

Assessment of Wind Energy Potential as a Power Generation Source in the Azraq South, Northeast Badia, Jordan

Omar Al-Nhoud¹, Mohammad Al-Smairan^{2*}

¹Civil Engineering Department, Faculty of Engineering, Al al-Bayt University, Mafraq, Jordan

²Renewable and Sustainable Energy Engineering Department, Faculty of Engineering, Al al-Bayt University, Mafraq, Jordan

Email: wesam93@yahoo.com

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Abstract

Due to several climate changes caused by greenhouse gases and to increasing need for clean energy sources, more attention has been given to renewable energy sources and wind energy is one of the most promising energy source in the future. The current paper presents an investigation of the wind power potential in Azraq south area, a remote location in the Northeast Badia of Jordan using real wind speed data. Also, other wind characteristics with the help of one method of meteorological and Weibull are assessed to evaluate of which at a height of 10 m above ground level and in open area. Long term data (1991-2001) period measured mean wind speed data measured at 10 m height was analyzed. Based on these data, the highest and the lowest wind power potential are in July and December, respectively. Also, it was indicated that the shape and scale parameters for Azraq south varied over a wide range. The monthly values of Weibull shape parameter k ranged from 1.05 to 4.2 with a mean value of 3.06. While the monthly values of the Weibull scale parameter c were in the range of m/s, with a mean value of 4.57 m/s. It was also concluded that the site studied was not suitable for electric wind application in large-scale. It was found that the wind potential of the region could be adequate for non-grid connected electrical and mechanical applications, such as wind generators, battery charging and water pumping as well as agricultural applications.

Keywords

Wind Energy Potential, Weibull Distribution, Turbine, Badia, Jordan

*Corresponding author.

1. Introduction

Energy is vital for sustaining life on earth. Energy is and will remain the basic foundation as it continues to play its crucial role in human and economic development and world peace. World energy demand has been increasing exponentially. It has been estimated that the world population will reach 8 billion by 2020. On the other hand, it is very clear that conventional energy resources are limited on earth, concern for energy security and greenhouse gas emission compel governments and policymakers to develop new strategies to utilize renewable energy sources and clean energy for power generation. Therefore, it is essential that we exploit these resources in such a way that present and future generations are able to flourish without jeopardizing their life supporting systems [1]-[6].

Most of the problems present in the world are closely related to problems of energy distribution, dwindling fossil-fuel supplies, and the environmental effects of various methods of energy production and utilization, thereby making current energy trends to be unsustainable thus necessitating a better balance between energy security, economic development and protection of the environment [4] [7]-[9].

Jordan is one of the smallest economies in the Middle East and unlike other neighboring Arab countries; it is a non-oil-producing country with limited natural resources and minerals. Given that Jordan has to import approximately 100,000 barrels of oil per day, upward fluctuations in oil prices can increase both the trade deficit and the balance of payments deficit, while placing pressure on the demand for foreign currency. The National Energy Strategy 2008-2020 aims to supply 29 percent of energy needs from natural gas, 14 percent from oil shale, 10 percent from renewable energy resources and 6 percent from nuclear energy by 2020 [10].

The use of renewable energy *i.e.*, energy generated from wind, solar, biomass, geothermal, hydropower and ocean resources is very old and increases the diversity of energy supplies and offers us clean energy beyond all doubt. Among these wind power has become an important option for electricity generation [2]-[4] [9] [11]. Wind energy today is competitive at specific sites with favorable wind regimes, as can be found in many places. There are many advantages which make wind power superior to the other renewable and non-renewable energy resources, among them are: wind provides a free, clean, safe, diverse and sustainable source of energy. The external and social cost of wind energy is very low. Wind energy is a domestic source of energy and the installation of wind turbines is fast. Wind energy and other renewable energy sources can improve a nation's degree of self-sufficiency. Wind energy has become one of the least-cost power sources. Wind electricity by medium-scale wind turbines is preferable in remote locations and in small islands for being socially valuable and economically competitive [4] [6] [12]-[17].

