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Estimation of Weibull Parameters for Wind Energy Application in Al Shihabi City

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A B S T R A C T

Wind energy is environmentally friendly and low-cost energy compared to other renewable energy technologies and is easily exploited by different users. Al-Shihabi ia a city with high potential wind resources. The aim of the research is to assess the mean winds and Weibull parameters such as shape parameter and scale parameter. The assessment helps in understanding the wind behavior for the application of the wind energy project. Field data for year 2019 were collected at an interval of 10 minutes at altitudes of 50 and 100 meters. Then the data was analyzed using the statistical Weibull distribution function. The annual average of monthly means at 50 m and 100 m heights are 5.04 m/s and 5.56 m/s, respectively. While the annual average of monthly maximum winds at 50 m and 100 m heights were 13.65 m/s and 15.05 m/s. The larger values were in summer months. The mean wind speed and maximum wind speed values suggest that Al-Shihabi City is a promising site to install a wind farm.

Estimating Weibull distribution parameters showed for 50 m and 100 heights that the annual average of monthly values of shape parameter and scale parameter were 5.6840, and 2.4035, respectively. At 100 m height, It was found that the annual average of monthly values of shape parameter, scale parameter were 6.2634 and 2.3215, respectively. It can also be noted that the values of parameters are higher in summer than in winter. It was found that the Weibull distribution is applicable to describe the probability density of wind speed.

Keywords: *Weibull parameters, shape and scale parameter, maximum likelihood method, Al-Shihab*

1. Introduction

Energy is important and essential for our society and is a requirement of any house, building, plant, city, or nation. to ensure the quality of our life and support all other elements of our economy. Renewable energy technologies offer the promise of clean and abundant energy that is self-renewing source such as sun, wind and biomass and plants. Almost all regions of the world have renewable resources of one kind or another. The common term "renewable energy" is energy derived from a wide range of natural resources, namely these energies are based on self-renewing energy sources such as natural sunlight, wind, water, earth's internal heat and biomass where these resources can be used to produce electricity for all economic sectors, fuel for transport and heat for buildings and industrial processes [1]. Wind energy is one of the renewable energy resources, which have been widely developed in recent years. It has many advantages such as no pollution, and the least cost of renewable energy technologies [2]. Because wind energy is not dependent on fossil fuels for power generation, therefore it has become a promising technology to replace fossil fuels to generate electricity. This has become an increasingly attractive energy resource due to increased energy demand global and environmental concerns [3]. It mathematically clear that wind energy is closely related to wind speed. That is, the intensity of wind energy increases with the value of the wind speed cube, therefore, a higher wind speed produces more electric energy by turbines, and therefore the cost of energy will decrease per kWh [4]. Two important factors, average wind speed and wind distributions, are the main keys to assessing winds in a particular location. It is known and common that the wind speed is variable and unstable with time and place. It is affected by weather phenomena, the topography of the site and some other factors. The two-parameter Weibull distribution has become the most important and most widely used probability distribution in wind speed analysis and statistics. The Weibull distribution function is used comprehensively to determine the potential and intensity of wind power at a specified location. The two-parameter Weibull distribution is the most widely used probability fitting distribution in wind speed and wind energy density analysis and statistics. The Weibull distribution function is comprehensively used for delineating the wind power potential at a destined site.

In the current study, the Weibull distribution was used to estimate the scale and shape parameters for Al Shihabi City, 185 km southeast of Baghdad, Iraq. This will help to understand the behavior of wind and whether the region is suitable to establish a wind farm with best productivity and least loss.

1.1 Wind Profile Law

The wind profile law is a formula that describes how the wind speed changes with altitude. Basically, the wind speed increases as moving further away from the ground. The law can be expressed mathematically as [5]:

$$v_2 = v_1 \left(\frac{z_2}{z_1}\right)^{\alpha} \tag{1}$$

where $v(z)$ is the wind speed at height z, (v_o) is the wind speed at a reference height (usually 10 meters), (z_o) is the reference height, and (α) is a constant that depends on the roughness of the terrain.

This law is important in fields like meteorology, wind energy applications, and building design, as it helps to predict wind speeds at different heights and design structures to withstand wind loads [6]. Roomi (2000) used the logarithmic law and the power law to estimate the wind speed at various altitudes based on the surface data of wind speed and some other parameters and stability [7].

