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Data bank: nine numerical methods for determining the parameters of weibull for wind energy generation tested by five statistical tools

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Article Info

ABSTRACT

This study aims to determine the potential of wind energy in the mediterranean coastal plain of Palestine. The parameters of the Weibull distribution were calculated on basis of wind speed data. Accordingly, two approaches were employed: analysis of a set of actual time series data and theoretical Weibull probability function. In this analysis, the parameters Weibull shape factor 'k' and the Weibull scale factor 'c' were adopted. These suitability values were calculated using the following popular methods: method of moments (MM), standard deviation method (STDM), empirical method (EM), maximum likelihood method (MLM), modified maximum likelihood method (MMLM), second modified maximum likelihood method (SMMLM), graphical method (GM), least mean square method (LSM) and energy pattern factor method (EPF). The performance of these numerical methods was tested by root mean square error (RMSE), index of agreement (IA), Chi-square test (X^2), mean absolute percentage error (MAPE) and relative root mean square error (RRMSE) to estimate the percentage of error. Among the prediction techniques. The EPF exhibited the greatest accuracy performance followed by MM and MLM, whereas the SMMLM exhibited the worst performance. The RMSE achieved the best prediction accuracy, whereas the RRMSE attained the worst prediction accuracy.

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1. INTRODUCTION

The electric energy crisis has emerged as a significant global problem in the last decade. Therefore, many governments tried to achieve the goal to supply an essential portion of the electrical grid from sustainable energy resources such as wind energy and PV solar system. The critical situation in the Mediterranean coastal plain of Palestine, the siege imposed and the growing need due to the high number of population for alternative sources of energy have become urgent concerns [1]. This study estimates wind

energy production in Palestine by analyzing wind data using the expert probability function. Recently, the Weibull distribution becomes the preferred distribution in software designed for commercial wind energy, like wind atlas [2]. There is a proportional relationship between wind power extraction and the cube of wind speed, thus, the distribution of wind speed for a specific wind farm should be determined. The abscissa scale of the Weibull probability distribution is controlled by the scale parameter. The shape parameter characterises the width of the Weibull distribution, such as a large shape factor equates to a less narrow Weibull distribution with a high peak value. The following numerical methods can be used to determine the shape and scale factor for a given data series, method of moments (MM), standard deviation method (STDM), empirical method (EM), maximum likelihood method (MLM), modified maximum likelihood method (MMLM), second modified maximum likelihood method (SMMLM), graphical method (GM), least mean square method (LSM) and energy pattern factor method (EPF) [3]-[11].

The Weibull distribution is widely utilized to assess wind energy potential and analyse wind for a specific region [6], [12]-[28]. Jowder [29], applied the EM and GM to analyse the wind power density (WPD) at the altitudes of 10, 30 and 60m in the Kingdom of Bahrain. He calculated and compared two Weibull parameters then noted that the EM more accurately estimates power density and MWS than the GM. Sulaiman, *et. al.*, [30] analysed wind speed record in Oman and referred to the concept of wind speed data following the Weibull probability distribution. Nevertheless, actual observed wind speed is not required in the Weibull distribution. Costa Rocha, *et. al.*, [31] compared and analysed seven numerical methods to assess their performance in estimating the parameters of the Weibull probability distribution by using the actual wind speed data of Paracuru and Camocim in Brazil. Studies [32]-[34] concluded that the LSM gave better efficiency performance than MLM. Odo *et. al.*, [35] employed a Weibull probability distribution to estimate wind energy potential for 13 years in Nigeria. Oyedepo *et. al.*, [36] analysed the actual long-term wind data in southeast Nigeria at a height of 10 m from 24 to 37 years. Abbas, *et. al.*, [37] statistically analysed the actual wind speed record in Pakistan to estimate the best fitting probability distribution of the wind speed record. They used two-parameter Weibull, Rayleigh and other types of probability distributions to fit the data. They also used MLM to determine the parameters of every distribution [34], [38]-[45]. Mostafa eipour and Mohammadi [46] utilised two methods (PDM and STDM) to assess wind record in Iran. Genc, *et. al.*, [47], Senoglu and Kantar [48] compared several numerical methods in terms of accuracy in estimating Weibull parameters. However, the scale parameters that they applied were all less than 1.5m/s, which is likely less than the cut-in wind speed for most small-scale wind turbines. They convened that MWS approximately 10% lower than the scale factor, if the shape factor is approximately 2. Stathopoulos, *et. al.*, [49] applied statistical and numerical models to estimate wind power. Zhou, *et. al.*, [50] conducted a case study and comprehensively estimated the wind speed distribution curves for North Dakota.

Wind energy applications require the evaluation of Weibull parameters. Thus, determining the method with superior performance on shape and scale factor values is important. The Kolmogorov–Smirnov statistic test is selected to test the goodness of fit of Weibull distribution in measured data at the 1% and 5% significance levels [11]. Dorvlo [51] analysed the actual wind speed record from four different stations in Oman. He determined that the chi-square estimation method yields better estimates of Weibull parameters than the MM and GM on the basis of the Kolmogorov–Smirnov statistic. In examining the feasibility of wind energy at a specific location, the best strategy seen by calculating the WPD according to the measured information of a target meteorological location. Another strategy is the WPD using different frequency distribution functions, such as Weibull distribution, chi-square distribution, Rayleigh distribution, lognormal distribution, generalized normal distribution, gamma distribution, three-parameter lognormal distribution, kappa distribution, inverse Gaussian distribution, wake distribution, normal two-variable distribution, hybrid distribution and the normal square root of wind speed distribution [52]-[54]. Researchers have indicated that the Weibull function is better suited for the wind probability distribution in comparison with other functions [55]. The Weibull function is used to fit time series data. This distribution is essential in maintainability and reliability analyses. The appropriate values for the shape and scale parameters of the Weibull probability distribution are crucial in identifying ideal sites for the installation of wind turbine generators. The Weibull scale parameter, in particular, is essential in determining the effectiveness of wind farms [56], [57].

