Analysis of Wind Speed Data and Annual Energy Potential at Three locations in Iraq

Ali M. Rasham
University of Baghdad
College of Engineering
Energy Engineering Department

ABSTRACT
Analysis of wind speed data and annual wind energy potential at three selected sites in Iraq has been investigated in this study. The wind speed data was collected from the Weather Underground Organization (WUO) at stations elevation. Extrapolation of stations elevations used to estimate the wind velocities at 60 m, 90 m, and 120 m via wind shear law. The objectives were to analysis of wind speed data and to assess the wind energy potential for the selected sites. Computer code for MATLAB software has been developed and written to solve mathematical model. Results in the form of the measured and Weibull estimated of monthly and annual average of wind velocities ($\overline{V}$), wind shear, wind velocity carrying maximum energy (V_{mE}), most probable wind velocity (V_{mp}), probability density function (PDF), cumulative distribution function (CDF), monthly and annual wind power density (WPD) and wind energy density (WED) were presents. At stations elevation, the (WED) was the best for Basrah, Amarah, and Nasiriyah respectively and the selected sites are suitable for off grid applications. While at selected heights it was best for Basrah, Nasiriyah, and Amarah respectively. Basrah at (60, 90, 120 m) and Nasiriyah at (120) are acceptable for connecting to power grid.

Keywords
Weibull distribution, assessment of wind resource, Wind energy potential, Analysis of wind speed data.

1. INTRODUCTION
Since several years, many countries have begun to use of renewable energies projects because it is clean, new energies, inexhaustible and environmentally friendly. On the other hand, it contribute to being reduce global warming, air pollution, and reduce the depletion of non-conventional fossil fuels. It is worth mentioning that the wind energy projects are considered one of the most renewable energy projects globally increasing. Nowadays, an advanced ranking are occupies by wind energy projects as compared with other renewable energy resources and conventional resources. Due to the reduction of production cost for wind energy projects and improvements of its technology as compared with traditional and renewable resources, the growing of wind energy projects was in a fast rate. Obviously, the problem of the growing demand for electricity in Iraq, leading to a move to the use of renewable energy as an alternative and successful solution to face this crisis. Efforts for assessing wind energy potential are so important in this field in order to select the appropriate sites for the installation of wind turbines. The wind's statistical models are used to analysis and assess the energy potential available for a specific sites. The wind data of three sites in the south of Iraq, Amarah, Nasiriyah, and Basrah, were collected to analysis wind speed data and to assess wind energy potential.

Majority of the studies were presented to assess the wind energy potential, wind speed characteristics, the diurnal and seasonal of wind parameters, and the electricity generation potential were analyzed by most of previous studies in many countries. It is worth mentioning that the present study is one of the important steps to assess wind speed data and wind energy potential of the selected sites in Iraq. Accordingly, the selection of suitable wind turbines for selected sites in order to install wind farms will be possible.

The wind speed data of most studies in this field, were collected or recorded at 10m above the ground level. The wind speed data of five coastal locations of the kingdom of Sudia Arabia were collected via meteorological measurement for 14 years, where wind data recorded at 10 m height of four locations except at one location at 8 m height above the ground level [1]. The wind speed data for the Waterloo region in Canada for 5 years, four locations in Ethiopia, three locations in southeastern of Nigeria for (25 -37) years, and Ardabil city of Iran for 6 years, were measured at 10m above the ground level [2, 3, 6, and 9]. At 700 m from the sea level of Naxos Island of Greece, the wind speed data were measured via a measurement mast [4]. The NASA Langley research center of Oman, Islamic Republic Iran Meteorological Organization at 10 m, and Meteorological Department Oshodi at 10 m of Kano in Nigeria, were used to collect the wind speed data in these countries in order to analyze the wind speed data and assess the wind energy potential. In this study, the daily wind speed data were collected at the stations height of selected sites.

The average of wind speed, standard deviation, shape factor, scale factor, most probable wind speed, wind speed carrying maximum energy, wind power density, and wind energy density were achieved by different wind statistical models. The Weibull distribution which is a famous model was used for majority of several studies. The Weibull distribution and Rayleigh distribution was used to analyze wind data and wind energy potential [4]. Several methods were used to estimate the Weibull parameters. Six methods (Probability weighted moments, graphical method, Empirical method, Moment method, Maximum Likelihood method, and Energy Pattern factor method) of Weibull distribution were used to calculate the average of wind speed, standard deviation, shape factor, scale factor, most probable wind speed, wind speed carrying maximum energy, wind power density, and wind energy density [7]. Graphical method [4, and 8] and Empirical method [6, and 9] were used to evaluate Weibull parameters. In some studies, a software tools were used to conclude the Weibull parameters. (HOMER) software tool were used to estimate the shape and scale factors in order to assess wind energy potential and wind speed characteristics [6]. In this study, the Weibull distribution was used to estimate the specified parameters and the accuracy of Weibull distribution was checked.

The results of previous studies were presented as average of hourly, monthly, and annual for wind speed, shape factor, scale factor, probability density function, cumulative distribution function, duration curve, most probable wind speed, wind speed carrying maximum energy, capacity factor and energy output of wind turbine. According to [3], the three of four locations were reasonable for wind energy potential. A spatial distribution of wind characteristics for whole Oman were provided [5]. The electricity generation from the wind were viable economically at and above 10 m height [8]. The wind potential is very suitable for off-grid connections and is acceptable for connecting to power grid [9].

2. SITES INFORMATION AND WIND DATA SOURCE

The wind data for three selected sites in Iraq were collected from the metrological weather web site of weather underground organization (WUO) [10] as a daily average wind velocity. The elevation, latitude, and longitude of selected stations were (9 m, 31.83 °N, 47.17 °E), (5 m, 31.02 °N, 46.23 °E), (3 m, 30.37 °N, 48.25 °E) for Amarah, Nasiriyah, and Basrah respectively, **Table. 1**. The maximum, minimum, and average daily of wind speed are available in (WUO) web site. In present study, the average of daily wind speed was used as input parameter. The collected wind speed data were compared with wind speed data from another web site for verification. The wind speed data from (WUO) web site were significantly identical with the wind speed data of intellicast web site. According to daily average wind velocities, the monthly and annually average wind velocities were estimated at stations heights. Extrapolation of stations elevations has been used to estimate the wind velocities at 60 m, 90 m, and 120 m via wind shear power law.

3. MATHEMATICAL MODEL

The daily average of wind velocities are collected from the web site of (WUO). Accordingly, the monthly and annually average of measured wind velocity and Weibull estimated of wind velocity are calculated as [11, PP.64]:

$$\overline{V} = \left\{\left(\sum_{i=1}^{N} V_i^3\right)/N\right\}^{1/3} \quad (1)$$

Here (V_i) is the individual wind velocity collected from (WUO), (N) is the number of collected data, and ($\overline{V}$) is the average of wind velocity (m/s).

The wind is stochastic quantity. Consequently, the standard deviation is necessary to be estimated, it can be formulated as [11, P.64]:

$$\sigma = \sqrt{\sum_{i=1}^{N}(V_i - \overline{V})^2/N} \quad (2)$$

Here (σ) is the standard deviation (m/s).

The shape and scale factors of Weibull distribution for wind data analysis can be expressed as [11, PP.75-76]:

$$k = (\sigma/\overline{V})^{-1.090} \quad (3)$$

$$C = (\overline{V}\, k^{2.6674}/(0.184 + 0.816\, k^{2.73855})) \quad (4)$$

Here (k) is the shape factor (dimensionless), and (C) is the scale factor (m/s).

The Weibull probability density function f(V) is used to describe wind speed. The integral of the probability density function represent the cumulative distribution F(V). It can be defined as [11, PP.68]:

$$f(V) = [K/C][V/C]^{K-1} e^{-(V/C)^K} \quad (5)$$

$$F(V) = \int_0^{\infty} f(V)dV = 1 - e^{-(V/C)^K} \quad (6)$$

According to Weibull distribution, the average of wind speed, and standard deviation also can be estimated as [11, PP.69-71]:

$$\overline{V} = C\,\Gamma\,[1 + (1/k)] \quad (7)$$

$$\sigma = C\,\{\Gamma\,[1 + (2/k)] - \Gamma^2[1 + (1/k)]\}^{1/2} \quad (8)$$

Here (Γ) is the gamma function.

