NATURALISTA CAMPANO
ISSN: 1827-7160
Volume 28 Issue 1, 2024

The Wind Energy Potential in Iraq: A Case Study of Several Specific Locations in Iraq.

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Abstract: Wind energy is a prevalent and sustainable source of electricity generation, employed worldwide. This paper assesses the Possibility of exploiting wind power for electricity production in Iraq. Daily wind speed data from ten strategically selected stations across Iraq, spanning from the first of January 2022 to the thirtieth of December 2022, was analyzed for three altitudes: 10, 50, and 100 meters, obtained from the Iraqi Meteorological Organization and Seismology, and the data has been enhanced from NASA's website for various locations. The data was analyzed to obtain the mean wind speed (MWS) and the standard deviation. After that, The wind power(WP) and the wind power density(WPD) were calculated using the method of graphical to obtain the parameters of Weibull. Finally, by the regression statistical analysis correlation method for whole locations, the most efficient results were in Amara, the mediocre at Baghdad (Airport), and the most down value was in Mosul (Mosul).

Keywords: the potential of power generation, power density, graphical method, regression analysis, a case study, Iraq

1. Introduction

sustainable energy encompasses naturally occurring and continuously replenished energy sources that can be advantageous for all human benefit without causing significant environmental harm. Harnessing wind energy, is one of the frontrunners among these new, sustainable, clean, and affordable resources, using the kinetic energy in wind to generate mechanical power or electricity through wind turbines(WT). This mechanical power can be directly utilized for specific tasks like grinding grain or pumping water or transformed into electricity using generators. The availability of wind energy varies significantly with time and location [1]. Despite being an oil-rich nation, Iraq possesses abundant renewable energy sources, including hydroelectric, solar, and wind power. This study examines wind characteristics and assesses Iraq's wind power potential using Weibull analysis, evaluating its feasibility for electricity generation [2].

1.1- The power available in the wind

The calculation of wind power (WP) is based on the principle of kinetic energy(KE), which is expressed mathematically as:

$$WPD = \frac{1}{2}mv^2 \qquad \text{--} \ (1)$$

The air mass, denoted by 'm', is the outcome of its density 'ρ' and volume 'V'. The volume, in turn, depends on area 'A' through which the air moves, its speed 'v', and the duration of its travel 't'. Therefore, the air mass can be calculated using the following formula:

$$m = \rho.A.v.t \qquad \text{--} \ (2)$$

Considering the air density 'ρ' equals 1.225 kg/m3 this is in the case of dry air at 1 Atmospheric and 15°C, the area facing the wind is referred to as 'A', the WS 'v', and the elapsed time 't', the wind power eq. (WP) can be expressed as [3]:

$$WP = \frac{1}{2}\rho..Av^3.t \qquad \text{--} \ (3)$$

1.2- Calculating wind energy density

The power density(WPD) of wind refers to the quantity of power obtainable in wind per unit area perpendicular facing the wind movement. In practical applications, (WPD) is employed to assess the potential electricity generation of farms of wind, considering the area that is mopped by rotors and the efficiency of the system. The equation for (WPD) is derived by dividing (WP) by the area [4], as shown:

$WPD = \frac{1}{2}\rho v^3$ -- (4)

The most effective way to assess wind potential is by analyzing (WPD), which provides a clear understanding of mean wind speed distribution. This parameter can be evaluated in practice by the Weibull dis., which relies on two parameters scale parameter (c) and shape parameter (k). The Gamma function (Γ) plays a crucial role in the Weibull distribution [5].

$WPD = \frac{1}{2}\rho c^3\Gamma(\frac{1+3}{k})$ -- (5)

1.3- Vertical Estimation of WS

The wind speed increases as the height increases due to the lack of obstacles and barriers represented by buildings, trees, etc., and to deduce the wind speed relative to a reference speed, the (1/7) power-law model can be applied.