The available electricity generated by a wind power generation framework in a given wind field depends on the MWS, standard deviation of wind speed and installation location. Although several studies have been conducted in various Palestine territories, the authors believe that this study is the first relevant research on the Gaza Strip [58].

Wind speed data recorded from the coastal city of Ashqelon from January 2012 to December 2015. The wind industry should be describing the variations in wind speed in any location is vital for any further wind energy analysis. Such information benefits the proper selection of the wind turbine that is appropriate for this location. In this study, it can be estimated the wind energy potential in the southern coastal plain of

Palestine and describe how varying wind speeds can aid the optimization of wind energy turbine design for cost-effective wind energy generation.

2.   ESTIMATION OF WIND POWER DENSITY (WPD)

WPD is a very important indicator to estimate the potential of wind speed data. Two main approaches determine the capacity of wind energy in a specific location, i) available power based on the observed MWS of the meteorological station and ii) frequency distribution function (two-parameter Weibull method) [52], [59]-[63]. In this study, we only adopted the Weibull distribution to assess wind power. Accordingly, the Weibull probability distribution function (PDF) is selected in calculating WPD and is used to illustrate the wind speed frequency distribution. To estimate Weibull parameters, nine numerical methods adopted MM, EM, MLM, MMLM, SMMLM, GM, LSM, STDM and EPF. The estimation is performed to i) distinguish past conditions retrospectively, ii) predict future power generation at one site, iii) predict power generation among a grid of wind turbines and iv) calibrate meteorological records [52], [64]-[66].

3.   WEIBULL PARAMETERS CALCULATION

The Weibull probability distribution is a random variable that is used to describe the wind potential for a specific region. Two main parameters controlled the Weibull curve shape factor k and scale factor c. This parameter is generally applied in statistical analyses [13], [67], [68], and its use requires time-series records of wind speed data. Based on the wind speed data collected, the Weibull probability distribution can be represented as a cumulative distribution function (CDF) or Weibull function, $F(\upsilon)$, and Weibull PDF, $f(\upsilon)$ [27]. The CDF is obtained by computing the integral of the PDF [69]-[71], which is ultimately determined using (1) [7,] [27], [56], [67], [69]-[72].

$$F(\upsilon) = 1 - \exp\left(-\left(\frac{\upsilon}{c}\right)^k\right)$$

(1)

The probability function can be derived as (2).

$$f(\upsilon) = \frac{dF(\upsilon)}{d(\upsilon)} = k\frac{v^{(K-1)}}{c^K}e^{-\left(\frac{\upsilon}{c}\right)^K} \qquad k > 0, \upsilon > 0, \ c > 1$$

(2)

Where v, c and k are the mean wind speed (m/s), c (m/s), k (dimensionless), respectively. Parameter k indicates the width of the wind speed probability distribution, which represents the wind probability distribution peak of any specific region [71], [73], [74]. Parameter c indicates the abscissa scale of the wind probability distribution, which shows the wind in particular location [71], [75]. Parameters c and k can be obtained using MM, STDM, EM, MLM, MMLM, SMMLM, GM, LSM and EPF. These methods are frequently compared in the literature on wind energy basis. However, the results, conclusions and recommendations of previous studies differ greatly due to the change of wind speed data conditions. Hence, it can be concluded that the appropriateness of the methods may change with the sample data distribution, sample data size, goodness-of-fit tests and sample data format [9], [52]. Based on the Weibull PDF, WPD is determined using (3) to simulate the required electric power output for wind turbine model [71], [76]-[80].

$$\bar{P} = \frac{1}{2}\rho\int_0^\infty \upsilon^3 f_w(\upsilon)d\upsilon = \frac{1}{2}\rho c^3\Gamma\left(1+\frac{3}{k}\right) \qquad \left(\frac{W}{m^2}\right)$$

(3)

4.   NUMERICAL METHODS FOR DETERMINING WEIBULL PARAMETERS
4.1. Method of moments (MM)

The MM is recommended by Justus and Mikhail [81], [82]. The standard and mean deviations of the elements are noted initially at a suitable scale MM. On the basis of the numerical iteration of (4) and (5), the standard deviation σ and mean ($\bar{v}$) of wind speeds are calculated [11], [67], [81], [83]-[88]. The MM is an effective approach to deriving Weibull parameters. The first moment relates to the origin, and the second

moment pertains to the mean. These moments are used to calculate parameters k and c, as expressed in (4) and (5) respectively. The calculation includes the MWS and standard deviation which are obtained from the calculated wind speed [88], [89].