Given a specific wind regime, the economic value of any wind turbine is the energy that it yields on its power characteristics. So the energy output from the wind turbine is equal to the power output at any certain wind speed multiplied by the time interval during which this wind speed is to be expected for a given period of time, and this period of time is usually one year [18] [19]. Therefore, the total energy that the wind energy conversion system will produce depends on both the characteristic curve of the wind turbine (wind speed-power curve), the turbine's size and wind speed frequency distribution at the site [3] [4] [20].

The wind speed probability distribution and the function representing them mathematically are the main tools used in the wind related literature. Weibull distribution function is the most commonly used in application. The variation of wind velocity is often described using the Weibull two parameter density function. Wind energy potential is not easily estimated because, contrary to solar energy, it depends on the site characteristics and topography to a large degree, as wind speed are influenced strongly by local topographical features [3] [21]-[24].

The assessment of the suitable regions for wind energy utilization and the estimation of the expected power production of wind turbines are a prerequisite for efficient wind turbine sitting under economical, social and environmental constraints [25].

Therefore, accurate wind resource assessment is essential in the choice of a profitable location for harnessing wind power. Northeast Badia of Jordan with average wind speed range between 4 - 5 m/s and based on this, a careful wind resource assessment and viability of adopting the location for wind power generation using wind energy conversion system was done. A 11-year (1991-2001) monthly wind data at 10 m height were obtained from the archive of the Jordanian Meteorological Department [26].

Our study aims to establish an accurate assessment of wind energy potential in the Northeast Badia region, Jordan, Azraq south case study by the application of well assessed methodologies that are recalled within the paper.

2. Wind Energy Status in Jordan

Wind energy is available over parts of Jordan at low to moderate rate suitable for water pumping, while there are few regions having an excellent wind power suitable for power generation [27]. In the north part of the country, the annual average wind speed reaches about 7 m/s at 10 m height, which is suitable for power generation. In general, in many parts of Jordan reasonable wind energy potential is expected [28]. The application of wind energy in Jordan is for water pumping in the arid region. Wind electricity generation is limited to some areas in Jordan [29].

Wind energy in Jordan is used mainly for electricity generation and water pumping [28] [30]. In Jordan, more than 12 demonstration projects totaling 1620 kW of wind turbines were implemented, tested and evaluated for water pumping and electricity generation, where the use of wind turbines for pumping water is acceptable to people in remote areas. Mechanical wind pumps pump more than 40,000 m³ of water per annum, while electrical wind pumps pump more than 80,000 m³ of water per annum. These systems contribute towards the social and economic development of remote areas. For electricity generation, there are two wind farms connected to the electricity grid in the Northern part of the country; one with a capacity of 320 kW in Al-Ibrahimya, consisting of 4 wind turbines of 80 kW each. The other has a capacity of 1125 kW in Hofa, consisting of 5 wind turbines of 225 kW each [28] [30]-[36]. **Figure 1** shows a wind farm in Hofa, in the north part of Jordan.

The development of wind power has gotten a deserving attention nowadays in Jordan leading to the construction of the country's first big wind power station in the south of the country, but it cannot be said that the work in this field is satisfactory. Much more is needed to be done to increase interest in this subject. Wind energy will play an important role in future energy needs of Jordan.

3. Materials and Methods

3.1. Badia Climate and Site Description

Jordan lies in the Middle East within latitude 29°11' to 36° north and longitude 34°59' to 39° east. It is a small country with a total area of 89,206 km² including 329 km² of water. Jordan is comprised of several different geographical areas with special features. It provides a diverse landscape, from hills and mountains, like the al-Sharah mountains and Jabal Ram 1734 m height in the south and in some areas, like the area surrounding the Dead sea that are 400 meters below sea level (bsl). There are steep valleys like the Jordan valley to the fertile areas near Irbid in the north of the country, and there is the desert, which is called the Badia plains that extend in an eastward direction into Saudi Arabia. The Jordanian climate is mostly arid desert and moderate in temperature, where winter temperatures average around 8°C - 10°C and summer temperatures range from 28°C - 35°C. The rainy season is in the period (November to April), where the average annual rainfall varies from less than 50 mm to over 400 mm in some parts of the country. The largest part of Jordan is classified as arid and semi-arid land known as the Badia. This region lies in the eastern part of the country, from north to south and covers an area of 72,660 km². It has an arid climate, harsh weather conditions and little natural vegetation [36]-[38].