Several parameters were corrected at stations elevation and selected heights. The air density correction with height have been employed [12, PP.31]:

$$\rho = \rho_o - [1.194 \times 10^{-4} \times H] \quad (9)$$

Here (ρ) is the air density at any height (kg/m^3), ($\rho_o = 1.225\ kg/m^3$) represent the air standard density at ($T = 15$°C) and ($P = 1\ atm$), and (H) is the height in (m).

The change in wind speed with height can be calculated by using wind shear power law as [13, PP.37]:

$$V_2 = V_1(H_2/H_1)^{\alpha} \quad (10)$$

Here (H_1) is the stations elevation in (m), (H_2) is the selected height in (m), (V_1) is the wind velocity (m/s) at stations elevation, (V_2) is the corrected wind velocity (m/s) at selected height, and (α) is the wind shear exponent.

The wind shear exponent can be formulated as [14, PP. 15]:

$$\alpha = [0.096\, log_{10}(Z) + 0.016\,(log_{10}(Z))^2 + 0.24] \quad (11)$$

Here (Z) is the roughness height of terrain in (m).

According to the table of [14, PP.14], the appropriate value of roughness height (Z) for selected sites is (1.5 m).

Also, the correction of shape and scale factors with selected heights can be modified as [7]:

$$k_{H2} = k_{H1}[1 - 0.0881\, ln(H_2/H_1)]^{-1} \quad (12)$$

$$n = [0.37 - 0.0881 \ln(C_{H1})] \quad (13)$$

$$C_{H2} = C_{H1}\,(H_2/H_1)^n \quad (14)$$

The individual corrected of measured wind power density and energy density at any height can be considered as

$$PD_{ci} = (1/2)\rho\, \overline{V}_i^3 \quad (15)$$

$$ED_{ci} = (1/2)\rho\, \overline{V}_i^3\, T \quad (16)$$

Here (T) is the time duration.

Accordingly, the total corrected of measured wind power density and wind energy density at any height by using the corrected wind velocities from wind shear power law, can be written as:

$$PD_{ct} = \sum_{i=1}^{N}(1/2)\rho\, \overline{V}_i^3/N \quad (17)$$

$$ED_{ct} = PD_{ct}\, T \quad (18)$$

According to the Weibull distribution, the corrected of estimated wind power density and wind energy density at any height for selected sites, can be expressed as [9]:

$$PD_{cW} = (1/2)\,\rho\, C^3 \Gamma(1 + \langle 3/k \rangle) \quad (19)$$

$$ED_{cW} = (1/2)\,\rho\, C^3 \Gamma(1 + \langle 3/k \rangle)\, T \quad (20)$$

The most probable wind velocity V_{mp} (m/s) and wind velocity carrying maximum energy V_{mE} (m/s) in term of shape and scale factors, become [11, PP.82-83]:

$$V_{mp} = C[1 - (1/k)]^{1/k} \quad (21)$$

$$V_{mE} = C[1 + (2/k)]^{1/k} \quad (22)$$

The accuracy of Weibull distribution in estimating the site's actual parameters with predicted Weibull results, can be check by calculated the determination factor (R^2) and root mean square error (RMSE) as [8] :

$$R^2 = \frac{\sum_{i=1}^{N}(y_i - z_i)^2 - \sum_{i=1}^{N}(x_i - y_i)^2}{\sum_{i=1}^{N}(y_i - z_i)^2} \quad (23)$$

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}(y_i - x_i)^2\right]^{1/2} \quad (24)$$

Here $(y_i), (x_i)$, and (z_i) is the actual data, predicted Weibull results, and mean of actual data respectively.

4. RESULTS AND DISCUSSION

Analysis of wind speed data and wind energy potential at three selected sites in Iraq has been investigated in this study. The daily average of wind speed data for Amarah, Nasiriyah, and Basrah over whole 1-year from August 2014 to July 2015 were collected and analyzed. Monthly and annually average of wind velocities, standard deviation, wind power densities, and wind energy densities were estimated according to measured wind velocities. According to the Weibull distribution the monthly and annually average of estimated wind velocities, standard deviation, shape factor, scale factor, most probable wind velocity, wind velocity carrying maximum energy, wind power densities, and wind energy densities were determined. The difference between the Weibull estimated and measured parameters were showed with the blue color on the bars of **Figs. (1, 2, 8, 9, 10, and 11)**. All the parameters mentioned above listed in **Tables. (2, 3, 4, 5, and 6)**.

In general, the measured and Weibull estimated monthly and annually average of wind velocities for the same site of selected sites are approximately identical. **Fig.1** illustrate the measured and Weibull estimated monthly average of wind velocities for selected sites. While **Fig.2** demonstrate the measured and Weibull estimated annual average of wind velocities. The higher and lower of measured and Weibull estimated monthly average of wind velocities were (6.4643, and 2.4149 m/s) and (6.4704, and 2.4170 m/s) at June and November respectively for Amarah, (4.5369, and 2.7567 m/s) and (4.5374, and 2.7598 m/s) at May and December respectively for Nasiriyah, and (5.5146, and 2.2044 m/s) and (5.5181, and 2.2046 m/s) at June and December respectively for Basrah. From **Tables. (2, 3, and 4)** the sites have the highest measured and Weibull estimated annual average of wind velocity at stations elevation, were (4.0138 and 4.0166 m/s), (3.9241 and 3.9253 m/s), (3.5707 and 3.5743 m/s) for Amarah, Basrah, and Nasiriyah respectively.

Fig.3 display the wind velocity profiles for selected sites at selected heights of annual shape and scale factors. Extrapolation of stations elevations were used to estimate the wind velocities at 60, 90, and 120 m according to the wind shear power law. The wind shear power law is an indication to the change of wind velocity with height. At selected heights, the wind velocities were used to correct the shape and scale factors of Weibull distribution. Also, to estimate the wind power density and wind energy density. From **Fig.3** the best velocity profiles were for Basrah, Nasiriyah, and Amarah respectively. The measured and Weibull estimated of wind velocities, wind power density, wind energy density, shape factor, and scale factor are shown in **Table.6**.

Indeed, the wind velocity carrying maximum energy always more than most probable wind velocity. In the wind energy analysis, the most frequent wind velocity for wind probability distribution is the most probable wind velocity. **Fig.4** show the monthly average of the most probable wind velocity and wind velocity carrying maximum energy for selected sites at stations elevation. The higher and lower of Weibull estimated monthly average of wind velocities carrying maximum energy were (8.5628 and 3.2185 m/s) at June and November respectively for Amarah, (6.8325 and 3.5663 m/s) at May and December respectively for Nasiriyah, and (7.5780 and 3.3528 m/s) at June and December respectively for Basrah. Also, the higher and lower of Weibull estimated monthly average of most probable wind velocities were (6.3452 and 2.3594 m/s) at June and November respectively for Amarah, (4.4528 and 2.7507 m/s) at June and December respectively for Nasiriyah, and (5.2531 and 1.8805 m/s) at June and December respectively for Basrah. From **Tables. (2, 3, and 4)**, the sites have the highest Weibull estimated annual average of wind velocity carrying maximum energy were (5.4989, 5.0839, and 4.4895 m/s) for Basrah, Amarah, and Nasiriyah respectively. In addition, the sites have the highest Weibull estimated annual average of most probable wind velocity were (3.5208, 3.4652, and 3.2793 m/s) for Amarah, Nasiriyah, and Basrah respectively.

Fig. 5 show the annual average of wind energy carrying maximum energy and most probable wind velocity for selected sites at selected heights (60, 90, and 120 m) respectively. From **Fig. 5** and **Table.5**, the higher of the annual average of wind energy carrying maximum energy and most probable wind velocity were for Basrah, Nasiriyah, and Amarah respectively for any of selected heights. The blue colors in **Fig. (4, 5)** of every bar, represent the difference between wind velocity carrying maximum energy and most probable wind velocity.

