Statistical Wind Energy Potential Assessment in Ras Munif, Jordan

Nour Khlaifat and Zakaria Al-Omari

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Nour Khlaifat
Renewable Energy Engineering Dept. Engineering Faculty
Isra University
Amman, Jordan
noor.alkhlaifat@iu.edu.jo

Zakaria Al-Omari
Renewable Energy Engineering Dept. Engineering Faculty
Isra University
Amman, Jordan
zakaria.alomari@iu.edu.jo
https://orcid.org/0000-0002-3433-3503

***Abstract*— The primary goal of this paper is to assess the wind energy potential (WEP) in Ras Munif, Jordan, using the four-probability density to provide insight into the energy that can be produced from the chosen site. The data were collected over 5 years at a height of 10 meters above ground level (from 2015 to 2019). Different statistical indicators are studied to find that the Weibull distribution (WD) function is the most proper function. The shape and scale parameters are assessed using the Maximum Likelihood approach. The study's findings also revealed that the annual mean power density of Ras Munif, values ranging from 110 to $370\ \mathrm{W/m^2}$ are acceptable. The wind rose of this region was built to assess the prevailing wind direction and to determine the optimal location of the wind generator. The results of the calculation of wind frequency for estimating the distribution of various wind speeds (WSs) are presented. For Ras Munif, it is noted that the highest WS direction occurs in the sector between 270^o to 285^o.**

Keywords*— *wind energy potential; Weibull Distribution; Ras Munif; shape parameter, scale parameter

I. Introduction

Jordan's energy consumption is rapidly increasing, and oil is the dominant energy market for social and economic development [1-4]. Jordan is an oil-importing country, thus a large portion of the governmental foreign cash is expended on crude oil imports. For instance, in 2004, the kingdom spent approximately 1.65 million United States dollars on importing and refining crude oil [5-7]. The importance of such an economic issue, as well as the environmental degradation difficulties associated with the consumption of traditional power sources, has been expected to motivate Jordan's universities and industry to place a strong emphasis on the usage of clean energy (solar and wind) resources [8, 9]. The "National Energy Strategy" 2008-2020 goal is to cover 29% of energy requirements with natural gas, 14% with shale oil, 10% with renewable and sustainable energy sources, and 6% with nuclear energy by 2020 [10].

The wind is an air movement caused by the sun's heating of the atmosphere and the earth's rotation. The total atmospheric kinetic energy of air motion is evaluated to be approximately 3×10^5 Watt hour or approximately 0.2% of the energy reaching the earth from the sun [11, 12].

The utilization of renewable and sustainable energy, which includes power generated from the sun, wind, biofuels, geothermal, and hydro energy, as well as ocean resources, is very old. It expands the variety of energy production and, without a doubt, provides us with renewable power. Wind energy has emerged as a viable alternative for generating electricity [13-17].

Wind energy is now able to compete in specific places with preferable wind regimes, that can be found in a variety of locations. Wind power has numerous advantages over other renewable and non-renewable fossil fuels, including wind energy is a clean, free, diverse, safe, and long-term source of power [18].

The feasible value for each wind turbine (WT), in a specific wind regime, is the generated energy on its power characteristics. Therefore, the WT generated energy is equal to the output generated power at any specific WS multiplied by the interval of time throughout which this WS is predicted for a specified period, which is typically one complete year [19-20]. As a result, the total energy produced by the wind energy conversion system is determined by the WTs characteristic curve (WS-power curve), the WTs size, and the WS frequency distribution at the site [14, 15], [21, 22].

The WS probability distribution and also the mathematical function that represents it is the primary tool used in wind-related publications [11]. In applications, the WD function is among the most commonly used. The Weibull two-parameter density function is frequently used to describe WS variation. WEP is difficult to estimate because, unlike solar energy, it is heavily influenced by site characteristics and topography, as WSs are strongly influenced by surface topography [13, 14].

As a result, precise and reliable WEP evaluation is crucial in selecting a commercially viable site for wind power generation. A careful WEP evaluation and effectiveness of implementing the site for wind energy utilizing a WT was done in Jordan's Ras Munif, depending on Four different "probability density functions. The Jordanian Meteorological Department archive held monthly wind data at 10 m height for 5 years (2015-2019) [22].