Figure 1. Wind farm in Hofa (photo: researcher).

Azraq south is located on the Northeast Badia of Jordan. It is at an elevation of 400 m above sea level. With regard to general weather conditions, the temperature varies from a minimum of -2°C in winter to a maximum of 45°C in summer, while the temperature gradient between day and night is 25°C . The average monthly wind speed, relative humidity and temperature over 11 year are shown in **Table 1** as a representative year for calculations.

The topography of the area is characterized by small hills, mountains and flat desert terrain with a weak surface roughness. There are no obstacles around the study area.

3.2. Wind Data Used in This Study

The estimation of wind energy potential is based on the knowledge of wind regimes on the considered territory. The accuracy of this phase is crucial as the provided power is proportional to the cube of wind speed [25]. In this work, the assessment of the Northeast Badia of Jordan wind potential has been carried out. The data on wind speed for this study are taken from Jordan Meteorological Department.

Wind speed was collected every 3 hours at a 10 m height during 11 years from 1991 to 2001 for Azraq south in the Northeast Badia of Jordan.

The reason for performing wind measurements at 10 m height was that for climatologically and practical reasons, where it has been agreed that this should be the standard meteorological reference level in order to achieve representative recording of the wind potential of the area. Furthermore, the wind speed at higher heights could be calculated using the power law [9] [39].

According to the requirements for wind energy assessment, representative year can be used to estimate the wind energy resource potential. The representative year refers to the mean value of the minimum, maximum, middle from wind speed records (1991-2001) as shown in **Table 1** [26].

The data have been used to evaluate the annual frequency of wind speed, the vertical profile of the wind speed and the assessment of potential wind power.

3.3. Calculation

3.3.1. Wind Speed Extrapolation

In most locations wind speed varies considerably with height, a phenomenon known as wind shear. The two factors that the degree of wind shear depends upon are the atmospheric mixing and the roughness of the terrain. The term roughness length is really the distance above ground level where the winds speed theoretically should be zero [40]. The vertical variation of the wind speed, the wind speed profile, can be expressed by different functions. The variation of wind speed with altitude can be estimated using the following relationship [4] [17] [22] [23] [25] [39]-[46]:

$$V_2 = V_1 \left(\frac{z_2}{z_1} \right)^{\alpha} \quad (1)$$

where, z_2 : the height above the ground level (m); V_2 : the wind speed at height z_2 (m/s); z_1 : reference height (m); V_1 : wind speed at the reference height (m/s); and α is an exponent which depends on the roughness of the terrain. A typical value of for open country, few surface features might be 0.12 [42].

3.3.2. Frequency Distribution of Wind Speed

Statistical analysis can be used to determine the wind energy potential of a given site and to estimate the wind energy output at this site. The statistical distribution of wind speeds varies from place to place around the globe, depending upon local climate conditions, the landscape and its surface. The wind speed distribution for a typical

Table 1. Average monthly, wind speed, relative humidity and temperature for Azraq south [26].

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Wind speed (m/s)	2.45	3.43	4.29	4.59	4.95	5.95	6.1	5.41	4.8	2.89	2.52	1.71	4.09
Relative humidity [-]	79.9	65.3	61.3	44.2	42	48.5	42.2	47.6	43.6	50.6	50.9	56.1	52.7
Temperature ($^{\circ}\text{C}$)	13.8	17	19.2	27.9	32.1	35.9	38.4	40.3	35.3	30.9	26	18.6	28

site is usually described using the so-called Weibull distribution [3] [4] [9] [11] [22]-[25] [39] [42] [44]. The Weibull probability density function can be given by:

$$p(V) = \frac{k}{C} \left(\frac{V}{C}\right)^{k-1} \exp\left\{-\left(\frac{V}{C}\right)^k\right\} \quad (2)$$

where $p(v)$ is the probability of observing wind speed, k is the unitless shape parameter, c is the scale parameter in m/s and v is the wind speed.