$$\bar{\upsilon} = c\Gamma(1 + 1/k) \tag{4}$$

$$\sigma = c\sqrt{\Gamma(1 + 2/k) - \Gamma^2(1 + 1/k)} \tag{5}$$

where,

$$\bar{\upsilon} = \frac{1}{n}\sum_{i=1}^{n}\upsilon_i \tag{6}$$

$$\sigma = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(v_i - \bar{v})^2} \tag{7}$$

$$\Gamma(x) = \int_{0}^{\infty} t^{x-1}\exp(-t)dt \tag{8}$$

Where $\Gamma(x)$ is the gamma function expressed as and vi is the wind speed in time step i (m/s) and n is the number of non-zero wind speed data points. The Coefficient of Variance (COV) or variation coefficient is defined as the ratio between the mean standard deviation (σ) to average wind speed (υ) illustrated as a percentage. It presents the mutability of wind speed and can be illustrated as [90].

$$COV(\%) = \frac{\sigma}{\upsilon} \times 100 \tag{9}$$

4.2. Empirical method (EM)

The EM is also commonly known as the power density method. EM is easy and simple to implement [88]. The empirical approach involves a straight forward and practical solution that only requires knowledge of MWS $\bar{v}$ and standard deviation σ [81]. The EM uses the average of the cube of wind speed (v^3) and the cube of MWS $\bar{v}^3$ as Energy Pattern Factor (E_{pf}). The scale factor is determined from the E_{pf}. The equations used to determine the scale parameter are identical to those used in the MM and EM [91]. Thus, the EM can be categorised as a special case of the MM [11], [67]. On the basis of the EM introduced by Justus [71], [92], [93], parameters k and c are computed using (10) and (11), respectively [71], [83], [92], [93]. In the EM, the parameters of Weibull can be estimated (10).

$$k = \left(\frac{\sigma}{\bar{\upsilon}}\right)^{-1.086} \quad , \quad 1 \leq k \leq 10 \tag{10}$$

$$c = \frac{\bar{\upsilon}}{\Gamma\left(1 - \frac{1}{k}\right)} \tag{11}$$

4.3. Maximum likelihood method (MLM)

The MLM was put forward by Fisher [81], [94] and then introduced by Stevens and Smulders as an approach to obtain wind speed information [81], [95]. The MLM is based on the indirect results of numerical iteration methods for determining parameter k. Therefore, the MLM is effective despite being a laborious and complicated procedure [81]. The MLM is a mathematical formulation technique also recognized as the likelihood function in time series format for the wind speed data [71]. MLM requires extensive numerical iterations [11]. These numerical iterations are needed to estimate the parameters k and c of the Weibull function. Through the MLM, parameters k and c are calculated using (12) and (13), respectively [71], [96], [97].

$$k = \left[\frac{\sum_{i=1}^{n}\upsilon_i^k \ln(\upsilon_i)}{\sum_{i=1}^{n}\upsilon_i^k} - \frac{\sum_{i=1}^{n}\ln(\upsilon_i)}{n}\right]^{-1} \tag{12}$$

$$c = \left[\frac{\Sigma_{i=1}^{n} \upsilon_i^k}{n} \right]^{1/k} \tag{13}$$

4.4. Modified maximum likelihood method (MMLM)

The MMLM is only applicable when the wind speed data are in frequency distribution format. Similar to the MLM, the MMLM entails several iterations when used to determine Weibull parameters. Parameters k and c are obtained using (14) and (15) [31], [71], [98].

$$k = \left[\frac{\Sigma_{i=1}^{n} \upsilon_i^k \ln(\upsilon_i) f(\upsilon_i)}{\Sigma_{i=1}^{n} \upsilon_i^k f(\upsilon_i)} - \frac{\Sigma_{i=1}^{n} \ln(\upsilon_i) f(U \upsilon_i)}{f(\upsilon \geq 0)} \right]^{-1} \tag{14}$$

$$c = \left[\frac{1}{f(\upsilon \geq 0)} - \overset{n}{\underset{i=1}{\Sigma}} \upsilon_i^k f(\upsilon_i) \right]^{1/k} \tag{15}$$

Where vi is MWS central to bin i and n is the total number of bins, $f(vi)$ is the frequency of wind speed falling within bin i, where $f(v \geq 0)$ is the probability distribution curve that wind speed reaches or exceeds zero.

4.5. Second modified maximum likelihood method (SMMLM)

The SMMLM was developed by Christofferson and Gillette (1987) by replacing the iterative estimation of the shape parameter [99]. Which requires neither the iteration nor the sorting of data. Thus, SMMLM was selected by Hanitsch and Ahmed Shata in [100].

$$k = \frac{\pi}{\sqrt{6}} \sqrt{\frac{N(N-1)}{N(\sum_{i=1}^{N} ln^2 v_i) - (\sum_{i=1}^{N} ln v_i)^2}} \tag{16}$$

4.6. Graphical method (GM)

GM also called the LSM[101], is employed using the CDF. In GM, the wind speed record ought first to be categorised into bins. After using the logarithm of (17) twice, the GM can be obtained as. The GM is used by a logarithmic function of the CDF F(v), that is, the CDF F(v) is modulated for the inclusion of a dual logarithmic transformation [81]. Plotting $\ln(v)$ as the x-axis versus $\ln\{-\ln(1 - F(v))\}$ as the y-axis shows a straight line in which k is the slope and the y-intercept is $k \times ln(c)$[11], [71], [102].

$$\ln\{-\ln[1 - F(\upsilon)]\} = k \times \ln(\upsilon) - k \times \ln(c) \tag{17}$$

4.7. Energy pattern factor method (EPF)

The EPF is related to the mean records of wind speed; it is described by (18) [9], [67].

$$E_{pf} = \frac{\overline{V^3}}{\overline{V}^3} \tag{18}$$

$$k = 1 + \frac{3.69}{(E_{pf})^2} \tag{19}$$

Where, $\bar{v}$ is given as (4), and E_{pf} is the energy pattern factor and is represented by (18).