1.2 Probabilistic model of wind speed Weibull distribution

Many different statistical and numerical methods can be used to estimate potential wind power. However, Weibull distributions have most commonly used to determine the behavior of potential wind energy [8]. Recently, studies to assess the potential of wind energy in different regions have shown different uses probability distribution function. The Weibull probability density function is used to predict the wind speed, Wind intensity and wind energy potential. The Weibull distribution function is used to determine the value of k and c, the parameters that explain the style and behavior of the winds in the area under study. These two parameters are found from the wind speed dataset using several methods such as maximum probability, least squares, or Moment's method [9]. The Weibull distribution function can be generally expressed as following:

$$f(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{(k-1)} exp\left(-\left(\frac{v}{c}\right)^{k}\right) \tag{2}$$

where $f(v)$ denotes the probability of occurrence of v wind velocity, and k is a dimensionless shape parameter and c (m/s) is a scale parameter.

The Weibull cumulative distribution function is given as

$$f(v) = 1 - exp\left[-\left(\frac{v}{c}\right)^{k}\right] \tag{3}$$

1.2.1 Estimation of Weibull parameters

Many endeavors have been made by many different scientists in the world to determine the parameters of the Weibull shape and scale coefficient, and also the wind distribution, which is used to model the distribution of wind speed in a specific location to be studied and in turn helps in evaluating the wind resource in that location. Frequently used methods for determining Weibull parameters available in literature are maximum likelihood (MLM) [10].

1.3 Maximum Likelihood Method (MLM)

Maximum Likelihood Method is a method by Stevens and Smulders [11] The maximum likelihood method requires a lot of Iterative calculations. The shape and scale parameters of the Weibull distribution are calculated or estimated by these two equation

$$k = \left(\frac{\sum_{i=1}^{n} v_i^k \ln(v_i)}{\sum_{i=1}^{n} v_i^k} - \frac{\sum_{i=1}^{n} \ln(v_i)}{n} \right)^{-1} \tag{4}$$

$$c = \left(\frac{1}{n} \sum_{i=1}^{n} v_i^k \right)^{1/k} \quad (5)$$

where v_i is the wind speed and n is the number of nonzero wind speeds.

2. Methodology

2.1 Study Area

Al-Shihabi City (32.85o N, 46.29o E) is located in Wasit Governorate 185 km southeast of Baghdad, Iraq. It is considered one of the Iraqi cities that have potential high wind speeds and wind energy intensity. The topographic features of Al-Shihabi City are mostly open flat plain area. Wind speed data at 50 and 100 m altitude were acquitted for one year, 2019, at 10-min intervals. Then the data were analyzed using the Weibull distribution function.

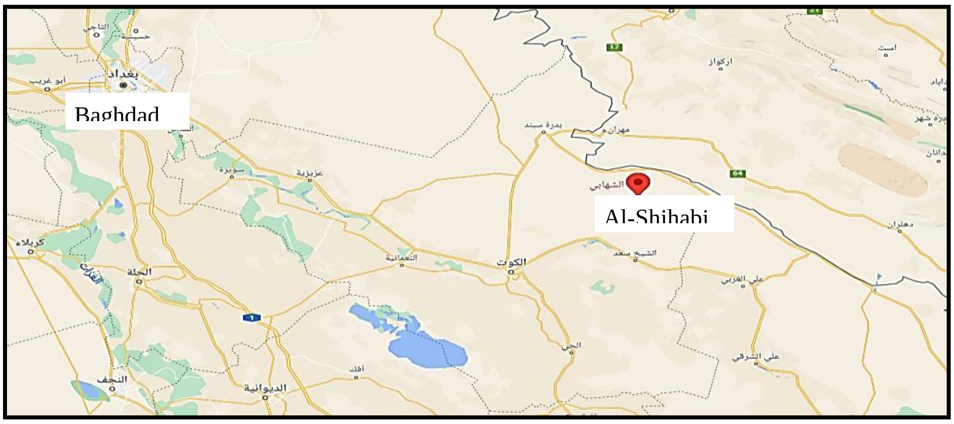

Figure 1. Location of Al-Shihabi City [9]

2.2 Analysis of Data

Weibull parameters are estimated using Maximum Likelihood Method (MLM) for Al-Shihabi in Iraq for year 2019 with focusing on winter and summer months. Many statistics were calculated such as mean, median and standard deviation for two altitudes 50 m and 100 m.