The cumulative Weibull distribution $P(v)$ gives the probability of the wind speed exceeding the value V , it is expressed as [4] [9]:

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

3.3.3. Wind Power Energy Calculation

The electric energy produced by a turbine over the year is given by the following relationship [39]:

$$E = N_h C_p \frac{1}{2} \rho \Pi \frac{D^2}{4} \int V^3 f(V) dV \quad (4)$$

where: N_h is the number of hours over the year = 8760 h; V is wind speed in (m/s); ρ is air density = 1.225 kg/m³; D is the rotor diameter in (m), C_p is the power coefficient.

The actual power available to drive a practical wind turbine is much less than the theoretical maximum value. A practical wind machine, experiences air drag on the blades and friction of the air on the blades causing heat losses. In addition, the rotation of the rotor causes swirling of the air, which reduces the torque imparted to the blades. The net effect of the various losses is incorporated into a parameter called the power coefficient or coefficient of performance C_p . Where parameter C_p is to be the dimensionless variable.

For practical wind turbines its value is usually in the range $0 \leq C_p \leq 0.4$. The power coefficient C_p has a value that depends on the wind velocity, turbine rotational velocity and turbine blade parameters [47].

4. Results and Discussion

4.1. Wind Speed

Azraq south annual average of wind speed was found to be 4.09 m/s for the studied period. The maximum value of monthly mean wind speed is computed as 6.1 m/s in July and a minimum value of 1.7 m/s in December. Long term seasonal wind speeds were found to be relatively higher during the period from March to September **Figure 2**. It can be observed from **Table 1** that the seasonal mean wind speed is higher in the dry season than rainy period. We

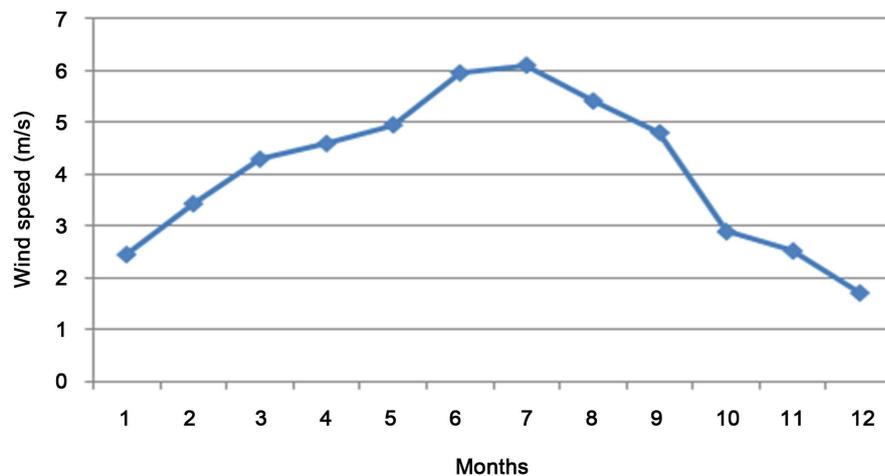


Figure 2. Mean wind speed for Azraq south.

can say that this period corresponds roughly to a period of maximum demand of electricity because it includes warm season (operating air-conditioners, refrigerators and irrigation pumps). It is however, clear that is becomes generalized to the Azraq south area, since the wind machineries are installed at an altitude of up 30 m. Nevertheless, these applications remain restricted to water pumping and the production of electricity on a small-scale.

4.2. Extrapolated Wind Speed

Considering the fact that rotors of the actual wind turbines are placed at heights more than 10 m and in order to choose the suitable height of the wind turbines, it is necessary to know the variations of wind speed with altitude.