4.8. Standard deviation method (STDM)

In this method, c and k are calculated as in (10) and (11). Several studies have adopted STDM to calculate Weibull parameters. In [46], this method was utilised to assess wind data in Zarrineh, Iran in 2012 as mentioned. Reference [67] analysed and compared seven numerical methods to assess their effectiveness in determining the parameters of the Weibull distribution using wind data collected from Camocim and Paracuru in the northeast region of Brazil. In [11], the authors conducted a statistical study to check the

efficiency performance by determining the Weibull shape and scale factor for six different numerical methods for wind energy applications.

4.9. Least mean square method (LSM)
This method determines the shape factor and scale factor based on the slope of GM. Therefore, this numerical method considers the same as GM and depends on (17) [28].

5.   GOODNESS OF FIT (GOF)
The performance of the five parameter estimation techniques of the Weibull probability distribution for calculating WPD is evaluated using several statistical techniques, including five statistical tools indicators. To achieve a comparative assessment, we utilise the Root Mean Square Error (RMSE), Chi-square test (X^2), Index of Agreement (IA), Mean Absolute Percentage Error (MAPE), and Relative Root Mean Square Error (RRMSE), along with some other statistical tools. In the aforementioned subsections, we present a summary of the statistical tools' parameters used in this work.

5.1. Root mean square error (RMSE)
RMSE shows the accuracy of a model by comparing the deviations between the values gathered by the Weibull function besides those obtained from measurement data. The positive value of RMSE is calculated as in (20) [71].

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(P_{i,W}-P_{i,M}\right)^2} \tag{20}$$

Where $P_{i,w}$ and $P_{i,M}$ are the ith calculated wind power density via WDF and the ith calculated WPD by measured data, respectively.

5.2.   Chi-square test (X^2)
X^2 is applied to analyse proportions of independent variables, that is, possible inconsistency between the expected frequencies and observed of the events of occurrence. X^2 is a non-parametric test that is independent of factors like the average population and variance. Two series behave comparably if the variance between the frequencies for every category is negligible, therefore, close to 0. Souza [103] indicated that for this model, the groups should be independent, the items should be randomly selected from each group, the observations should be frequently counted, and every observation should belong to only one group [81]. F(v) is the empirical probability distribution estimated from any wind speed record. Then, parameters k and c are determined to be minimum [104].

$$X^2 = \sum_{i=1}^{N}\frac{(y_{i,m}-x_{i,m})}{x_{i,m}} \tag{21}$$

Where y is the observed value and x is the expected value.

5.3. Index of agreement (IA)
The IA presents the precision degree of predicted values relative to observed values. The IA that changes from 0 to 1 is computed by [28], [71], [105].

$$IA = 1 - \frac{\sum_{i=1}^{n}\left|P_{i,W}-P_{i,M}\right|}{\sqrt{\sum_{i=1}^{n}\left|P_{i,W}-P_{W,avg}\right|+\left|P_{i,M}-P_{M,avg}\right|}} \tag{22}$$

Where $P_{w,avg}$ and $P_{M,avg}$ are the average $P_{i,W}$ and $P_{i,M}$ values, and n is the total number of observations.

5.4. Mean absolute percentage error (MAPE)
MAPE presents the average absolute percentage variance between the estimated wind power using the Weibull probability function and that calculated from the observed data (measured data wind speed). MAPE can be calculated by [71].

$$MAPE = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{P_{i,W} - P_{i,M}}{P_{i,M}}\right| \times 100$$

(23)

5.6. Relative root mean square error (RRMSE)

RRMSE can be acquired by dividing the RMSE with the mean wind power calculated by the observed values. Various domains of RRMSE can be set to demonstrate model precision according to the percentage as is clarified below [71], [106], [107]. RRMSE is considered, excellent if the efficiency performance is less than 10%, Good if 10% < RRMSE < 20%, average if 20% < RRMSE < 30% and Poor if RRMSE is more than 30%. RRMSE, MAPE, IA, X^2, and RMSE with values close to zero are considered satisfactory [27].

$$RRMSE = \frac{\sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(P_{i,W} - P_{i,M}\right)^2}}{\frac{1}{n}\sum_{i=1}^{n}P_{i,M}} \times 100$$

(24)

6. RESULTS AND DISCUSSION

6.1. Mean wind speed (MWS) for Asqelon city

Wind speed records from wind monitoring stations are adopted to identify the most ideal numerical method for the Weibull distribution. Wind speed data in Ashqelon was recorded from January 2012 to December 2015. Wind speed data from Ashqelon during the period of January 2012 to December 2015 are selected and used in performance testing. Nine numerical methods used in the statistical analysis are employed to compute the *c* and *k* parameters of the Weibull curve.