II. Data and Information on the Site

Ras Munif (Latitude: 32.3809364; Longitude: 35.8055488) is in the province of Ajloun, 76 kilometers Northwest of Amman, Jordan's capital as shown in "Fig. 1" This village was selected due to its elevation as the highest mountain in Jordan.

It is “1198 meters” above sea level and has the country's highest average WS. The village's annual average WS is 13.4 knots ($6.895 m/s$) [23]. The weather in Ras Munif is distinguished by dry summers and mild, wet winters. The annual rainfall is approximately 467 mm, and the average temperature is approximately 16.7 C°. For each year of study, Jordan's meteorological department provided hourly WS data (WSD). The data were collected over 5 years at an elevation of 10 meters above ground level (from 2015 to 2019).

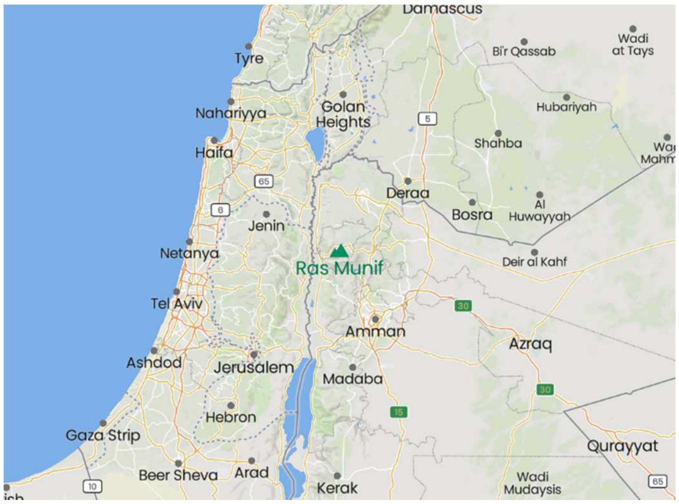

Fig. 1. The Map of Jordan showing Ras Munif’s location [24]

WS varies from region to region, even within the same location, due to seasonal and daily variations, which describes the need for our case study on the feasibility and WEP at a particular site. As previously quantified, some statistical procedures of collected WSD were conducted in various regions around the world. This paper provides an in-depth data study of Jordan's WEP as a power source. An analytical evaluation was conducted based on WSD collected at the “meteorological station of Ras Munif”, a town in the Gilead highlands of Northwest Jordan's “Ajloun Governorate”.

Four different "probability density functions", Weibull, Gamma, Rayleigh, and Lognormal, distributions are used in this research to estimate the WEP at Ras Munif, a townsite in Jordan. The form of WS distribution function used has a significant impact on the output of available wind energy and WT performance at a specific region. Therefore, four “probability density functions” have been assessed utilizing “statistical parameters” to determine their accuracy. The result shows the most appropriate “probability distribution function” for WS frequency. Finally, in the section, the conclusions have been drawn.

III. Research Methodology

This section offers a summary of the approaches, that concentrates on statistical data analysis of WS variation utilizing four “probability density functions”.

A. Weibull distribution

The WD is a common “probability density function” that many researchers use to assess WS characteristics [25]. The following is the ruling equation of the Weibull model types of a probability density function, the “cumulative distribution function” is obtained by:

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

where c – is the “scale parameter” (m/s) and k - the “shape parameter” (dimensionless) [26].

$F(U)$ is calculated as [27]

$$F(U) = 1 - \exp\left[-\left(\frac{U}{c}\right)^{k}\right] \tag{2}$$

The scale and shape parameters are obtained by following equations:

$$c = \left(\frac{\sum_{i=1}^{N} U_i{}^{k}}{N}\right)^{\frac{1}{k}} \tag{3}$$

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

B. Rayleigh distribution

$$f(U) = \frac{U}{c^2}\exp\left(-\frac{U^2}{2\,c^2}\right) \tag{5}$$

where is the scale factor [28]

$$F(U) = 1 - \exp\left[-\frac{1}{2}\left(\frac{U}{c}\right)^{2}\right] \tag{6}$$

$$c = \sqrt{\frac{\sum_{i=1}^{N} U_i{}^{2}}{2N}} \tag{7}$$

C. Lognormal distribution

$$f(U) = \frac{1}{U\,\alpha\sqrt{2\pi}}\exp\left[\frac{(\ln(U)-\beta)^2}{-2\alpha^2}\right] \tag{8}$$

$$F(U) = \frac{1}{2} + \frac{1}{2}\,erf\left(\frac{ln(U)-\beta}{\sqrt{2}\,\alpha}\right) \tag{9}$$

And $erf(U)$ - the error function, which is defined by [29]:

$$erf(U) = \frac{2}{\sqrt{\pi}}\int_0^U exp(-t^2)\,dt \tag{10}$$

where β, and α - the scale and shape, respectively [30].