$v(z) = v(z_o)(\frac{z}{z_o})^{\frac{1}{7}}$ --- (6)

where (z) refers to any height, and (zo) represents a reference height. the value (1/7) can vary depending on terrain, barriers, and vegetation conditions [6].

1.4- Wind speed probability density distribution

The Rayleigh and Weibull distributions are among the probability distributions that are widely used to analyze and model wind speed fluctuations. There are two functions for wind speed fluctuations they are the function of probability density (PDF) and the function of cumulative distribution (CDF). The Weibull distribution has proven its potential to represent a large range of wind speed data effectively, the K and C parameters are determined by this distribution, as there are several ways to determine these parameters, including the graphical method, (SD) methods, moment methods, maximum likelihood methods, and methods of energy pattern factor, the Weibull PDF is given by;

$f(v) = (\frac{k}{c})^{k.v^{k-1}} * \exp[-\left(\frac{v}{c}\right)^k]$ ---------------------------------- (7)

where: v is the wind speed, k is the shape parameter, and c is the scale parameter.

$f(v) = 1 - \exp[-\left(\frac{v}{c}\right)^k]$ ------------------------------------- (8)

The parameter k characterizes the shape of the PDF. A value of close to 1 indicates a Rayleigh distribution, while a value of much greater than 1 indicates a narrow peak in the PDF, the parameter (c) characterizes the scale of the PDF. An increase in the value indicates a higher mean wind speed [7].

$1 - f(v) = 1 - e^{-\left(\frac{v}{c}\right)^k}$ -- (9)

Considering the logarithm twice, we get

$\ln\{-\ln[1 - f(v)]\} = kln(v) - klnc$ -- (10)

We get. $Y = a + bX$

$C = e^{-\left(\frac{a}{b}\right)}$ --- (11)

wind speed variability, estimate the probability of different WSs, the mean WS, the standard deviation of wind speed, and the wind energy potential of a site It can be reached via The Weibull distribution because is a versatile tool for modeling[8].

2. Study Locations and Data Collection

Table 1. Stations

No.	Stations	Latitude	Longitude	Sea Level
1	Mosul	36 19	43 09	228
2	Baghdad	33 18	44 24	30.4
3	Najaf	31 57	44 19	19
4	Basra Al-Hussein	30 31	47 47	7
5	Karbala	32 34	44 03	49
6	Wasit	32 30	45 49	27.2
7	Amara	31 50	47 10	9
8	Dhi Qar	31 01	46 14	7
9	Heet	33 38	43 45	45.6
10	Kirkuk	35 28	44 24	227.9

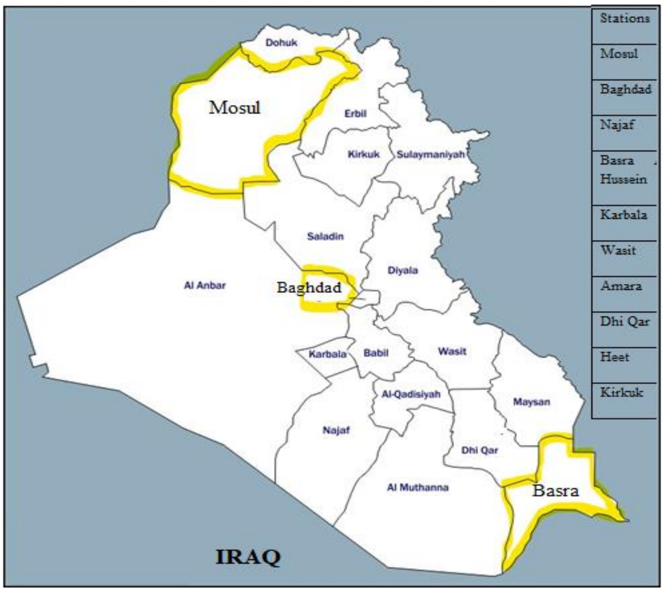


Figure 2. Map of Selected Stations in Iraq.