The nine techniques had been tested to check the percentage of error based on five statistical tools. The statistical tools are RMSE, X^2, IA, MAPE and RRMSE. The ranking is performed using the aforementioned statistical tools to ensure an accurate diagnosis. Figure 1 shows the percentage of the monthly MWS of Ashqelon in the coastal plain of Palestine between 2012 and 2015. The sources of the meteorological data on Ashqelon, which is adjacent to Gaza City, are recorded on a daily basis according to the MWS that is usually calculated every month. The graph shows that MWS dramatically decreased from February-April 2012, reaching an all-time low of 3.2m/s. In January, MWS rose as high as or more than 5m/s. MWS increased steadily and reached approximately 4m/s. In the last three months, the curve declined. In April 2013, MWS increased dramatically, reaching around 4.7m/s. The curve suddenly fluctuated during the last eight months of the year. In January to August 2014, MWS significantly increased, reaching 4.8m/s before finally dropping in the last four months of the year. In January 2015, MWS jumped and reached 5.1m/s. It then fluctuated significantly and reached a peak point in June. However, MWS gradually declined between July and December, reaching an all-time low of 3m/s. Overall, MWS fluctuated between 3-5m/s during this period. Wind speed in this area is generally below 15m/s, and strong wind speed does not exceed 25m/s. Figure 2 illustrates the frequency distribution of the actual MWS records of Ashqelon between January 2012 and December 2015. The bar graph is extremely close to the Weibull curve (PDF) of the wind speed data. More than 90% of the frequency lies between 1 and 7m/s of wind speed for four years.
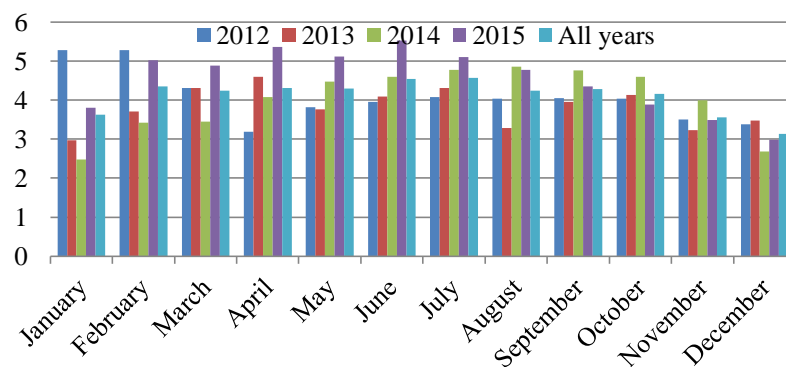

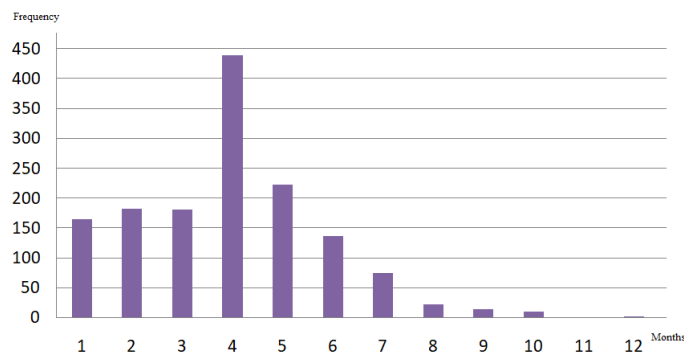Figure 1. MWS in Ashqelon from January 2012 to December 2015 [108]

Figure 2. Frequency of actual MWS records from January 2012 to December 2015

6.2. PDF and CDF for Ashqelon city

Measured and estimated cumulative distribution function (CDF) and probability distribution function (PDF) have been investigated using nine numerical methods for the Ashkelon site from 2012-2015. Figure 3 shows PDF for Ashqelon city for the four years. The PDF is represented the Weibull curve using nine numerical methods based on shape factor value (around 2). The red line is represented as the observed PDF, x-axis is wind speed and y-axis is PDF values. It can be seen that the peak of the curve at 4m/s. This study has been conducted a statistical Weibull analysis of the wind speed data plots of the PDF and CDF for the entire data and seasons. Figure 4 represents the CDF for the four years. The red curve is the observed CDF. This curve is considered the integral of Weibull PDF as (1).

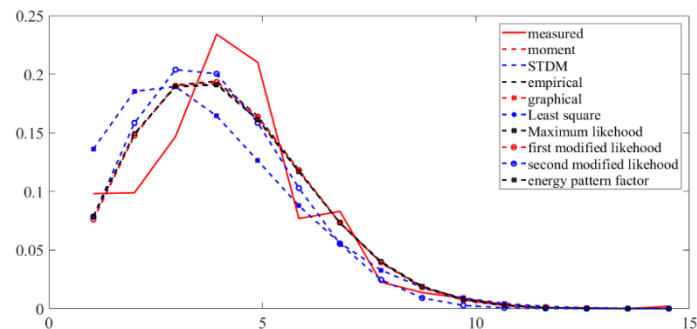Figure 3. Comparison between observed and estimated PDF curves for Ashqelon from 2012 to 2015
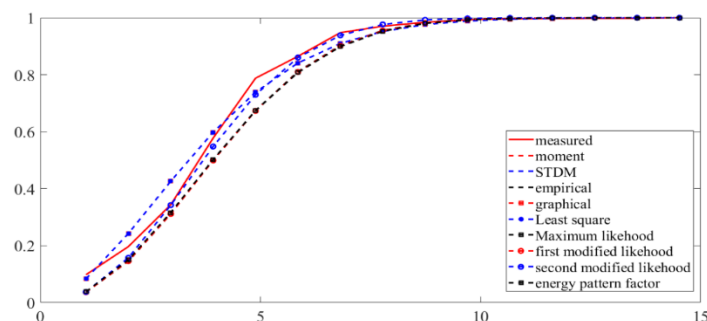

Figure 4. Comparison between observed and estimated CDF curves for Ashqelon from 2012 to 2015

Table 1 presents the variations in the values of the Weibull shape factor k and scale c parameters, along with the standard deviations of the measured data and Weibull results for both site analyses in 2012.