In fact, the famous distribution which used in wind energy analysis is the Weibull distribution. It is used to describe the wind variations with suitable accuracy. **Fig.6** and **Fig.7** illustrates the probability density function and cumulative distribution function of selected sites at stations elevation for annual shape and scale factors, in order to characterize the wind velocity variations for the selected sites.

Fig.8 illustrate the monthly average of wind power density at stations elevation of selected sites. The higher and lower of measured monthly average of wind power densities were (165.3063 and 8.6183 W/m^2) at June and November respectively for Amarah, (57.1705 and 12.8252 W/m^2) at May and December respectively for Nasiriyah, and (102.6883 and 6.5592 W/m^2) at June and December respectively for Basrah. Also, the higher and lower of Weibull estimated monthly average of wind power densities were (231.5886 and 12.1919 W/m^2) at June and November respectively for Amarah, (98.8831 and 17.3148 W/m^2) at May and December respectively for Nasiriyah, and (152.5685 and

11.5366 W/m^2) at June and December respectively for Basrah. From **table (2, 3, and 4)**, the sites have the highest measured annual average of wind power densities at stations elevation were (39.5725, 36.9985, and 27.8722 W/m^2) for Amarah, Basrah, and Nasiriyah respectively. Also, the sites have the highest Weibull estimated annual average of wind power densities at stations elevation were (52.3616, 45.5274 and 33.8317 W/m^2) for Basrah, Amarah, and Nasiriyah respectively.

Fig.9 state the measured and Weibull estimated annual average of wind power densities for selected stations at selected heights (60, 90, and 120 m). The measured annual average of wind power densities were (170.0043, 231.7114, and 288.3992 W/m^2) , (188.3153, 256.6677, and 319.4584 W/m^2), and (370.5608, 505.0603, and 628.6229 W/m^2) for Amarah, Nasiriyah, and Basrah at (60, 90, and 120 m) respectively. Also, the Weibull estimated annual average of wind power densities were (166.4422, 219.9666, and 268.0718 W/m^2) , (206.3821, 277.4621, and 342.1760 W/m^2), and (386.6496, 508.9844, and 618.6966 W/m^2) for Amarah, Nasiriyah, and Basrah at (60, 90, and 120 m) respectively. Obviously, from **Fig. 9** and **Table. 6** the best annual average of wind power density were for Basrah, Nasiriyah, and Amarah respectively.

The assessment classification for the wind resource as [9]:

Fair $(\boldsymbol{P_D} < 100\ \boldsymbol{W/m^2})$

Fairly good $(100 \le P_D \le 300\ W/m^2)$

Good $(300 \le P_D < 700\ W/m^2)$

Very good $(P_D \ge 700\ W/m^2)$

So, the wind classes according to the above classification for the selected sites was tabulated in **Table. 7.**

Fig.10 clarify the monthly average of wind energy density at stations elevation of selected sites. The higher and lower of measured wind energy densities were (119.02 and 06.21 kWh/m^2) at June and November respectively for Amarah, (42.535 and 09.542 kWh/m^2) at May and December respectively for Nasiriyah, and (73.936 and 04.880 kWh/m^2) at June and December respectively for Basrah. Also, the higher and lower of Weibull estimated energy of power densities were (166.74 and 08.78 kWh/m^2) at June and November respectively for Amarah, (73.569 and 12.882 kWh/m^2) at May and December respectively for Nasiriyah, and (109.85 and 08.58 kWh/m^2) at June and December respectively for Basrah. From **Tables. (2, 3, and 4)**, the sites have the highest measured annual average of wind energy densities at selected stations elevation were (345.41, 322.08, and 244.41 kWh/m^2) for Amarah, Basrah, and Nasiriyah respectively. Also, the sites have the highest Weibull estimated annual average of wind energy densities at selected stations elevation were (530.52, 511.08 , and 335.38 kWh/m^2)for Basrah, Amarah, and Nasiriyah respectively.

Fig.11 show the annual average for measured and Weibull estimated of wind energy densities of selected stations at selected heights (60, 90, and 120 m). The annual average of measured wind energy densities were (1483.9, 2022.5, and 2517.3 kWh/m^2) , (1615.5, 2251.0, and 2801.7 kWh/m^2), and (3225.8, 4396.7, and 5472.3 kWh/m^2) for Amarah, Nasiriyah, and Basrah at (60, 90, and 120 m) respectively. Also, the annual average of Weibull estimated wind energy densities were (1727.8, 2249.7, and 2714.1 kWh/m^2) , (1935.7, 2583.6, and 3170.8 kWh/m^2), and (3688.6, 4820.3, and 5829.8 kWh/m^2) for Amarah, Nasiriyah, and Basrah at (60, 90, and 120 m) respectively. Obviously, from **Fig. 11** and **Table. 6** the best annual average of wind energy density were for Basrah, Nasiriyah, and Amarah respectively.

5. CONCLUSIONS

The results of the present study lead to the following conclusions:

1. The annual average for measured and Weibull estimated of wind velocities at stations elevation were (4.0138, 3.5707, and 3.9241 m/s) and (4.0166, 3.5743, and 3.9253 m/s) for Amarah, Nasiriyah, and Basrah respectively.
2. The Weibull estimated annual average of shape and scale factors at stations elevation were (2.7901, 3.5023, and 2.3279) and (4.1590, 3.8779, 4.1943 m/s) for Amarah, Nasiriyah, and Basrah respectively.
3. The annual average of wind velocity carrying maximum energy and most probable wind velocities at stations elevation were (5.0839, 4.4895, and 5.4989 m/s) and (3.5208, 3.4652, and 3.2793 m/s) for Amarah, Nasiriyah, and Basrah respectively.
4. The annual average for measured and Weibull estimated of wind power densities at stations elevation were (39.5725, 27.8722, and 36.9985 W/m^2) and (45.5274, 33.8317, and 52.3616 W/m^2) for Amarah, Nasiriyah, and Basrah respectively.
5. The annual average for measured and Weibull estimated of wind energy densities at stations elevation were (345.41, 244.44, and 322.08 kWh/m^2) and (511.08, 335.38, and 530.52 kWh/m^2) for Amarah, Nasiriyah, and Basrah respectively.
6. From the annual average of wind power densities at stations elevation, It is worth mentioning that the selected sites are suitable for off-grid applications in remote and populated areas such as pumping water, batteries charging, lightening of streets, and domestic applications.
7. The wind classes for selected sites were fair at stations elevation. While the wind classes were fairly good at (60, 90, 120 m) for Amarah, fairly good at (60, and 90 m) but it were good at 120 m for Nasiriyah. While, it were good at selected heights for Basrah. So, Basrah is acceptable for connecting to power grid and Nasiriyah at height 120 m.
8. According to the values of determination factor and root mean square error in **Table.6**, the statistical model of Weibull distribution have a good accuracy in estimating the site's actual data.

Table 1. Elevations of different stations in Iraq.

No.	Stations	Elevation (m)	Latitude	Longitude	Location in Iraq
1	Amarah	9	31.83 °N	47.17 °E	South-eastern Iraq
2	Nasiriyah	5	31.02 °N	46.23 °E	Southeast Iraq
3	Basrah	3	30.37 °N	48.25 °E	South of Iraq

Table 2. Measured and Weibull estimated parameters of Amarah at station elevation.