3. Results and discussion

3.1 Monthly mean wind speed data of Al-Shihabi City at 50 m and 100 m heights

Table 1 and Table 2 lists the monthly mean wind speed data of the station at 50 m and 100 m height, respectively. At 50 m height the larger values of mean and median were in July, (8.19 m/s) and (7.58 m/s), respectively. The maximum wind was in March (16.37 m/s). The annual average of monthly means and maximum winds were (5.04 m/s) and ((13.65 m/s), respectively.

At 100 m height, the larger mean values of mean and median were in July also, (9.02 m/s) and (8.35 m/s), respectively. The maximum wind was in March (18.04 m/s).

Table 1. Monthly mean wind speed (m/s) data of the station at 50 m height.

Month	Mean	Median	Standard Deviation	Min.	Max.
January	4.345778	3.714330	2.557778	0.125273	13.84261
February	4.448703	3.939821	2.045973	0.037582	13.8300
March	4.777715	3.958612	2.808674	0.238018	16.37311
April	3.976724	3.776966	1.653467	0.275600	13.22877
May	4.582095	4.372011	1.569291	0.864380	12.48967
June	6.166870	5.662318	2.317684	0.588781	13.50437
July	8.194658	7.585251	2.888702	2.192269	15.33335
August	6.242932	5.699899	2.398020	0.488563	13.01581
September	5.727420	5.048482	2.384037	0.388345	13.80503
October	4.250308	3.933557	1.905832	0.375818	11.75056
November	4.077081	3.708066	1.981611	0.225491	14.23095
December	3.797458	3.200713	2.397098	0.150327	12.50219

Table 2. Monthly mean wind speed (m/s) data at 100 m height.

Month	Mean	Median	Standard Deviation	Min.	Max.
January	4.7886	4.0928	2.818	0.138	15.253
February	4.9020	4.3413	2.2544	0.041	15.23
March	5.2645	4.362	3.094	0.262	18.041
April	4.381	4.1618	1.821	0.303	14.576
May	5.049	4.817	1.729	0.952	13.762
June	6.7953	6.239	2.553	0.648	14.88
July	9.029	8.358	3.183	2.415	16.895
August	6.879	6.280	2.642	0.538	14.342
September	6.311	5.562	2.626	0.427	15.211
October	4.683	4.334	2.100	0.414	12.984
November	4.492	4.085	2.183	0.248	15.681
December	4.184	3.526	2.641	0.165	13.776

3.2 Weibull distribution parameters

Table 3 and Table 4 lists the parameters of Weibull distribution at height 50 m and 100 m for year 2019. The aim of using the maximum likelihood method is to get the values of shape and scale parameter and other parameters that are essential in designing the wind farm. It was found that the Weibull distribution is applicable to describe the probability density of wind speed. These values of wind speeds suggests that Al-Shihabi City is a promising site for installing wind farms. The annual average of monthly means and maximum winds were (5.56 m/s) and (15.05 m/s) , respectively.

From Table 3, at 50 m height, it was found that the larger values of scale parameter and shape parameter, (9.184)and (3.077), respectively were in July. The larger value of lower 90% confidence for shape parameter was in July, (2.968)and smaller value was in December, (1.635). The larger value of upper 90% confidence for shape parameter was in July, (3.19)and smaller value was in December, (1.753). The larger value of lower 90% confidence for scale parameter was in July, (9.036)and smaller value was in December, (4.15). The larger value of upper 90% confidence for scale parameter was in July, (9.333)and smaller value was in December, (4.405). The annual average of monthly values of shape parameter, scale parameter, lower 90 % confidence for shape parameter, upper 90% confidence for shape parameter, lower 90% confidence for scale parameter, upper 90% confidence for scale parameter were (5.6840, 2.4035, 2.3215, 2.4873, and 5.805), respectively.

