and the NASA dataset. The results reveal that the NASA data exhibit a steeper cumulative curve, reaching higher probabilities at lower wind speeds, when contrasted with the measured data. This behavior proposes that the NASA dataset forecasts a higher frequency of moderate wind speeds, while the measured data show a more progressive increase, implying the presence of a wider variability and a slightly higher mean wind speed in the actual site conditions.

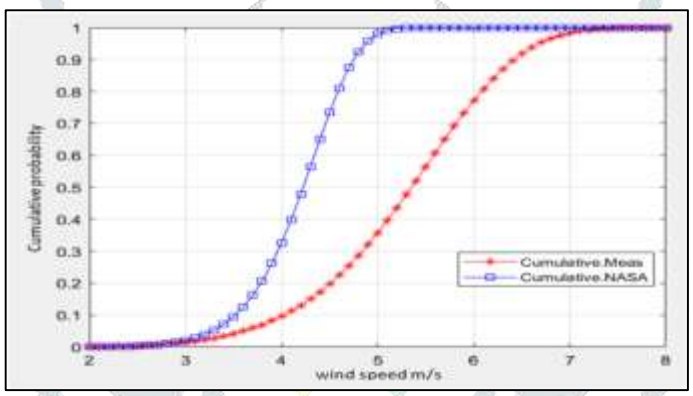

Figure (24) Cumulative distribution for measured and NASA data for Sebha

3.2 Monthly wind speed

Figure (25) shows the comparison between measured data and NASA data for Sebha city displays a consistent seasonal pattern. Both datasets record their maximum wind speeds in April, consistent to the spring season, when regional pressure gradients typically intensify. Measured data reaches a peak of about (7.0 m/s), while NASA data peaks near (5.0 m/s). Conversely, both datasets display their minimum values in October, during the autumn season, with wind speeds declining to (4.0–4.5 m/s) in measured data and around(3.5 m/s) in NASA data. The fact that NASA data derived values remain lower throughout the year, reflects the smoothing effect of spatial averaging in satellite recoveries, which underestimates local near-surface winds relative to point-based ground measurements. Nevertheless, the strong agreement in the timing of seasonal maxima and minima indicates that both datasets capture the same underlying atmospheric controls governing wind variability at the site.

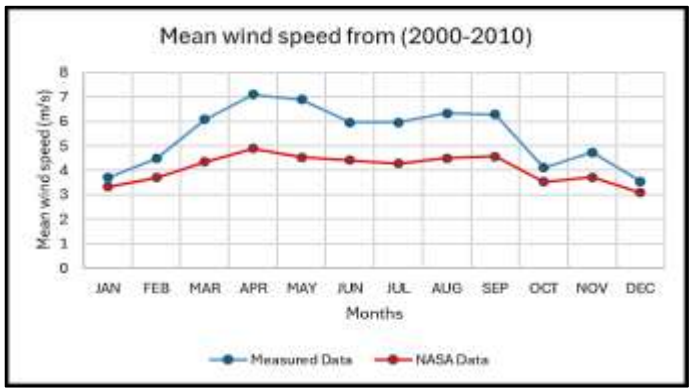

Figure (25) Monthly mean wind speed for measured data at (10 m) for Sebha city.

3.2 Wind Rose

As shown in Figure (26), the prevailing wind direction for measured speed for the city of Sebha is (NNE) at a frequency of about (49%), and the speeds frequencies in this direction with range (4-6.5 m/s). Also, the frequency of wind speeds is very small, not exceeding 9% in directions (NW), (NNW), (W), (S) and (SSW).