The shape parameter lies between 2.0608 and 2.2526, this means that the Figures are Weibull as mentioned in Figure 3 and the scale parameter is between 4.1000m/s and 4.7555m/s. There are three cases for the shape factors control the PDF curve, a) k≤1 PDF is exponential, b) 1<k≤2 PDF is Weibull (the most common curve) and c) k>2 PDF is bell-shape distribution or Gaussian. Different wind parameters reflect dissimilar wind turbine systems or energy potential. Estimating these parameters accurately for a particular period is necessary for wind energy applications. Table 2 shows that the scale and shape factors (4.3119m/s and 2.1006, respectively) of the MLM are completely identical to the observed values in 2013. The standard deviation for 2013 ranges from 1.7264m/s to 1.9224m/s, whereas the observed value is 1.9179m/s. Table 3 indicate that k and c are nearly the same for the MM, STDM, EM, MLM and EPF. The results of the MM, STDM, EM, MLM and EPF are close and are better than those of the other methods. Table 4 shows the value of the Weibull parameter for 2015. Standard deviation and variation coefficient have been calculated using each numerical technique. The shape factor is around 2 and the scale factor is from 4.4-5.1m/s. It can be seen that EM and STDM have the same result from Table 1 to Table 4. Moreover, GM and LSM have the same result as mentioned in Section 4.9. Table 1 to Table 4 indicate that k and c are nearly the same for the MM, STDM, EM, MLM and EPF. The results of the MM, STDM, EM, MLM and EPF are close and better than those of the other methods.

The parameters of Weibull can be calculated using the GM of every year as shown in Figure 5 to Figure 8. The method to calculate the shape and scale factor is to plot the natural logarithm of the observed speed versus ln(-ln(1-F(υ))). Therefore, the Weibull parameters can be found by linearly fitting the plotted points; thus, k is the slope of the fitted line, and c is equal to exp(b/k), where b is the y-intercept of the fitted line. Where, $\ln(v)$ as x axis versus ln(-ln(1-F(υ))).

Table 1. Estimation of Weibull parameters, standard deviation σ and Coefficient of variance (COV) for 2012

2012	Estimated c and k using the nine numerical methods				
	c(m/s)	k	MWS(m/s)	σ(m/s)	COV (%)
MM	4.5988	2.0608	4.0738	2.0729	50.8836
EM	4.5991	2.0725	4.0738	2.0624	50.6248
MLM	4.6053	2.0616	4.0795	2.0751	50.8663
MMLM	4.7555	2.3526	4.2142	1.9041	45.1831
SMMLM	4.1000	2.2322	3.6313	1.7198	47.3613
GM	4.3642	1.7848	3.8827	2.2492	57.9291
EPF	4.5946	1.9559	4.0738	2.1727	53.3336
STDM	4.5991	2.0725	4.0738	2.0624	50.6248
LSM	4.3642	1.7848	3.8827	2.2492	57.9291
Observed	4.6053	2.0616	4.0800	1.9873	51.1173

Table 2. Estimation of Weibull parameters, σ and COV for 2013

2013	Estimated c and k using the nine numerical methods				
	c(m/s)	k	MWS(m/s)	σ(m/s)	COV (%)
MM	4.3076	2.0990	3.8152	1.9095	50.0496
EM	4.3077	2.1105	3.8152	1.9002	49.8045
MLM	4.3119	2.1006	3.8190	1.9101	50.0166
MMLM	4.3513	2.1937	3.8536	1.8538	48.1071
SMMLM	4.0403	2.1865	3.5781	1.7264	48.2480
GM	3.7570	1.8225	3.3391	1.8981	56.8458
EPF	4.3074	2.0834	3.8152	1.9224	50.3863
STDM	4.3077	2.1105	3.8152	1.9002	49.8045
LSM	3.7570	1.8225	3.3391	1.8981	56.8458
Observed	4.3119	2.1006	3.8200	1.9179	50.2685

Table 3. Estimation of Weibull parameters, σ and COV for 2014

2014	Estimated c and k using the nine numerical methods				
	c	k	MWS (m/s)	σ(m/s)	COV (%)
MM	4.5376	2.2464	4.0190	1.8927	47.0934
EM	4.5374	2.2570	4.0190	1.8847	46.8951
MLM	4.5231	2.2089	4.0058	1.9152	47.8094
MMLM	4.4696	2.0668	3.9592	2.0093	50.7497
SMMLM	4.2750	2.2924	3.7872	1.7514	46.2446
GM	3.8086	1.6942	3.3990	2.0644	60.7359
EPF	4.5375	2.2536	4.0190	1.8873	46.9588
STDM	4.5374	2.2570	4.0190	1.8847	46.8951
LSM	3.8086	1.6942	3.3990	2.0644	60.7359
Observed	4.5231	2.2089	4.0200	1.8993	47.2570