From Table 4, at 100 m height, the larger values of scale parameter and shape parameter were in July (10.12)and (3.077), respectively. The larger value of lower 90 % confidence for shape parameter was in July, (2.968)and smaller value was in December, (1.635). The larger value of upper 90 % confidence for shape parameter was in July, (3.19)and smaller value was in December, 1.753. The larger value of lower 90% confidence for scale parameter was in July, (9.957)and smaller value was in December, (4.577). The larger value of upper 90 % confidence for scale parameter was in July, (10.23)and smaller value was in December, (4.854). The annual average of monthly values of shape parameter, scale parameter, lower 90 % confidence for shape parameter, upper 90% confidence for shape parameter, lower 90% confidence for scale parameter, upper 90% confidence for scale parameter were (6.2634, 2.3215, 2.4881, 6.133, and 6.3921), respectively.

Table 3. Scale, shape and parameters for Weibull distribution at height (50 m) 2019

Month	Scale parameter	Shape parameter	Mean	Standard Deviation	Lower 90% confidence for shape parameter	Upper 90% confidence for shape parameter	Lower 90% confidence for scale parameter	Upper 90% confidence for scale parameter
January	4.915	1.822	4.368	2.483	1.761	1.886	4.782	5.051
February	5.023	2.28	4.45	2.068	2.199	2.363	4.91	5.14
March	5.409	1.837	4.806	2.713	1.776	1.889	5.265	5.558
April	4.476	2.492	3.971	1.704	2.409	2.578	4.386	4.567
May	5.116	3.03	4.571	1.646	2.93	3.134	5.033	5.201
June	6.924	2.797	6.165	2.386	2.701	2.897	6.8	7.051
July	9.184	3.077	8.21	2.917	2.968	3.19	9.036	9.333
August	7.019	2.779	6.248	2.432	2.682	2.879	6.895	7.146
September	6.46	2.55	5.735	2.411	2.461	2.642	6.334	6.59
October	4.801	2.342	4.254	1.93	2.263	2.423	4.7	4.904
November	4.605	2.143	4.079	2.004	2.074	2.214	4.498	4.715
December	4.277	1.693	3.817	2.32	1.635	1.753	4.153	4.405

Table 4. Scale, shape and parameters for Weibull distribution at (100 m) 2019.

Month	Scale parameter	Shape parameter	Mean	Standard Deviation	Lower 90% confidence for shape parameter	Upper 90% confidence for shape parameter	Lower 90% confidence for scale parameter	Upper 90% confidence for scale parameter
January	5.415	1.822	4.813	2.736	1.761	1.886	5.269	5.565
February	5.535	2.28	4.903	2.279	2.199	2.363	5.41	5.664
March	5.961	1.837	5.296	2.989	1.775	1.899	5.801	6.125
April	4.932	2.492	4.375	1.878	2.409	2.578	4.833	5.033
May	5.637	3.03	5.036	1.814	2.93	3.134	5.546	5.731
June	7.63	2.797	6.794	2.629	2.701	2.897	7.493	7.769
July	10.12	3.077	9.047	3.214	2.968	3.19	9.957	10.23
August	7.734	2.779	6.885	2.68	2.682	2.879	7.597	7.874

September	7.119	2.55	6.319	2.657	2.461	2.642	6.979	7.261
October	5.29	2.342	4.687	2.127	2.263	2.423	5.179	5.404
November	5.075	2.143	4.494	2.208	2.074	2.214	4.956	5.196
December	4.713	1.693	4.207	2.557	1.635	1.753	4.577	4.854

3.3 The probability functions of the Weibull distribution at 50 m and 100 m

The probability density function and the probability function of the Weibull distribution in year 2019 at 50m and 100 m were drawn as in Figure 2 and Figure 3 for winter and summer months. It was found that the Weibull distribution is applicable to describe the probability density of wind speed