D. Gamma distribution

$$f(U) = \frac{U^{\xi-1}}{\beta^{\xi}\Gamma(\xi)}exp(-\frac{U}{\beta}) \tag{11}$$

where, Γ - the Gamma function, ξ, and β - shape and scale parameters, respectively [31].

$$F(U) = \int \frac{U^{\xi-1}}{\beta^{\xi}\Gamma(\xi)}exp\left[\frac{-U}{\beta}\right]\,dU \tag{12}$$

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Four statistical indicators are used to assess the fitness and performance of four distribution models in order to determine their superiority: the "root mean square error" ($RMSE$), the "determinant coefficient" (R^2), the information of Schwarz Bayesian criterion (BIC), and the information Akaike criterion (AIC). Because the determination coefficient cannot show the accuracy of distributions alone, different indicators were employed to evaluate the precision.

IV. Results and discussion

The values of WS change in real time. The recorded WSD for a particular period can be investigated statistically to get the necessary information about the distribution of wind frequency. The WS frequency curve can be represented by various "probability distribution functions (PDF)". The Weibull, Rayleigh, Gamma, and Lognormal distributions are the most common PDF utilized in this section for the WSD study. "Fig. 2" shows a graphical representation of the four PDFs discussed above for Ras Munif, Jordan. This figure illustrates the comparison of the fitting functions based on the Weibull, Rayleigh, Gamma, and Lognormal distributions to determine which probability functions provide the best fitting WSD. Also, "Fig. 3" presents the fitted cumulative distribution function plots of the Ras Munif site. The "cumulative distribution function" illustrates the probability that WS is less than or equal to the given WSD.