Table 4. Estimation of Weibull parameters, σ and COV for 2015

2015	Estimated c and k using the nine numerical methods				
	c	k	MWS (m/s)	σ(m/s)	COV (%)
MM	5.0981	2.4321	4.5205	1.9827	43.8593
EM	5.0977	2.4414	4.5205	1.9759	43.7096
MLM	5.0839	2.3990	4.5068	2.0010	44.3994
MMLM	5.0234	2.2321	4.4491	2.1073	47.3645
SMMLM	4.8565	2.4650	4.3075	1.8666	43.3344
GM	4.4173	1.9389	3.9174	2.1057	53.7534
EPF	5.0981	2.4315	4.5205	1.9831	43.8692
STDM	5.0977	2.4414	4.5205	1.9759	43.7096
LSM	4.4173	1.9389	3.9174	2.1057	53.7534
Observed	5.0839	2.3990	4.5300	1.9873	43.9606

$$y = mx - b \tag{25}$$

Where $x = slope, k = slope b = k\ln(c)$.

$$\ln(c) = \frac{b}{k} \tag{26}$$

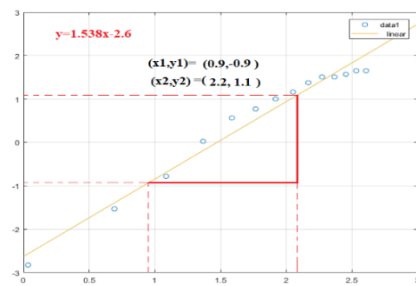$$c = e^{\frac{b}{k}} \tag{27}$$

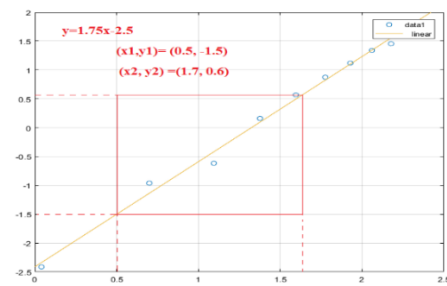Figure 5. GM estimated results for Ashqelon in 2012

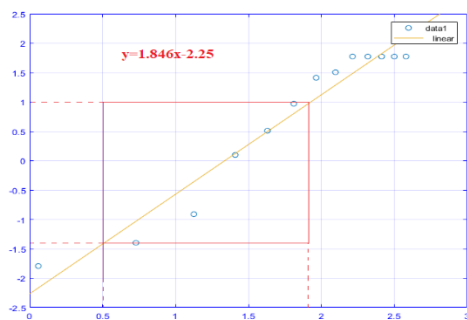Figure 6. GM estimated results for Ashqelon in 2013

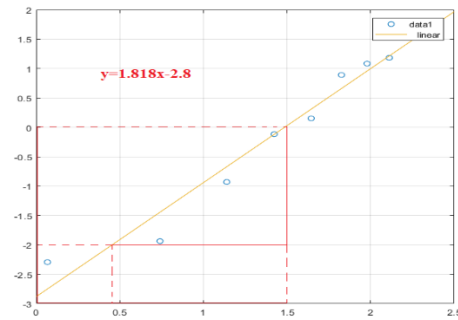Figure 7. GM estimated results for Ashqelon in 2014

Figure 8. GM estimated results for Ashqelon in 2015

Table 5 to Table 8 show the percentage of error based on the analysis of the five statistical techniques for nine numerical methods. Table 5 shows that the GM and LSM yield the greatest efficiency according to the RMSE, X2, IA and RRMSE in 2012. It is followed by EPF, MLM, MM, EM and STDM. The method with the worst efficiency reflected in the RMSE, X^2 and RRMSE is the SMMLM, followed by the MMLM. The ranking had been preceded on the basis of the percentage of error for each method. The wind speed effect in the efficiency for each method, in the other word it's difficult to approve that a specific method as the best one due to change wind speed condition.

Table 6 shows that GM and LSM achieve the best efficiency according to the RMSE in 2013. It is followed by EPF, MM, MLM SRDM and EM. The MM, STDM, EM and MLM showed approximately the same efficiency performance according to the RMSE, X^2, IA and MAPE in 2013. The SMMLM shows the worst efficiency performance according to the RMSE, X^2, IA and RRMSE.

In terms of the RMSE in 2014, the STDM and GM exhibit the best efficiency performance, followed by the EPF, MM and MLM as shown in Table 7. The SMMLM shows the lowest efficiency performance according to the RRMSE, X^2 and RMSE. Table 8 shows that in terms of the RMSE in 2015, the STDM and GM present the highest efficiency performance by the EPF, MM and MLM. By contrast, the SMMLM shows the lowest efficiency performance.

Table 5. Error percentage for checking accurate numerical methods in 2012

2012 Numerical methods		Goodness of fit tests for Coastal plain of Palestine- Ashqelon 2012 Comparative analysis							
		RMSE	Ranking	X^2	Ranking	IA	Ranking	MAPE	Ranking	RRMSE	Ranking
1	MM	0.0074	3	0.9780	4	0.7893	3	0.0196	3	11.1391	3
2	EM	0.0075	4	1.0926	5	0.7912	5	0.0194	2	11.2563	5
3	MLM	0.0074	3	0.9610	3	0.7895	4	0.0196	3	11.1577	4
4	MMLM	0.0089	5	13.5805	6	0.8316	6	0.0158	1	13.3614	6
5	SMMLM	0.0223	6	222.8923	7	0.7795	2	0.0215	5	33.3957	7
6	GM	0.0043	1	0.3073	1	0.7415	1	0.0239	6	6.4394	1
7	EPF	0.0066	2	0.4346	2	0.7705	2	0.0212	4	9.9210	2
8	STDM	0.0075	4	1.0926	5	0.7912	5	0.0194	2	11.2563	5
9	LSM	0.0043	1	0.3073	1	0.7415	1	0.0239	6	6.4394	1