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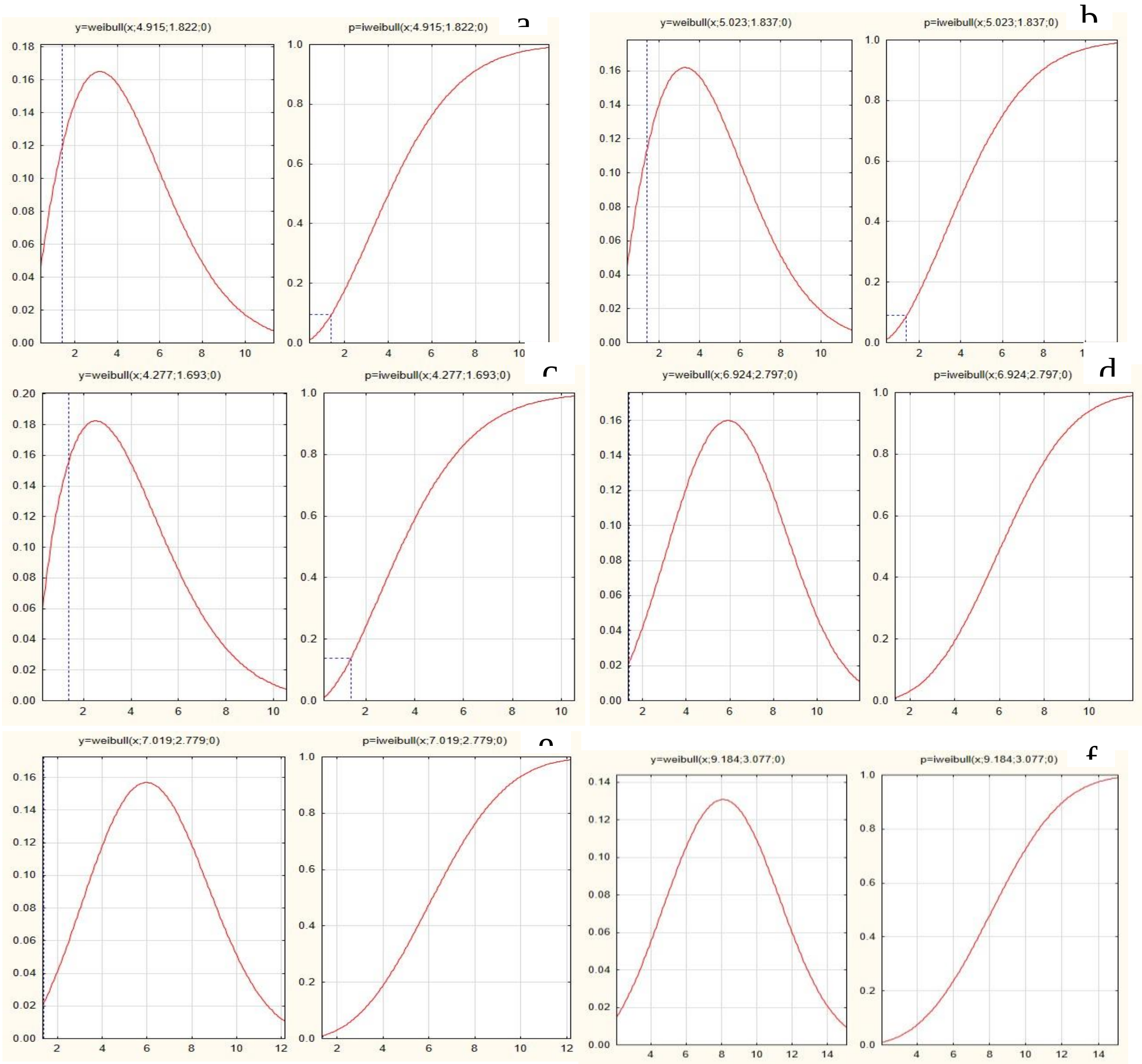

Figure 2. The probability density function and the probability function of the Weibull distribution year 2019 at 50m. (a) January (b) February (c) December (d) June (e) August (f) July