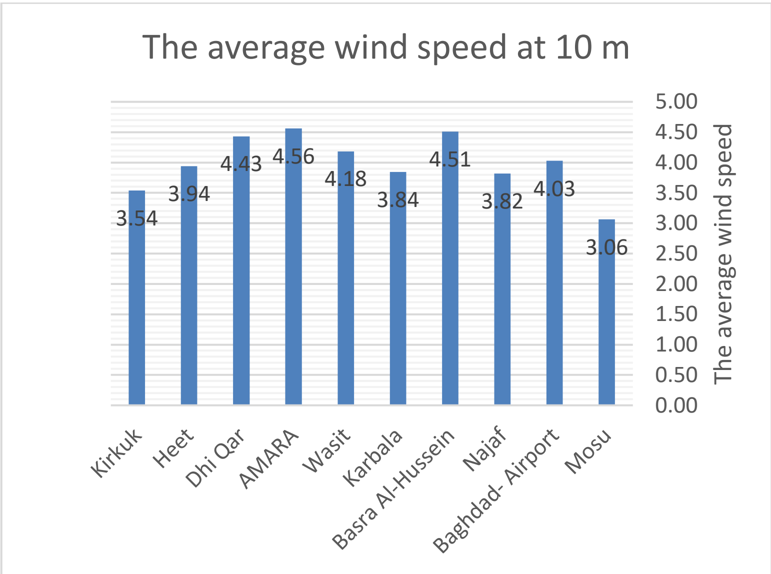
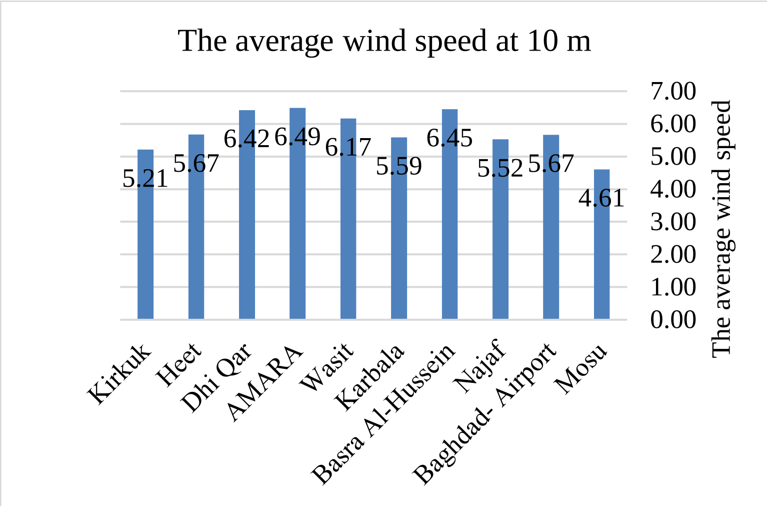


Figure 3. The average WS for specified stations at (10 m).



. Figure 4. The average WS for specified stations at (50 m).

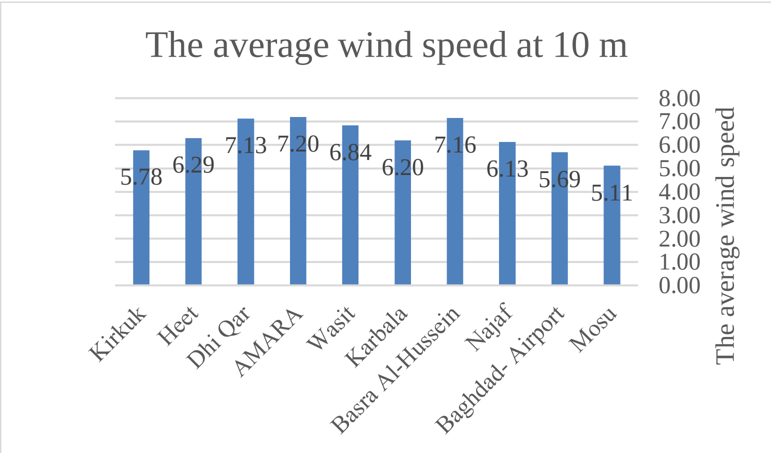


Figure 5. The average WS for Selected stations at (100 m).