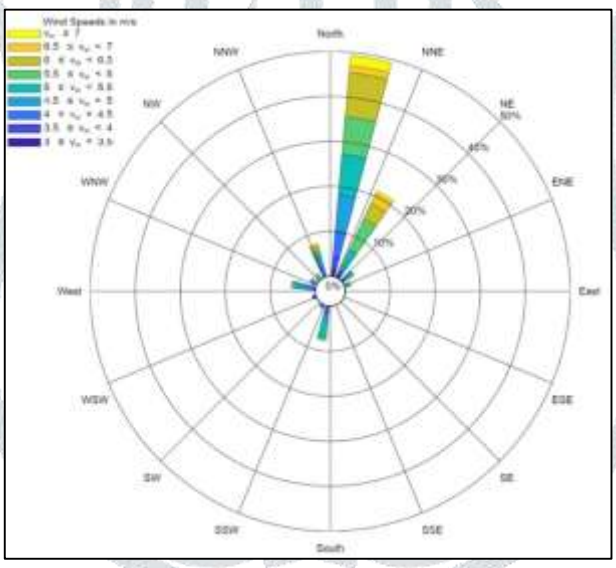

Figure (26) Wind Rose for measured data for Sebha city at (10 m).

As shown in Figure (27), the prevailing wind direction for the speeds obtained from NASA for the city of Sebha is (N) and (NNE) with a frequency of about (16%), and most of speeds that frequencies in these directions have a range of (4-5 m/s), also Wind speeds with a range of (3-5 m/s) at a frequency not exceeding (8%) in the direction (NNW) and wind speeds in the (NW) direction with a range of (3-4.5 m/s) with a frequency not exceeding (4%). Also, wind speeds with a range of (3-4 m/s) with a frequency of about (2%) in the directions of (W), (WNW), (WSW), (S), (SSW), (SW), (SE), (SSE), (ESE), and (E).

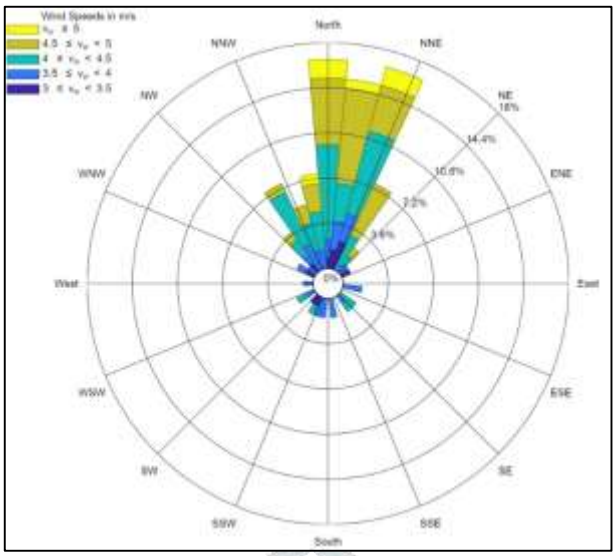

Figure (27) Wind Rose for NASA data for Sebha city at (10 m).

4. conclusion.

The analysis of measured and NASA data for Sebha city during (2000-2010) showed that the measured data was greater than the data obtained from NASA. The maximum annual wind speed for measured data were (5.78, 8.34, 9.13, 9.74 m/s) at (10, 50, 75, 100 m) respectively. The minimum annual wind speed for measured data were (4.75, 6.82, 7.47, 7.97 m/s) at (10, 50, 75, 100 m) respectively. The highest value of annual wind speed for NASA data were (4.35, 6.25, 6.84, 7.29 m/s) at (10, 50, 75, 100 m) respectively. The lowest value of annual wind speed for NASA data were (4.06, 5.83, 6.42, 6.80 m/s) at (10, 50, 75, 100 m) respectively. The upper limit of annual power density for measured data were (122.92, 363.39, 477.50, 579.58 W/m^2) at (10, 50, 75, 100 m) respectively. The lower limit of annual power density for measured data were (72.03, 212.95, 279.81, 339.64 W/m^2) at (10, 50, 75, 100 m) respectively. The maximum annual power density for NASA data were (44.87, 133.22, 168.43, 211.56 W/m^2) at (10, 50, 75, 100 m) respectively. The minimum annual power density for NASA data were (7.35, 21.82, 28.70, 34.64 W/m^2) at (10, 50, 75, 100 m) respectively. The maximum threshold annual energy density for measured data were (1076.76, 3183.29, 4182.86, 5077.14 Kwh/m^2). The minimum threshold annual energy density for measured data were (630.99, 1865.42, 2451.17, 2975.22 Kwh/m^2). The maximum magnitude annual energy density for NASA data were (393.04, 1167.03, 1535.19, 1853.26 Kwh/m^2). The minimum magnitude annual energy density for NASA data were (64.36, 191.11, 251.40, 303.48 Kwh/m^2). The prevailing wind direction for measured data is (NNE) with frequency (49%), and the prevailing wind direction for measured data is (N) and (NNE) with frequency (16%). For the city of Sebha, it is preferable to install one of the following turbines (Enercon E115/3000, EWT DW52-250, Gamesa G128-4.5 MW, Gamesa G126-2.625 MW, Gamesa G132-3.3MW, Gamesa G132-5 MW, GFF GF121-2.0, Lagerwey L136-4MW, Nova wind L100-2.5MW, SANY SE12525, Swiss ElectricYZ130/2.5, Siemens Gamesa SG3.6-145, Vastas V82-1.65 and Windey WD140-2500) due to their characteristics, namely that they start up at low speeds ranging between (1-2.5 m/s), with a rated wind speed varying from (8-13 m/s) and a power output