Thereby, the collected annual wind speed data for Azraq south was calculated at 30 m and 50 m hub height using Formula (1). At these heights the annual average of wind speed became 4.67 m and 4.96 m respectively, while it was only 4.09 m/s at 10 m above ground level, this corresponds to increase of, 14% and 21% respectively, from the 10 m average annual wind speed as shown in **Figure 3**.

4.3. Wind Speed Frequency Distribution

The wind speed frequency distribution is a method to provide a close approximation to the probability laws of many natural phenomena. It has been used to represent wind speed distributions for applications in wind load studies for some time. The use of this frequency distribution approach can provide a simple method to predict the energy output of a wind energy conversion system. The wind speed frequency distribution indicates the probability, or the fraction of time, where the wind speed is within the interval given by the width of the columns. The sum of the height of the columns is 1% or 100% [21].

Simple knowledge of the mean wind speed of the selected area could not be taken as sufficient for obtaining a clear view of the available wind potential. Therefore, in order to surpass the no predictability of the wind characteristics, a statistical analysis was considered necessary. For this reason, Weibull distribution probability density function was applied. The probability density function indicates the fraction of time for which a wind speed possibly prevails at the area under investigation. In this study, the tow parameters of the Weibull probability density function have been determined by the standard deviation (SD) and least squares (LS) methods. Using Equation (2), the annual Weibull parameters, k and c for Azraq south have been calculated for this particular year. It can be seen that the annual shape parameter k for the selected area is 3.06. While, the annual scale parameter c is 4.57 m/s.

Figure 4 shows the annual wind speed frequency distribution from observed data. As shown from the figure, the frequency distribution of wind speed shows in the case of Azraq south location that wind speed remained at the model value 4 m/s and below it for about 32% of time during the entire year and a above it for the rest of the period.

Another important aspect considered during the statistical analysis was the prediction of the time for which potentially installed, in this area, wind turbine could be functional. In order to achieve that, the determination of

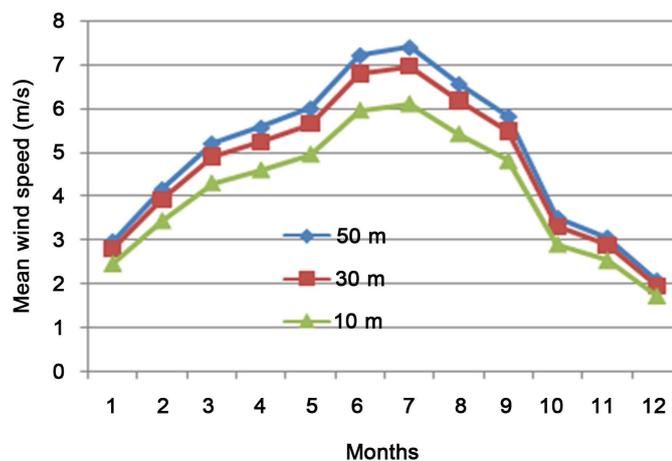


Figure 3. Seasonal wind speed profile at (10 m and extrapolation to 30 m and 50 m).

the cumulative distribution function was required. Since this function indicates the fraction of time the wind speed is below a particular speed. The annual cumulative frequency distribution of the Azraq south was calculated using Equation (3) and the results is shown in **Figure 5**.

4.4. Wind Energy Output

Wind energy is the kinetic energy of the moving air mass. Using Equation (4), we can calculate the maximum yearly mean wind energy per unit cross sectional area of a turbine. Thereby, this entity was estimated for wind energy extracted at different heights: 10 m, 30 m and 50 m as shown in **Figure 6**. As expected mean wind energy is proportional to hub height.

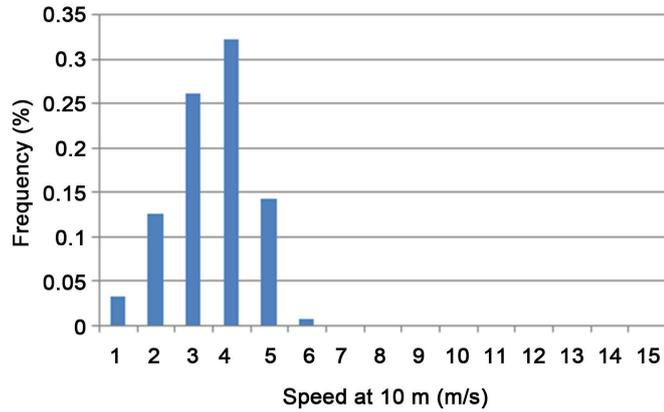


Figure 4. Probability distribution function of the annual wind speed.