Table 2. Mean WS X (m/s) and (S.D.) for three altitudes (10m, 50m, 100 m) for the Selected area [9].

Station	Mean and Stander Deviation	At (10 m)	At (50 m)	At (100 m)
Mosul	X	3.06	4.61	5.11
	SD	0.98	1.48	1.64
Baghdad	X	4.03	5.67	5.69
	SD	1.43	1.95	2.01
Najaf	X	3.82	5.52	6.13
	SD	1.32	1.89	2.10
Basra Al-Hussein	X	4.51	6.45	7.16
	SD	1.76	2.35	2.61
Karbala	X	3.84	5.59	6.20
	SD	1.38	1.95	2.17
Wasit	X	4.18	6.17	6.84
	SD	1.51	2.05	2.28
Amara	X	4.56	6.49	7.20
	SD	1.83	2.44	2.71

Dhi Qar	X	4.43	6.42	7.13
	SD	1.76	2.35	2.61
Heet	X	3.94	5.67	6.29
	SD	1.38	1.91	2.12
Kirkuk	X	3.54	5.21	5.78
	SD	1.15	1.65	1.83

By equ. (10, 11) we calculate the Weibull parameters k and c parameter (m/s) scale for three altitudes (10m, 50m, 100 m) as shown in Table (3)

Table 3. Weibull Parameters for three altitudes (10, 50, 100 m) for all Selected Locations.

Station	Weibull Parameters	At (10 m)	At (50 m)	At (100 m)
Mosul	**C**	**3.74**	**5.89**	**6.19**
	K	**2.01**	**3.54**	**1.72**
Baghdad	**C**	**4.97**	**6.79**	**7.10**
	K	**2.32**	**2.88**	**1.28**
Najaf	**C**	**5.26**	**6.01**	**6.58**
	K	**2.06**	**1.37**	**1.61**
Basra Al-Hussein	**C**	**5.59**	**8.56**	**8.59**
	K	**2.29**	**2.70**	**2.99**
Karbala	**C**	**4.73**	**6.01**	**7.45**
	K	**2.30**	**1.36**	**2.91**
Wasit	**C**	**5.72**	**8.36**	**8.27**
	K	**2.11**	**2.64**	**3.40**
Amara	**C**	**5.62**	**9.06**	**9.25**
	K	**2.23**	**2.32**	**2.87**
Dhi Qar	**C**	**5.53**	**9.08**	**8.63**
	K	**2.24**	**2.49**	**3.18**
Heet	**C**	**30.73**	**6.10**	**7.50**
	K	**0.83**	**1.38**	**3.14**
Kirkuk	**C**	**4.45**	**5.38**	**7.13**
	K	**2.57**	**1.54**	**3.68**

2.1- The Weibull Distribution

Due to the changing wind speed, we must know the intensity and frequency of the wind so that we can predict the production of WT. The Weibull dis. shows the distribution of wind intensity for three stations representing the lowest, medium, and most effective values, which are Mosul, Baghdad, and Amara, as shown in the figure (5,6,7), respectively.