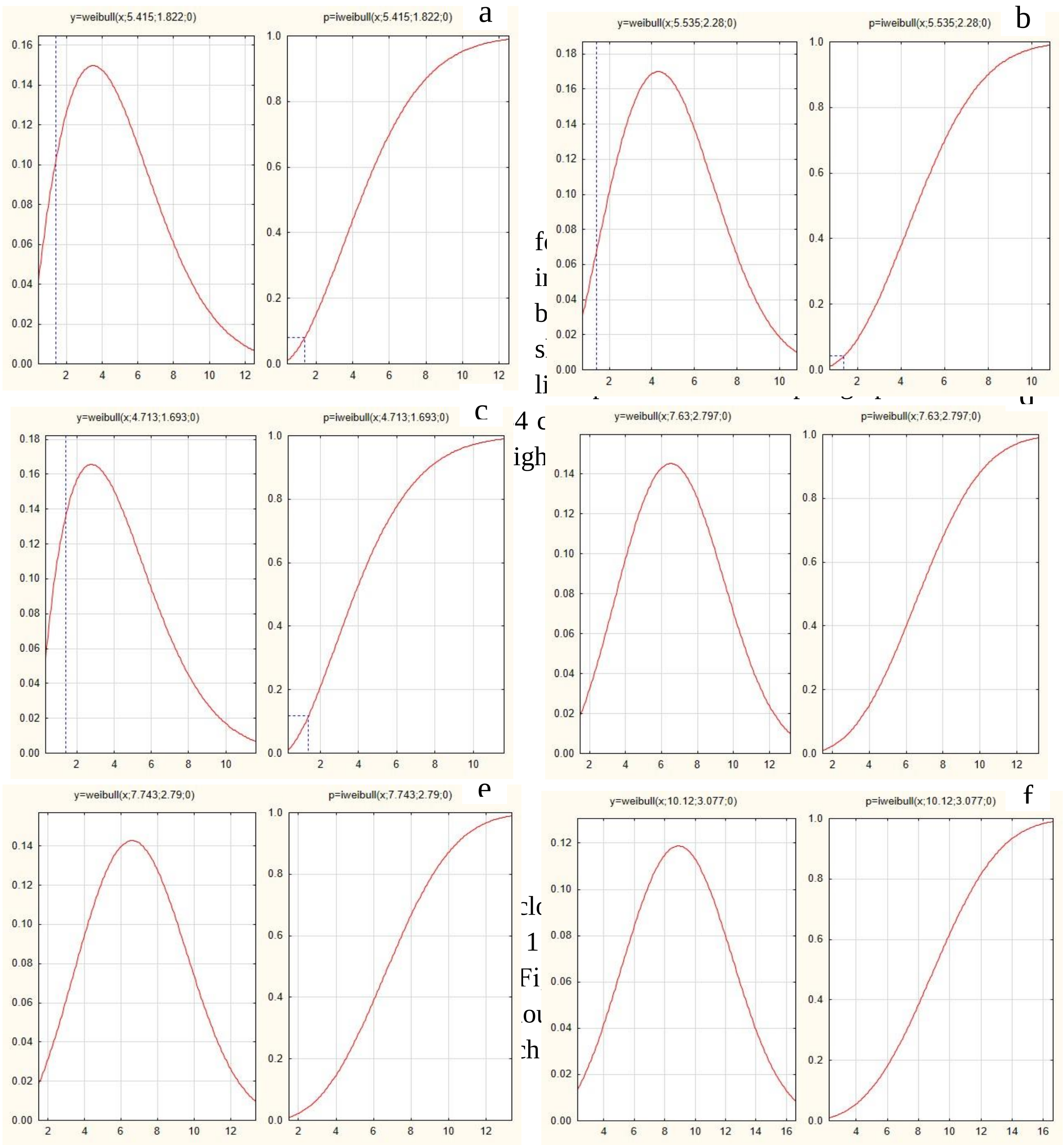

Figure 3. The probability density function and the probability function of the Weibull distribution 2019 at 100m. (a) January (b) February (c) December (d) June (e) August (f) July

4.Conclusions

1. Mean winds at 50 m and 100 m heights in Al-Shihabi City in addition to other statistics such as maximum winds suggests that Al-Shihabi City is a promising site to install a wind farm. The annual average of monthly means at 50 m and 100 m heights are (5.04 m/s) and (5.56 m/s), respectively. while the annual average of monthly maximum winds at 50 m and 100 m heights were (13.65 m/s) and (15.05 m/s). The larger values were in summer months.
2. Estimating Weibull distribution parameters showed for 50 m height that the annual average of monthly values of shape parameter, scale parameter, lower 90 % confidence for shape parameter, upper 90% confidence for shape parameter, lower 90% confidence for scale parameter, upper 90% confidence for scale parameter were (5.6840, 2.4035, 2.3215, 2.4873, and 5.805), respectively. At 100 m height, it was found that the annual average of monthly values of shape parameter, scale parameter, lower 90 % confidence for shape parameter, upper 90% confidence for shape parameter, lower 90% confidence for scale parameter, upper 90% confidence for scale parameter were (6.2634, 2.3215, 2.4881, 6.133, and 6.3921), respectively. It can also be noted that the values of parameters are higher in summer than in winter.
3. It was found that the Weibull distribution is applicable to describe the probability density of wind speed.

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