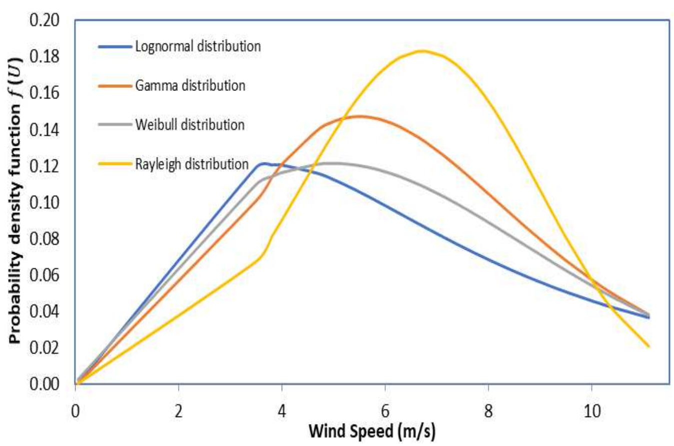

Fig. 2. Ras Munif's probability distributions function

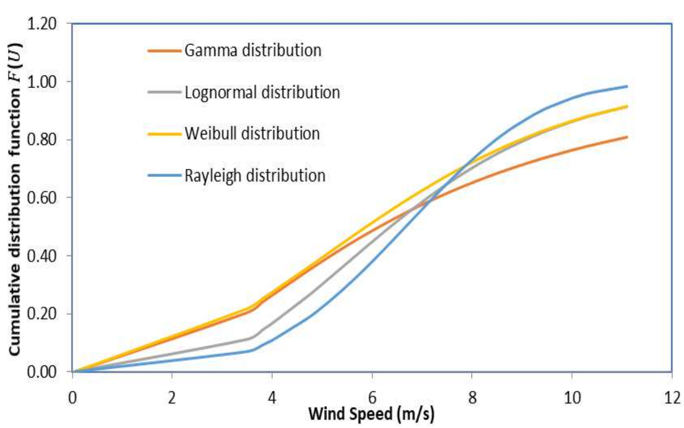

Fig. 3. The cumulative distribution functions at Ras Munif

The "coefficient of determination" (R^2) and the "root mean square error" (RMSE), which test the goodness of fit, are the commonly used statistical indicators. Greater R^2 values indicate a better fit, while lesser RMSE values indicate a good fit. It can be seen from "Table 1" that the R^2 values range from "0.984612 to 0.993690", except the value of 0.669467 for the Rayleigh function. The values of R^2 suggest the matching between the PDF and the recorded data are very high. At the same time, the RMSE varies between "0.025108 and 0.137383". The WD is the most "accurate distribution" according to R^2 and RMSE, which had values of "0.993690, 0.025108" respectively. RMSE variation is between "0.010771 and 0.027963". Rayleigh distribution still has lower values of R^2 when compared with the performance of other distributions, while RMSE varies by 0.137383. The second distribution which had a good fit is the Gamma distribution.

TABLE I. Statistical indicators for the performance of four distribution functions.

		R^2	$RMSE$	BIC	AIC	Rank
Ras Munif	Rayleigh	0.669467	0.137383	4.195322	0.768178	4
	Weibull	0.993690	0.025108	3.376613	-0.050531	1
	Gamma	0.993140	0.026387	2.009922	-1.417222	2
	Lognormal	0.984612	0.038528	6.146479	2.719334	3

When using WE correctly, determining wind direction is an important step in the assessment. The wind rose diagram depicts the WS frequency and wind directions. The wind rose diagrams for the selected site are presented in "Fig. 4". Polar wind figures are divided into 12 sectors, with each arc covering 30°. These diagrams show the direction percentages of various WSs. The sector with the highest WS frequency for Ras Munif is between 270° and 285°.

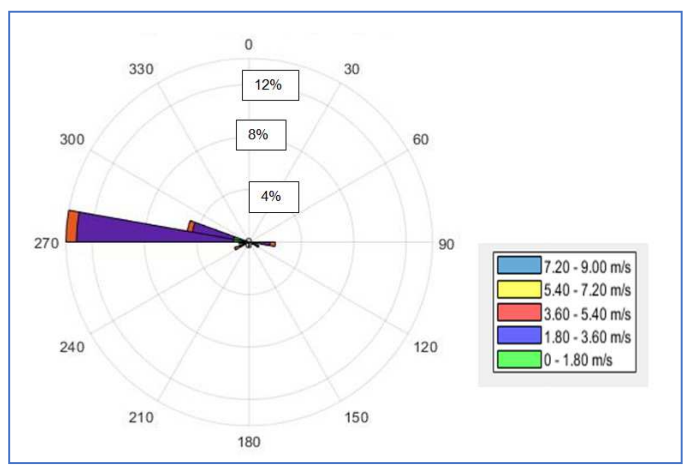

Fig. 4. The wind rose based on Ras Munif WSD.

According to WSD statistical methods, the WS is the most effective measure. This paper discusses and presents the statistical study of WS in Ras Munif utilizing two-parameter WD using the Maximal likelihood method. The parameters for "shape and scale are 2.218 and 6.278 m/s", respectively. The study's findings also revealed that the annual mean power density of Ras Munif, values ranging from 110 to 370 W/m^2.

V. Conclusion

This study assessed the WEP of Jordan's northern-west region/Ras Munif over 5 years (2015 – 2019). The WD function was applied to perform the analysis based on the shape and scale parameters. The following are the main results of the current study:

- At an elevation of 10 m where the WS was measured, WD results revealed that a WS ranging from 3.57 to 8.48 m/s, and is the most common in Ras Munif, with a probability of 29.7%.
- WSD variations revealed that the WS in the Ras Munif area has increased over time.
- The scale and shape parameters have been 6.278 m/s and 2.218, indicating that the wind spread is acceptable.
- According to global wind power generation classification standards, the Ras Munif region has accepted WEP, so it is still a viable solution for Medium-scale electrical energy generation.
- The highest amount of the WEP was recorded in January, while the lowest was recorded in October.

The future works are to integrate the WS profile in the Ras Munif with the wind rotor design to optimize the annual energy production.

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