Amarah at standard height (9 m)	Year	Month	Parameters of measured quantities				Estimated Parameters by Weibull Distribution								Annual parameters
			$\bar{V}$ (m/s)	σ (m/s)	PD (W/m²)	ED (kWh / m²)	K (-)	C (m/s)	$\bar{V}$ (m/s)	σ (m/s)	V_{mE} (m/s)	V_{mp} (m/s)	PD (W/m²)	ED (kWh / m²)	
	2014	Aug.	3.7517	1.6865	32.3154	24.04	2.3905	4.2334	3.7526	1.6714	5.4593	3.3748	52.7548	39.25	R^2 = 1.0000
		Sep.	3.6659	1.3666	30.1486	21.71	2.9317	4.1128	3.6690	1.3613	4.9112	3.5673	43.0022	30.96	
		Oct.	3.3782	1.2827	23.5929	17.55	2.8735	3.7930	3.3809	1.2771	4.5585	3.2684	34.0428	25.33	
		Nov.	2.4149	0.8881	8.6183	06.21	2.9751	2.7077	2.4170	0.8850	3.2185	2.3594	12.1919	08.78	
		Dec.	2.4871	0.9829	9.4147	07.00	2.7508	2.7967	2.4887	0.9776	3.4113	2.3731	13.9452	10.38	
	2015	Jan.	3.0990	1.3702	18.2133	13.55	2.4341	3.4959	3.0999	1.3586	4.4727	2.8130	29.3303	21.82	RMSE= 0.0086
		Feb.	3.2752	1.1549	21.5000	14.45	3.1150	3.6652	3.2785	1.1521	4.2978	3.2368	29.6778	19.94	
		Mar.	2.9744	1.1937	16.1036	11.98	2.7053	3.3465	2.9762	1.1867	4.1062	2.8217	24.1060	17.93	
		Apr.	4.6213	1.9729	60.3973	43.49	2.5289	5.2090	4.6231	1.9580	6.5588	4.2691	94.5962	68.11	
		May.	3.7781	1.2284	33.0024	24.55	3.4028	4.2105	3.7828	1.2278	4.8232	3.8012	43.6520	32.48	
		Jun.	6.4643	2.3389	165.3063	119.02	3.0287	7.2428	6.4704	2.3317	8.5628	6.3452	231.5886	166.74	
		Jul.	4.5132	2.0648	56.2573	41.86	2.3451	5.0941	4.5141	2.0455	6.6265	4.0191	93.2262	69.36	
Annual Average			4.0138	1.4609	39.5725	345.41	2.7901	4.1590	4.0166	1.4527	5.0839	3.5208	45.5274	511.08	

Table 3. Measured and Weibull estimated parameters of Nasiriyah at station elevation.

Nasiriyah at standard height (5 m)	Year	Month	Parameters of measured quantities				Estimated Parameters by Weibull Distribution								Annual parameters
			$\bar{V}$ (m/s)	σ (m/s)	PD (W/m²)	ED (kWh / m²)	K (-)	C (m/s)	$\bar{V}$ (m/s)	σ (m/s)	V_{mE} (m/s)	V_{mp} (m/s)	PD (W/m²)	ED (kWh / m²)	
	2014	Aug.	3.6666	1.1087	30.1776	22.452	3.6831	4.0695	3.6716	1.1097	4.5781	3.7341	38.5903	28.711	R^2 = 1.0000
		Sep.	3.2956	0.7416	21.9128	15.777	5.0821	3.5881	3.2976	0.7442	3.8302	3.4367	25.2393	18.172	
		Oct.	3.4156	1.2542	24.3947	18.150	2.9802	3.8294	3.4186	1.2499	4.5495	3.3386	34.4757	25.650	
		Nov.	3.0678	1.1119	17.6757	12.726	3.0230	3.4375	3.0707	1.1084	4.0662	3.0098	24.7876	17.847	
		Dec.	2.7567	0.9332	12.8252	9.542	3.2565	3.0787	2.7598	0.9319	3.5663	2.7507	17.3148	12.882	
	2015	Jan.	2.8797	0.9020	14.6196	10.877	3.5442	3.2026	2.8835	0.9022	3.6335	2.9166	18.9943	14.132	RMSE= 0.0127
		Feb.	3.1787	0.9956	19.6627	13.213	3.5444	3.5351	3.1828	0.9959	4.0107	3.2195	25.5454	17.167	
		Mar.	2.9722	0.8699	16.0742	11.959	3.8165	3.2924	2.9764	0.8712	3.6768	3.0405	20.2706	15.081	
		Apr.	3.8678	1.2753	35.4231	25.505	3.3513	4.3136	3.8724	1.2743	4.9601	3.8808	47.1781	33.968	
		May.	4.5369	2.1771	57.1705	42.535	2.2262	5.1231	4.5374	2.1541	6.8325	3.9192	98.8831	73.569	
		Jun.	4.3204	1.1819	49.3704	35.547	4.1078	4.7657	4.3263	1.1848	5.2489	4.4528	60.6134	43.642	
		Jul.	3.8582	1.2513	35.1600	26.159	3.4124	4.2992	3.8630	1.2507	4.9214	3.8837	46.4479	34.557	
Annual Average			3.5707	1.1502	27.8722	244.44	3.5023	3.8779	3.5743	1.1481	4.4895	3.4652	33.8317	335.38	

Table 4. Measured and Weibull estimated parameters of Basrah at station elevation.

Basrah at standard height (3 m)	Year	Month	Parameters of measured quantities				Estimated Parameters by Weibull Distribution								Annual parameters
			$\bar{V}$ (m/s)	σ (m/s)	PD (W/m²)	ED (kWh / m²)	K (-)	C (m/s)	$\bar{V}$ (m/s)	σ (m/s)	V_{mE} (m/s)	V_{mp} (m/s)	PD (W/m²)	ED (kWh / m²)	
	2014	Aug.	4.1749	1.8364	44.5571	33.151	2.4478	4.7091	4.1762	1.8211	6.0102	3.7998	71.4540	53.16	R^2 = 1.0000
		Sep.	3.8511	1.8415	34.9730	25.181	2.2349	4.3486	3.8515	1.8222	5.7884	3.3349	60.2885	43.41	
		Oct.	3.3378	1.5565	22.7698	16.941	2.2968	3.7683	3.3383	1.5412	4.9497	2.9381	38.3699	28.55	
		Nov.	2.5635	1.2482	10.3152	07.427	2.1911	2.8949	2.5637	1.2346	3.8920	2.1919	18.0895	13.02	
		Dec.	2.2044	1.0768	6.5592	04.880	2.1835	2.4893	2.2046	1.0650	3.3528	1.8805	11.5366	08.58	
	2015	Jan.	3.0682	1.6553	17.6860	13.158	1.9594	3.4606	3.0682	1.6337	4.9553	2.4037	34.4876	25.66	RMSE= 0.0035
		Feb.	4.2522	2.0752	47.0782	31.637	2.1857	4.8018	4.2526	2.0525	6.4641	3.6298	82.7324	55.60	
		Mar.	3.2939	1.7257	21.8832	16.281	2.0230	3.7175	3.2939	1.7041	5.2219	2.6539	41.3230	30.74	
		Apr.	4.4543	1.7655	54.1150	38.963	2.7421	5.0093	4.4571	1.7558	6.1170	4.2455	80.3146	57.83	
		May.	3.3716	1.2938	23.4686	17.461	2.8405	3.7871	3.3741	1.2878	4.5689	3.2506	34.0915	25.36	
		Jun.	5.5146	2.1892	102.6883	73.936	2.7375	6.2021	5.5181	2.1770	7.5780	5.2531	152.5685	109.85	
		Jul.	4.5555	2.3144	57.8878	43.069	2.0921	5.1435	4.5557	2.2869	7.0881	3.7697	105.8511	78.75	
Annual Average			3.9241	1.7149	36.9985	322.08	2.3279	4.1943	3.9253	1.6985	5.4989	3.2793	52.3616	530.52	

Table 5. Annual average of wind velocity carrying maximum energy and most probable wind velocity of selected sites.

Selected sits	Selected height (m)	wind velocity carrying maximum energy (m/s)	most probable wind velocity (m/s)
Amarah	60	7.9514	6.7328
	90	8.8247	7.4722
	120	9.5019	8.0456
Nasiriyah	60	7.3882	7.0350
	90	8.1996	7.8076
	120	8.8288	8.4068
Basrah	60	9.9136	8.8275
	90	11.0023	9.7970
	120	11.8466	10.5488

Table 6. Corrected annual parameters at selected heights of selected sites.