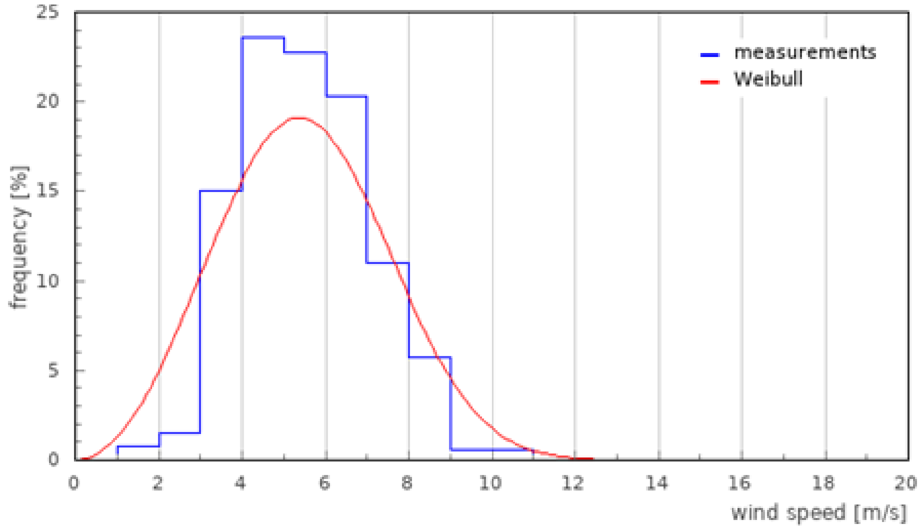


Figure 5.

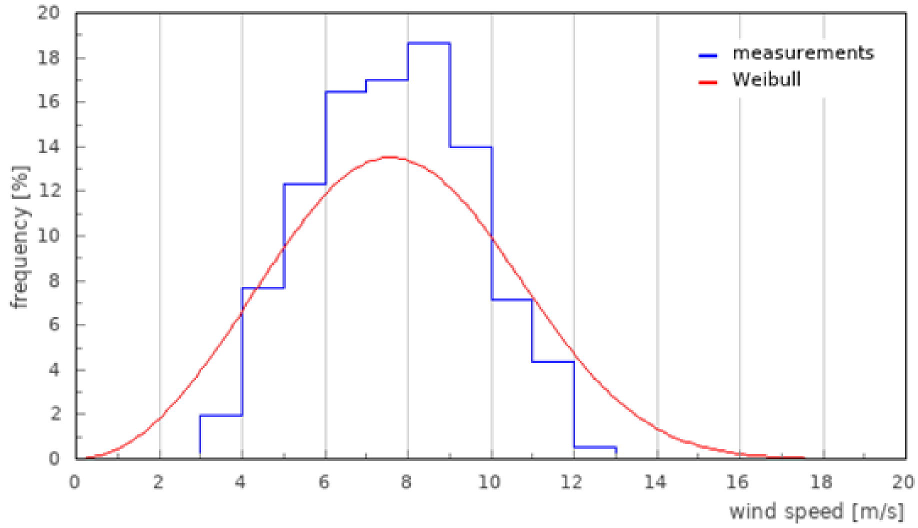


Figure 6.

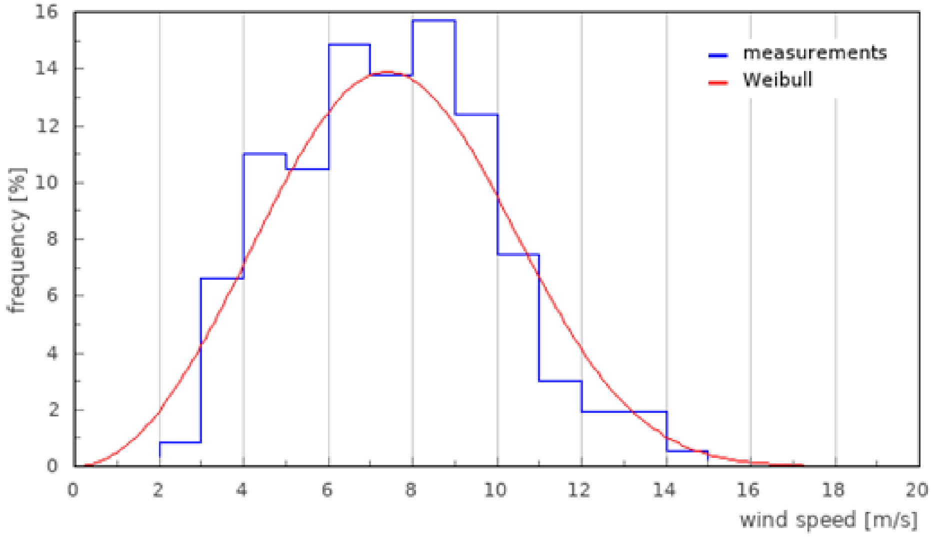


Figure 7.