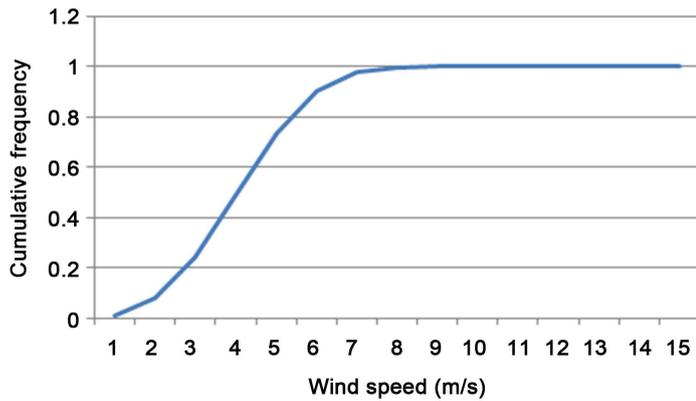


Figure 5. Cumulative distribution function of the annual mean wind speed.

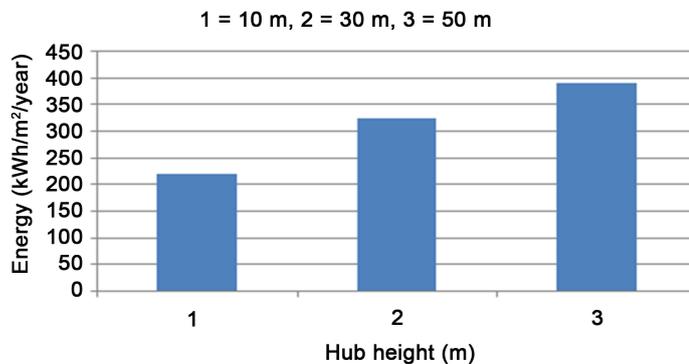


Figure 6. Maximum yearly mean wind energy per unit cross sectional area.

5. Conclusions

The aim of this study was to assess the potential of wind power in Azraq south, Northeast Badia of Jordan. Monthly average long term wind speed data of Azraq south during the period of 199-2001 have been statistically analyzed. The most important outcomes of this study can be summarized as follows:

- Long term seasonal wind speeds were found that the windiest months were during the period from March to September, while the calmest month was December. The monthly mean wind speeds are recorded as 6.1 and 1.7 m/s in July and December for the maximum and minimum values respectively at 10 m height. These periods' feet well with annual periods of maximum demand of electricity.
- Mean wind speed measured at 10 m height is determined as 4.09 m/s for the studied period. This speed increases by, respectively 14% and 21%, when it is extrapolated to 30 m and 50 m hub height.
- The mean annual value of Weibull shape parameter k is 3.06, while the annual value of the scale parameter c is 4.57 m/s.
- The frequency distribution of wind speed shows that wind speed remained at the model value 4 m/s and below it for about 32% of time during the entire year and above it for the rest of the period.
- The maximum yearly mean wind energy per unit cross sectional area of standard wind turbine was estimated at different heights: 10 m, 30 m and 50 m and shows that mean wind energy is proportional to hub height.
- The wind energy potential in Azraq south area is quite promising, because the wind speed range for electricity generation is within 5 - 6 m/s, therefore, the site studied is not suitable for electric wind application in large-scale, but may be adequate for non-grid connected electrical and mechanical applications, such as wind generators, battery charging and water pumping as well as agricultural applications.
- At the end the present work is only preliminary study in order to assess wind energy potential of Azraq south, Northeast Badia, Jordan and give useful insights to engineers and experts dealing with wind energy.

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