Locations	Height (m)	Parameters of measured quantities			Estimated Parameters by Weibull Distribution					Fit goodness	
		$\overline{V}$ (m/s)	PD (W/m^2)	ED (kWh / m^2)	K (-)	C (m/s)	$\overline{V}$ (m/s)	PD (W/m^2)	ED (kWh / m^2)	R^2	RMSE
Amarah	60	6.5358	170.0043	1483.9	3.3500	6.5782	6.2405	166.4422	1727.8	0.9594	0.4251
	90	7.2536	231.7114	2022.5	3.5002	7.2575	6.8667	219.9666	2249.7	0.9415	0.5563
	120	7.8103	288.3992	2517.3	3.6151	7.7821	7.3511	268.0718	2714.1	0.9272	0.6589
Nasiriyah	60	6.7625	188.3153	1651.5	4.4839	7.2131	6.6687	206.3821	1935.7	0.9433	0.0907
	90	7.5052	256.6677	2251.0	4.6988	7.9827	7.3897	277.4621	2583.6	0.9243	0.1058
	120	8.0812	319.4584	2801.7	4.8642	8.5782	7.9491	342.1760	3170.8	0.9094	0.1149
Basrah	60	8.4742	370.5608	3225.8	3.1625	8.6551	7.9951	386.6496	3688.6	0.9068	0.9767
	90	9.4049	505.0603	4396.7	3.3238	9.5496	8.8185	508.9844	4820.3	0.8826	1.1882
	120	10.1266	628.6229	5472.3	3.4486	10.2402	9.4562	618.6966	5829.8	0.8641	1.3522

Table 7. Wind classes of selected sites at station elevation and selected heights.

Selected Sites	Wind Classes at Stations height	Wind Classes at different heights		
		(60 m)	(90 m)	(120 m)
Amarah	Fair	Fairly good	Fairly good	Fairly good
Nasiriyah	Fair	Fairly good	Fairly good	Good
Basrah	Fair	Good	Good	Good

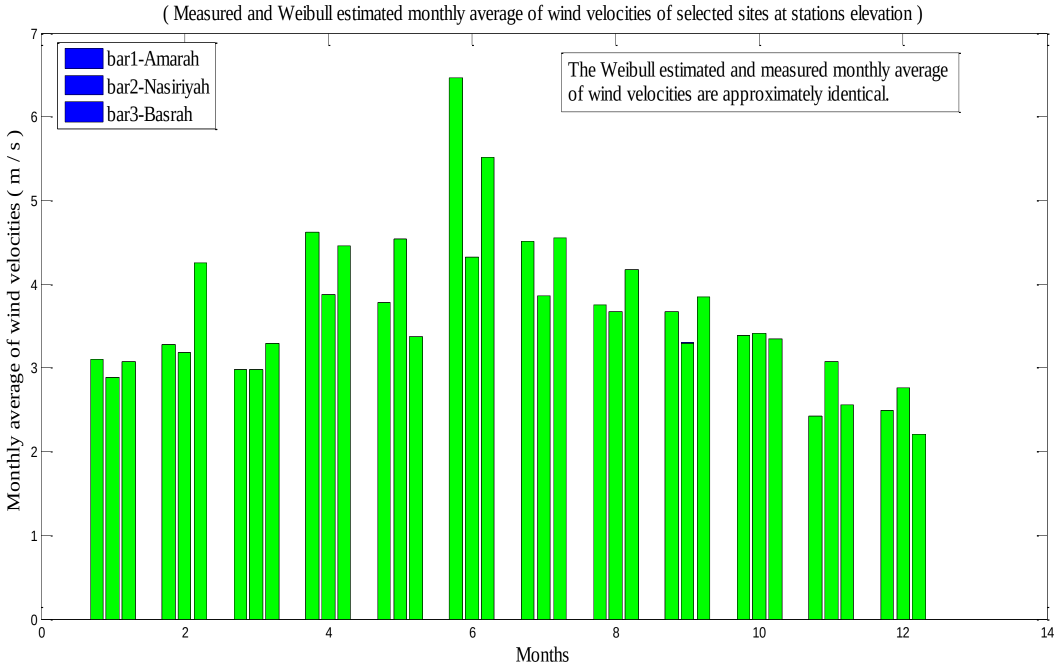

Fig 1: Monthly average of wind velocity of selected sites at stations elevation.

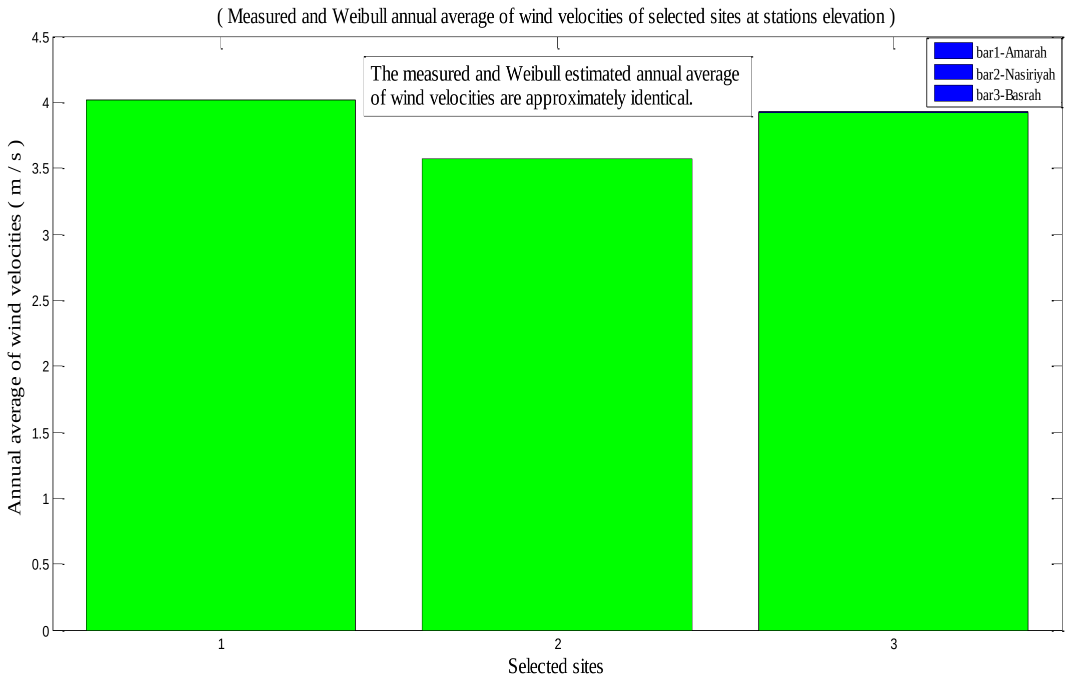

Fig 2: Annual average of wind velocity of selected sites at stations elevation.

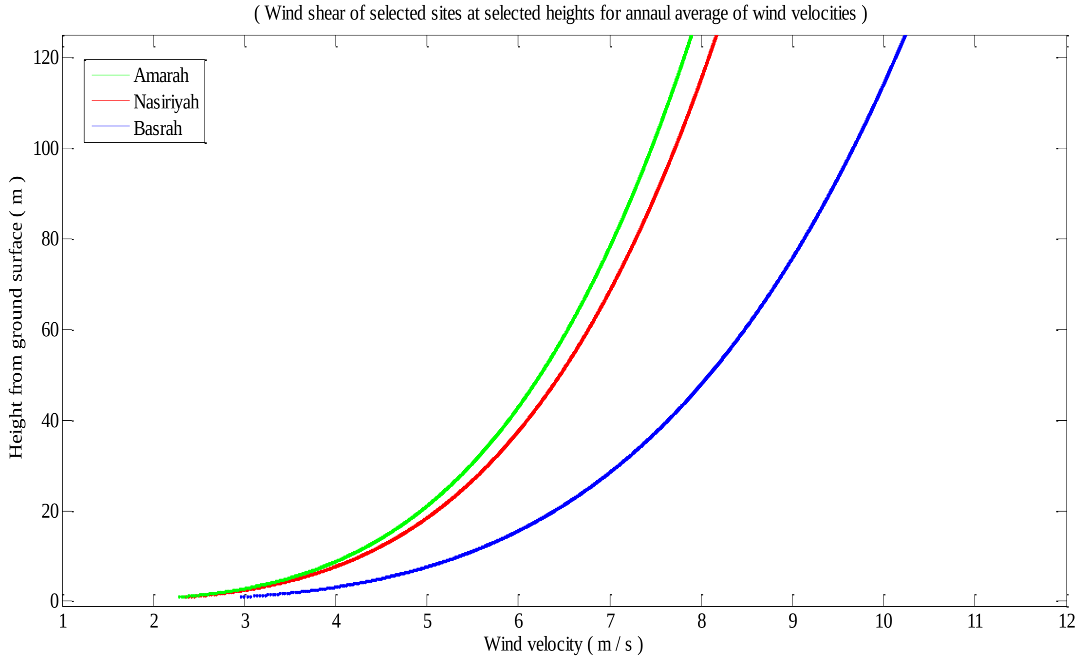

Fig 3: Wind shear of selected sites at selected heights for annual average of wind velocities.