By equ. (3 and 5) we calculated the (WP) and (WPD) by Weibull dis. for three altitudes (10m, 50m,100 m) for all selected locations as in Table (4) and Fig. (8).

Table 4.

Station	Weibull Parameters	At (10 m)	At (50 m)	At (100 m)
Mosul	WPD by Weibull dis.	36.13	117.92	143.35
	WP	60.02	168.44	222.34
Baghdad	WPD by Weibull dis.	71.33	183.86	132.22
	WP	88.2	222.34	222.34
Najaf	WPD by Weibull dis.	88.68	125.57	200.15
	WP	124.03	222.34	390.16
Basra Al-Hussein	WPD by Weibull dis.	112.24	339.13	381.08
	WP	168.44	362.29	588
Karbala	WPD by Weibull dis.	65.12	124.77	240.66
	WP	88.2	222.34	310.54
Wasit	WPD by Weibull dis.	116.89	323.49	328.78
	WP	168.44	362.29	482.34
Amara	WPD by Weibull dis.	121.79	389.98	478.24
	WP	222.34	450.19	708.05
Dhi Qar	WPD by Weibull dis.	109.68	401.87	380.26
	WP	168.44	450.19	588
Heet	WPD by Weibull dis.	21.06	127.63	244.53
	WP	88.2	222.34	310.54
Kirkuk	WPD by Weibull dis.	56.20	115.87	207.23
	WP	88.2	222.34	310.54

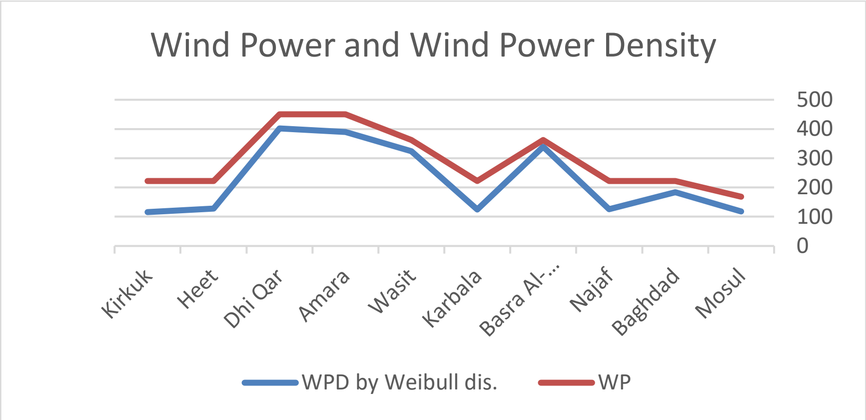


Figure 8.

The study also delves into the relationship between WS and WP over time using a Parameters Linear Regression statistical analysis formula of the first-order type. This analysis sheds light on how wind power varies with changes in wind speed.

$f = y_o + ax$ -- (12)

The equation above represents the relationship between wind speed or wind power f(x) and the number of days (x), where: y_o is the regression constant (equation 12),

$$y_o = \frac{\sum_{i=1}^{n}(\mathrm{xi}-\mathrm{x})-(fi-f)}{\sum_{i=1}^{n}(\mathrm{xi}-\mathrm{x})^2} \quad \text{-- (13)}$$

f(x) is the calculated WS or wind power [10]. a is the regression slope, indicating the change in wind speed or wind power per unit change in the number of days. y_o is the regression constant, representing the wind speed or wind power at x = 0