Table 6. Error percentage for checking accurate numerical methods in 2013

2013 Numerical methods		Goodness of fit tests for Coastal plain of Palestine- Ashqelon 2013 Comparative analysis							
		RMSE	Ranking	X^2	Ranking	IA	Ranking	MAPE	Ranking	RRMSE	Ranking
1	MM	0.0053	3	0.1393	2	0.7229	4	0.0317	3	5.2971	5
2	EM	0.0054	4	0.1402	3	0.7239	5	0.0316	2	5.4297	4
3	MLM	0.0053	3	0.1393	2	0.7224	3	0.0318	4	5.3135	3
4	MMLM	0.0063	5	0.1493	4	0.7254	6	0.0317	3	6.2557	6
5	SMMLM	0.0071	6	0.2126	6	0.7509	7	0.0295	1	7.1193	7
6	GM	3.2001e-04	1	0.1916	5	0.7027	1	0.0352	5	0.3200	1
7	EPF	0.0051	2	0.1383	1	0.7214	2	0.0318	4	5.1099	2
8	STDM	0.0054	4	0.1402	3	0.7239	5	0.0316	2	5.4297	4
9	LSM	3.2001e-04	1	0.1916	5	0.7027	1	0.0352	5	0.3200	1

Table 7. Error percentage for checking accurate numerical methods in 2014

2014 Numerical methods		Goodness of fit tests for Coastal plain of Palestine- Ashqelon 2014 Comparative analysis							
		RMSE	Ranking	X^2	Ranking	IA	Ranking	MAPE	Ranking	RRMSE	Ranking
1	MM	0.0046	2	1.9073	6	0.6761	5	0.0323	1	6.4148	3
2	EM	0.0045	1	2.1563	5	0.6764	6	0.0323	1	6.3530	1
3	MLM	0.0048	3	1.3660	3	0.6751	4	0.0324	2	6.6635	4
4	MMLM	0.0056	4	0.5520	1	0.6723	3	0.0325	3	7.8650	5
5	SMMLM	0.0304	6	22.2735	7	0.6501	2	0.0347	4	42.6080	7
6	GM	0.0117	5	0.5048	2	0.6119	1	0.0389	5	16.3687	6
7	EPF	0.0046	2	2.0717	4	0.6764	6	0.0323	1	6.3728	2
8	STDM	0.0045	1	2.1563	5	0.6764	6	0.0323	1	6.3530	1
9	LSM	0.0117	5	0.5048	2	0.6119	1	0.0389	5	16.3687	6

Table 8. Error percentage for checking accurate numerical methods in 2015

2015 Numerical methods		Goodness of fit tests for Coastal plain of Palestine- Ashqelon 2015 Comparative analysis							
		RMSE	Ranking	X^2	Ranking	IA	Ranking	MAPE	Ranking	RRMSE	Ranking
1	MM	0.0098	2	0.2858	2	0.5991	3	0.0468	5	9.7861	2
2	EM	0.0097	1	0.2867	4	0.5997	4	0.0468	5	9.7396	1
3	MLM	0.0099	3	0.2838	1	0.5987	2	0.0467	4	9.9406	4
4	MMLM	0.0110	4	0.2863	3	0.5948	1	0.0466	3	11.0351	5
5	SMMLM	0.0384	6	0.3746	5	0.6035	5	0.0462	2	38.4354	7
6	GM	0.0137	5	0.4159	6	0.6040	6	0.0460	1	13.6533	6
7	EPF	0.0098	2	0.2858	2	0.5991	3	0.0468	5	9.7892	3
8	STDM	0.0097	1	0.2867	4	0.5997	4	0.0468	5	9.7396	1
9	LSM	0.0137	5	0.4159	6	0.6040	6	0.0460	1	13.6533	6

7. CONCLUSION

Nine numerical techniques had been used to calculate the Weibull parameter for Ashqelon site. The PDF and CDF had been implemented using nine numerical methods for Ashqelon site from 2012 to 2015. The percentage of error had been calculated using five statistical tools to check the efficiency performance for the numerical techniques. GM and energy pattern factor EPF show the greatest efficiency, whereas the SMMLM shows the lowest efficiency based on statistical tools. Between 2014 and 2015. The EM and STDM show the best efficiency performance, followed by MM and MLM. Based on numerical analysis shape factor k is approximately 2. Therefore, the PDF for Palestine is Weibull, whereas, scale factor c value from 4 to 5 m/s. The MWS speed at Ashqelon was 4.07m/s, 3.82m/s, 4.02m/s and 4.52m/s for the year 2012, 2013, 2014 and 2015 respectively. The EPF applies to the assessment of any wind speed data and shows the greatest accuracy performance through the years followed by MM and MLM. The SMMLM presents the worst prediction performance followed by MMLM according to all statistical techniques. Among the five statistical tools, RMSE is the most accurately predicted technique. By contrast, the worst predicted technique is RRMSE. This research determined the wind energy conversion characteristics. Based on WPD calculations this study confirms the potential of electrical energy generation in Palestine using small-scale turbines.

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