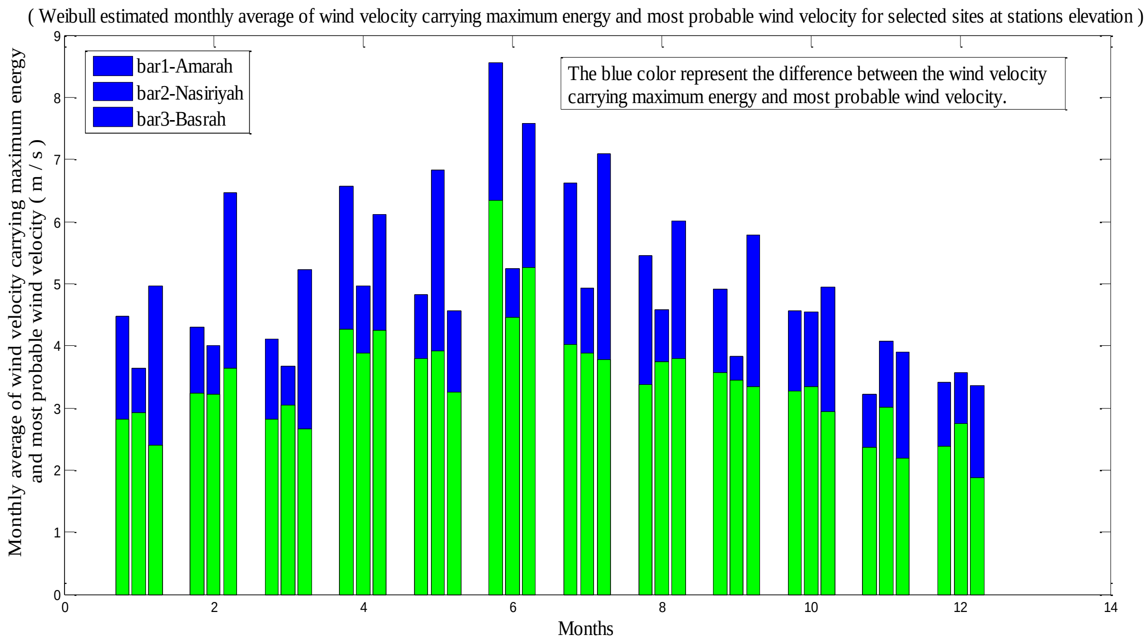

Fig 4: Monthly average of wind velocity carrying maximum energy and most probable wind velocity of selected sites at stations elevation.

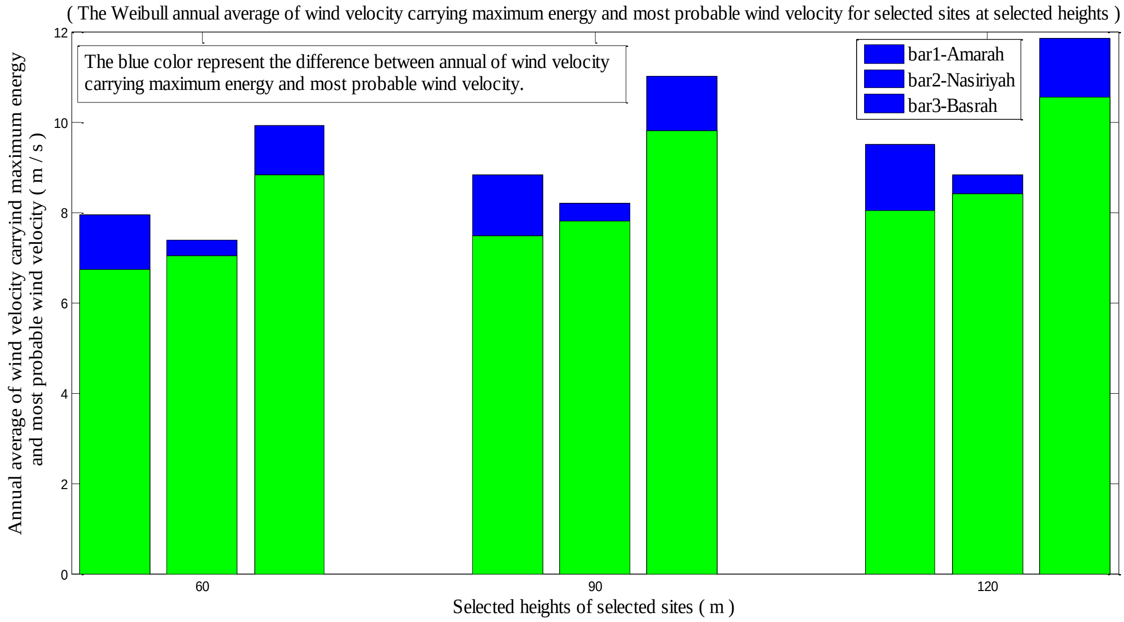

Fig 5: Annual average of wind velocity carrying maximum energy and most probable wind velocity of selected sites at selected heights.

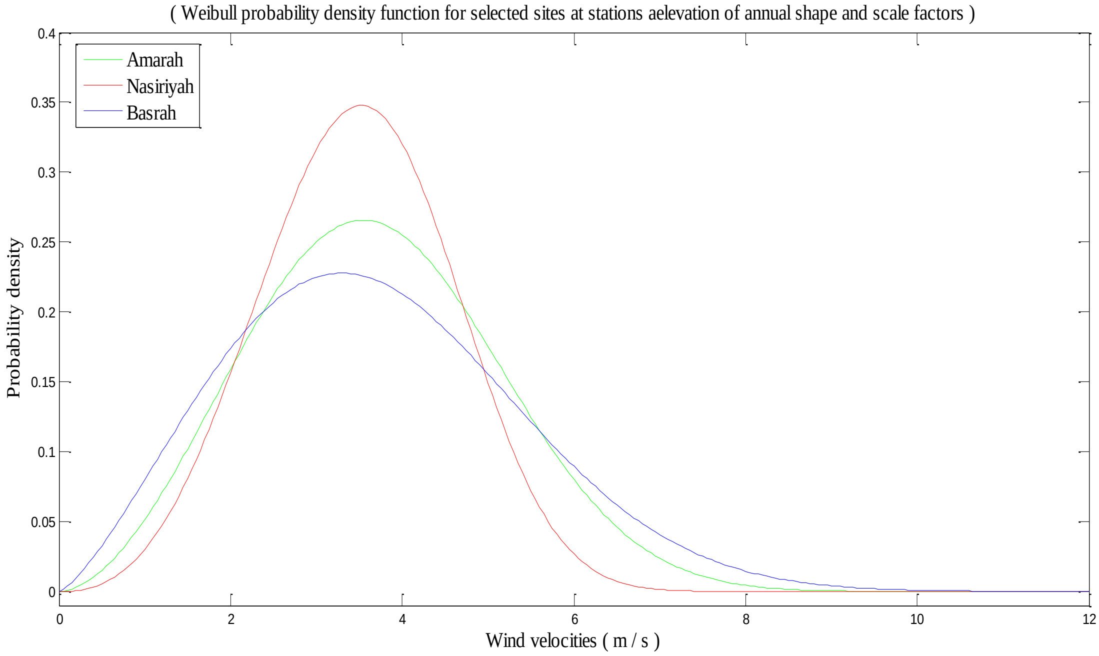

Fig 6: Weibull probability density function with wind velocity for selected sites at stations elevation of annual shape and scale factors.