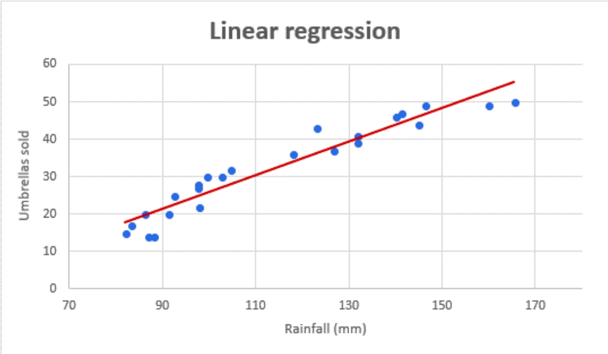


Figure 9. Linear regression graph

The slope of the regression line corresponds to the value of a and the y-intercept corresponds to the value of y_o. The regression analysis allows for quantifying the relationship between wind speed or wind power and the number of days, providing valuable insights into wind energy potential over time. Considering the geographical diversity of Iraq, we carefully chose three representative stations: Mosul for the north, Baghdad for the central region, and Amara for the south As Table (6)

Table 6. PLR for (WS) at three altitudes (10m, 50m, 100 m).

Stations	Parameters of Linear regression	Pearson correlation	At (10 m)	At (50 m)	At (100 m)
Amara		R	0.272	0.272	0.272
	y_o		4.923	5.989	6.964
	a		-0.05	-0.006	-0.007
Baghdad		R	0.231	0.231	0.231
	y_o		2.042	3.004	3.105
	a		-0.0017	-0.0022	-0.0024
Mosul		R	0.352	0.312	0.321
	y_o		2.168	2.640	2.937
	a		-0.003	-0.003	-0.004

Table 7. Parameters of Linear Regression for Wind Power (WP) at high (10, 50,100 m).

Stations	Parameters of Linear regression	Pearson correlation	At (10 m)	At (50 m)	At (100 m)
Amara		R	0.204	0.204	0.204
	y_o		1899.35	3863.59	5301.00
	a		-3.924	-8.120	-10.964
Baghdad		R	0.164	0.168	0.164
	y_o		215.20	425.08	527.70
	a		-0.50	-0.821	-1.181
Mosul		R	0.252	0.252	0.225
	y_o		125.47	250.06	348.02
	a		-0.251	-0.50	-0.609

2.2- Wind Power Classification

The classification shown in Figure (10) shows the division of areas into several categories, according to power density and WSs at an altitude of 50 m. This shows that the areas studied are areas located between poor and weak winds.

Wind Power Classification

Wind Power Class	Resource Potential	Wind Power Density at 50 m W/m ^{2}	Wind Speed[a] at 50 m m/s	Wind Speed[a] at 50 m mph
1	Poor	0 - 200	0.0 - 6.0	0.0 - 13.4
2	Marginal	200 - 300	6.0 - 6.8	13.4 - 15.2
3	Fair	300 - 400	6.8 - 7.5	15.2 - 16.8
4	Good	400 - 500	7.5 - 8.1	16.8 - 18.1
5	Excellent	500 - 600	8.1 - 8.6	18.1 - 19.3
6	Outstanding	600 - 800	8.6 - 9.5	19.3 - 21.3
7	Superb	> 800	> 9.5	> 21.3

[a] Wind speeds are based on a Weibull k of 2.4 at 500 m elevation.

Figure 10 Wind Power Classification (NREL)

3. The Discussion and Results

Across all the investigated locations, WP generation and WPD are consistently heightened in the southern areas due to stronger daily mean wind speeds at all heights. The highest values are observed in Amara and Basra Al-Hussein, followed by moderate values in Baghdad- Airport, and the lower values in the northern area, particularly in Mosul. Given the wind characteristics in these regions, medium-sized or small wind turbines are suitable for electricity generation.

Accurate computation of Weibull parameters is crucial for wind turbine manufacturers to assess the Performance effectiveness of their wind turbines. The graphical method, utilizing real-world WS data, provides a valuable tool for this purpose. The highest Weibull parameter values were observed in Amara, followed by moderate values in Airport, and the most down values in Mosul. Regression statistecal analysis revealed a correlation between WS and WP for all stations, with the strongest correlation observed in Amara, followed by Airport, and the weakest correlation in Mosul.

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