extending from (250-5000 Kw). These turbines are best installed at elevation of 75 meters and higher due to the significant increase in wind power and energy at these heights.

Nomenclatures.

c	Weibull scale factor (m/s)
E_D	Wind power density (W/m^2)
E_I	Wind energy density (Kwh/m^2)
f (υ)	Weibull distribution
F (υ)	Cumulative distribution
h	Height (m)
K	Dimensionless Weibull shape factor
T	Time (hour)
υ	Wind speed (m/s)
$V_{E\,max}$	Velocity contributing maximum energy to the regime (m/s)
$V_{F\,max}$	Most probable wind speed (m/s)
V_m	Mean wind speed (m/s)

Greek symbol.

α	Wind shear coefficient
Γ	Gamma function
ρ	Air density (kg/m^3)
σ_v	Standard deviation of wind speed

Abbreviation.

NASA	National Aeronautics and Space Administration

Acknowledgment.

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Appendix.

Turbin model	Rated power (*Kw*)	Cut in speed (*m/s*)	Rated wind speed (*m/s*)	Cut out speed (*m/s*)	Rotor diameter (*m*)	Swept area (m^2)	Number of blades	Power density (w/m^2)	Hub altitude (*m*)	Ref
Enercon E115/3000	3000	2	11.5	25	115.7	10515.5	3	285.3	92-135-149	[22]
EWT DW52-250	250	2.5	8	25	52	2124	3	117.7	35-40-50-75	[23]
Gamesa G128-4.5 MW	4500	1	12	27	128	12868	3	349.7	81-120-140	[24]
Gamesa G126-2.625 MW	2625	1	11	25	126	12469	3	210.5	84-102-129	[25]
Gamesa G132-3.3MW	3300	2	10	25	132	13685	3	241.1	84-97-114-134 and site specific	[26]
Gamesa G132-5 MW	5000	1.5	13	27	132	13685	3	365.4	95-120-140	[27]
GFF GF121-2.0	2000	2.5	8.7	22	121	11500	3	173.9	90	[28]
Lagerwey L136-4MW	4000	2	-	25	136	14655	3	272.9	120-132-166	[29]
Nova wind L100-2.5MW	2500	2	-	25	100	7845	3	318.7	75-99-135	[30]
SANY SE12525	2500	2.5	9	28	125	12272	3	203.7	80-85-90	[31]
Swiss ElectricYZ130/2.5	2500	1.8	8.8	20	130	13273	3	188.4	90-120-140	[32]
Siemens Gamesa SG3.6-145	3600	2	10	20	145	16513	3	218	127.5 and site specific	[33]
Vastas V82-1.65	1650	2.5	13	32	82	5281	3	312.4	59-108	[34]
Windey WD140-2500	2500	2.5	8.5	20	140	15394	3	162.4	85-90-100-120-140	[35]

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