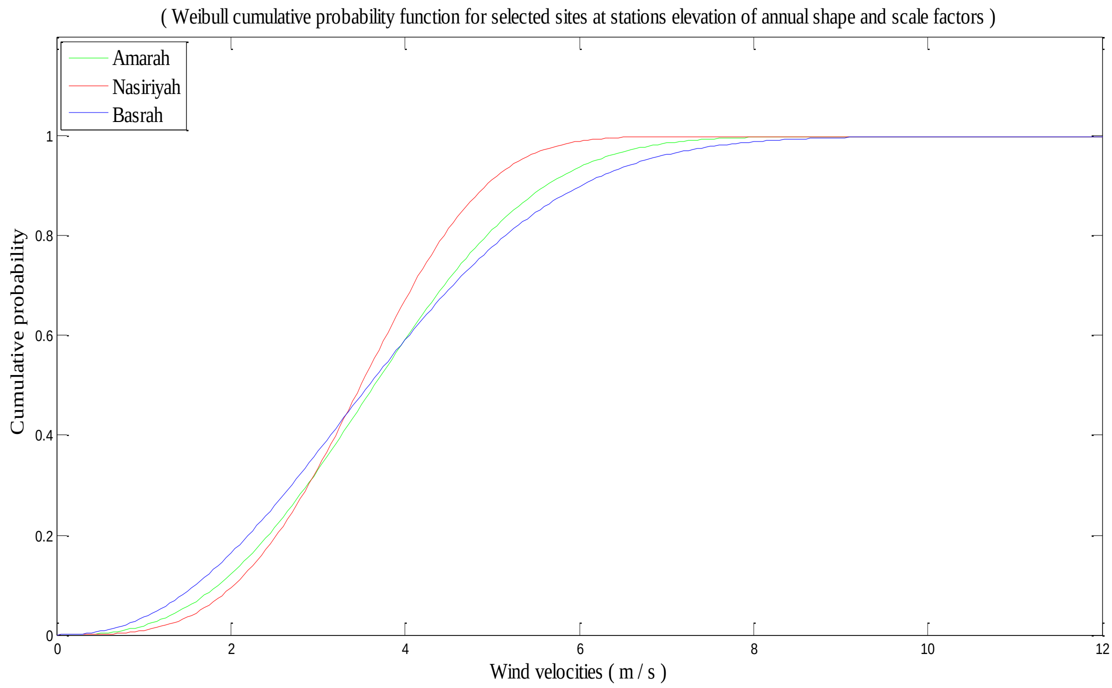

Fig 7: Weibull cumulative distribution function with wind velocity for selected sites at stations elevation of annual shape and scale factors.

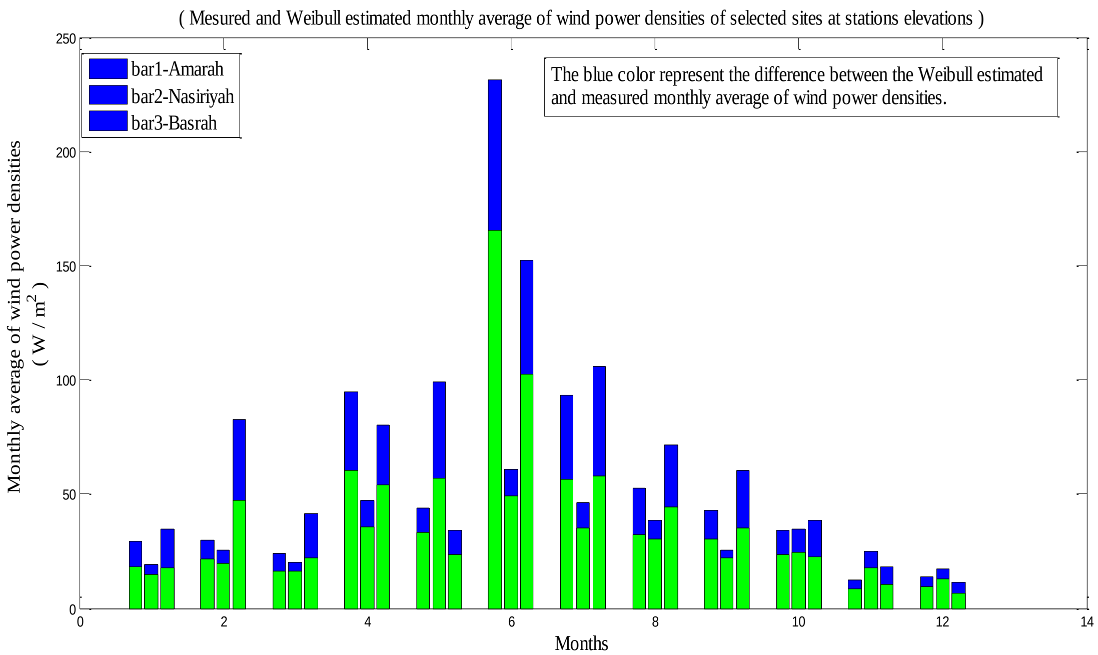

Fig 8: Monthly average for measured and Weibull estimated of wind power densities of selected sites at stations elevation.

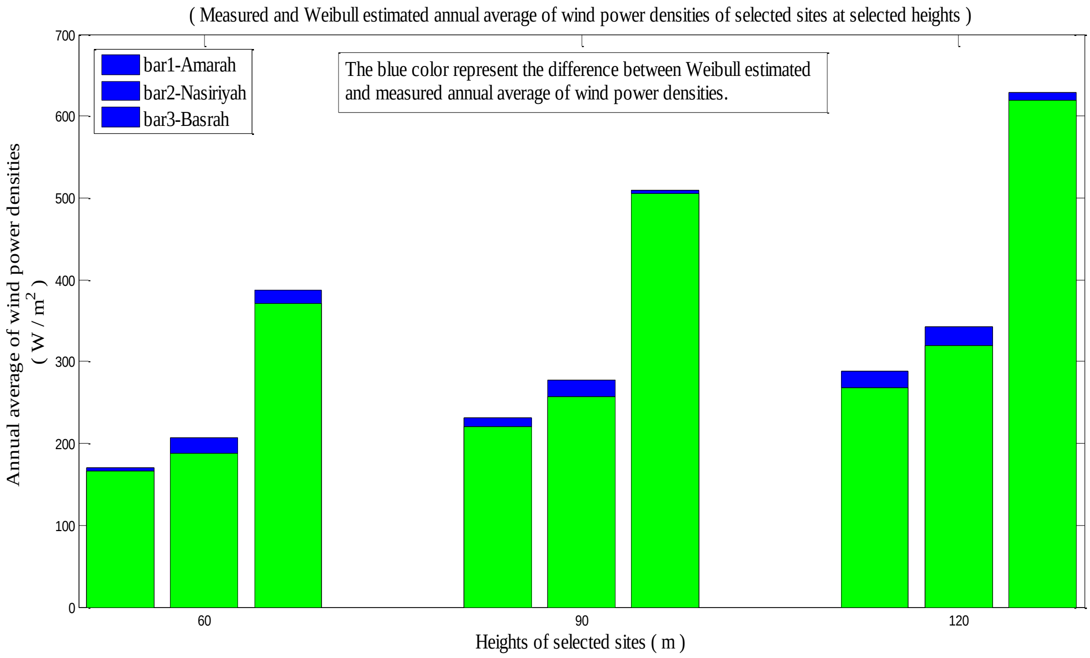

Fig 9: Annual average for measured and Weibull estimated of wind power densities of selected sites at selected heights.

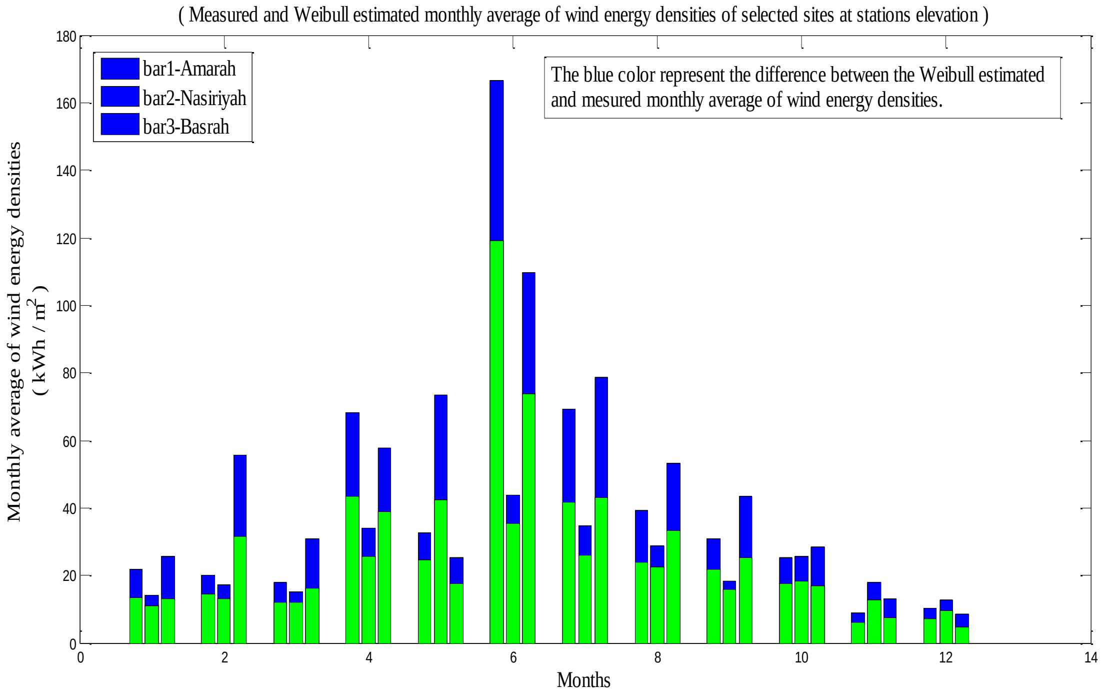

Fig 10: Monthly average for measured and Weibull estimated of wind energy densities of selected sites at stations elevation.

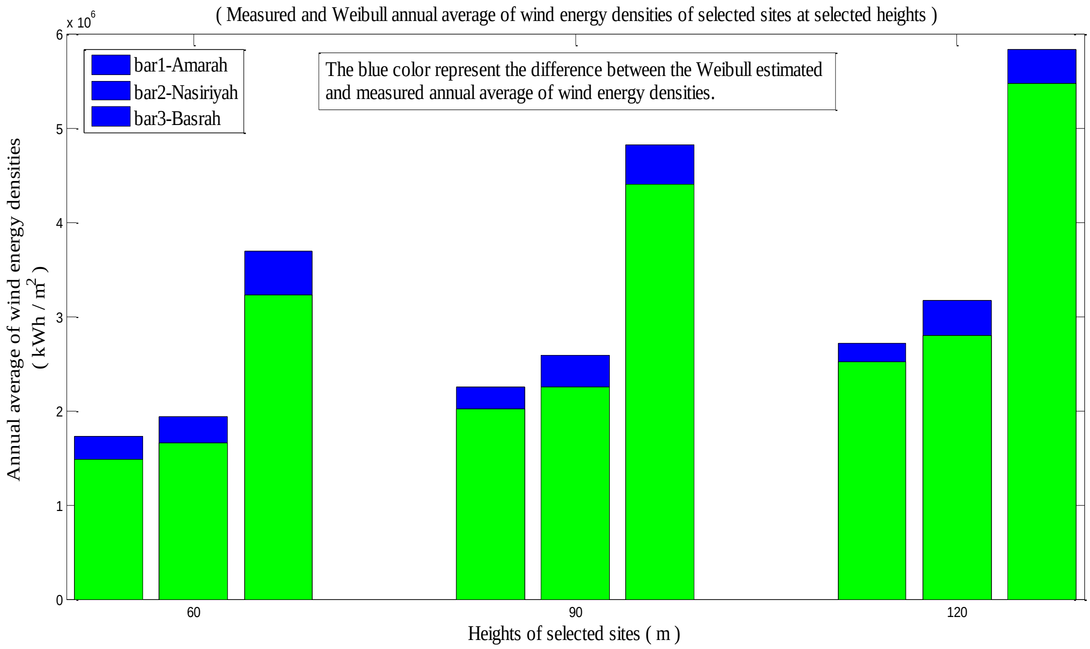

Fig 11: Annual average for measured and Weibull estimated of wind energy densities of selected sites at selected heights.

6. REFERENCES

[1] Shafiqur Rehman, and Aftab Ahmad, 2004, "Assessment of wind energy potential for coastal locations of the Kingdom of Saudi Arabia", Energy 29, PP. 1105–1115, doi:10.1016/j.energy.2004.02.026.

[2] Meishen Li, and Xianguo Li, 2005, "Investigation of Wind Characteristics and Assessment of Wind Energy Potential for Waterloo Region, Canada", Energy Conversion and Management 46, PP. 3014–3033.

[3] Getachew Bekele, and Björn Palm, 2009, "Wind Energy Potential Assessment at Four Typical Locations in Ethiopia", Applied Energy 86 PP. 388–396.

[4] Ioannis Fyrippis, Petros J. Axaopoulos, and Gregoris Panayiotou, 2010, "Wind Energy Potential Assessment in Naxos Island, Greece", Applied Energy 87, PP. 577–586.

[5] Joseph A. Jervase, and Ali M. Al-Lawati, 2012, "Wind Energy Potential Assessment for the Sultanate of Oman", Renewable and Sustainable Energy Reviews 16, 1496–1507.

[6] Sunday O Oyedepo, Muyiwa S Adaramola, and Samuel S Paul, 2012, "Analysis of wind speed data and wind energy potential in three selected locations in south-east Nigeria", International Journal of Energy and Environmental Engineering, 3:7, http://www.journal-ijeee.com/content/3/1/7.

[7] Saeed Jahanbakhsh Asl, Majid Rezaei Banafsheh, Yagob Dinpashoh, Marziyeh Esmaeilpour, Kasra Mohammadi, Ali Mohammad Khorshiddoust, 2014, "Assessing Wind Energy potential in Kurdistan Province, Iran", Int J Energy Environ Eng, 5:100, DOI 10.1007/s40095-014-0100-x.

[8] Oluseyi O Ajayi, Richard O Fagbenle, James Katende, Samson A Aasa and Joshua O Okeniyi, 2013, "Wind Profile Characteristics and Turbine Performance Analysis in Kano, North-Western Nigeria", International Journal of Energy and Environmental Engineering, 4:27, http://www.journal-ijeee.com/content/4/1/27.

[9] Farivar Fazelpour, Nima Soltani, Marc A. Rosen, 2014, "Wind Resource Assessment and Wind Power Potential for the City of Ardabil, Iran", Int J Energy Environ Eng, DOI 10.1007/s40095-014-0139-8.

[10] https://www.wunderground.com/global/stations/40680.html, https://www.wunderground.com/global/stations/40676.html, https://www.wunderground.com/global/stations/40689.html

[11] Sathyajith Mathew, 2006, "Wind Energy Fundamentals, Resource Analysis and Economics", (PP. 64, 68, 96, 71, 75, 82, and 83).

[12] Mukund R. Patel, 2006, "Wind and Solar Power Systems Design, Analysis, and Operation", 2nd edition, (PP.31).

[13] Vaughn Nelson, 2009, "Wind Energy Renewable Energy and the Environment", (PP.37).

[14] David Wood, 2011, "Small Wind Turbines Analysis, Design, and Application" (PP. 14-15).