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ASSESSMENT AND ANALYSIS OF WIND POWER DENSITY IN TAIZ- REPUBLIC OF YEMEN

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ABSTRACT :

Yemen has to make use of its renewable energy resources, such as wind and solar energy, not only to meet the increasing demand for energy, but also for environmental reasons. This paper presents the results of the analysis of wind speed data for one calendar year (2000) measured in hourly time-series wind speed data at Taiz City (13° 35′ N and 44° 01′ E) located at southwestern Yemen (about 1311 m above sea level).

According to the statistical analysis, the mean annual wind speed was about 4.4 m/s and the wind speed was more frequent between 3 and 6.5 m/s. The wind speed data showed that the maximum monthly wind speed occurs through March. The wind energy potential of the location is studied based on the Weibull and the Rayleigh models. It is concluded that location can be explored for wind energy.

INTRODUCTION:

Renewable energy sources, wind, solar, geothermal, hydro, biomass and ocean thermal energy, have attracted increasing attention from all over the world due to their almost inexhaustible and non-polluting characteristics.

Wind energy as one of these important sources is perhaps the most suitable, most effective and inexpensive sources for electricity production. As a result, it is vigorously pursued in many countries.

Yemen has to make use of its renewable resources, such as solar, wind and geothermal energy, not only to meet increasing demand, but also for environmental reasons.

Yemen has a long coastal strip of over 2500 kms with a width of 30-60 kms along the Red Sea, Gulf of Aden, and the Arabian Sea. Average annual wind speeds measured at 10 m height exceed 8 m/s at most of the coastal sites. There is good potential for wind energy at sites on the coastal strip, in addition to the offshore area. There is also a great wind energy on Yemeni islands and inland hills and mountains[1].

Some studies[1,6] have reported that the wind speed is relatively large at high altitudes and coastal areas. Yemen has a unique geographic location. It has a long coastline and plenty of high altitudes. Due to all these characteristics, Yemen is a perfect place for generating energy from the wind.

Yemen possesses a very good potential of solar and wind energy. However, the wind energy has not yet been studied seriously in Yemen though there are a few studies about wind speed for some locations.

In the present study, hourly time-series wind speed data were measured for the year 2000 in Taiz by the National Water Resources Information Center.

Taiz city is one of the largest cities in Yemen located in the southwest of Yemen (located at 13° 35′ N and 44° 01′ E). Its height above sea level is 1311m.

The aim of the present study is to analyze wind speed data at Al-Rowda area in Taiz due to the importance of statistical analysis of wind speed data and to predict the power density in this area.

THEORETICAL ANALYSIS:

1- Analysis of the used wind data:

The monthly mean of wind speed values and their standard deviations were calculated from the time series data using the following equations[2]:

$$v_m = \frac{1}{N}[\sum_{i=1}^{N} v_i] \quad \text{.................. (1)}$$

$$\sigma = [\frac{1}{N-1}\sum_{i=1}^{N}(v_i - v_m)^2] \quad \text{............(2)}$$

Where:

N is the number of hours in the considered period of time.

v_m is the mean wind speed (m/s) and v_i the observation values[3,4].

σ is the standard deviation.

Alternatively, the mean wind speed can be determined from:

$$v_m = \int_0^{\infty} v f(v) dv \quad \text{.............(3)}$$

if the probability density function of the Weibull distribution $f(v)$ is known[4].

2-Power density distributions and mean power density:

It is well known that the power of the wind that flows at speed (V) through a blade sweep area (A) increases as the cube of its velocity and is given by[5].

$$P(v) = \frac{1}{2}\rho A v^3 \quad \text{.............(4)}$$

Where:

ρ is the standard air density. A typical value used in all the literature consulted is average air density (1.225 kg/m^3), corresponding to standard conditions (sea level, 15° C).

The mean wind power density can be calculated directly from the following equation if the mean value of $(v^3)_m$, is already known,

$$P_m(V) = \frac{1}{2}\rho A (v^3)_m \quad \text{............(5)}$$

From Eq. (3), the mean value of v^3m, can be determined as

$$(v^3)_m = \int_0^{\infty} v^3 f(v) dv \quad \text{......(6)}$$

Integrating Eq.(6) the following is obtained for the Weibull function[4],

$$(v^3)_m = \frac{\Gamma(1+3/k)}{\Gamma^3(1+1/k)}(v_m)^3 \quad \text{.. (7)}$$

Where:

k is the Weibull shape factor,

Γ is the gamma function.

The monthly or annual wind power density per unit area of a site based on a Weibull probability density function can be expressed as follows:

$$P_W = \frac{1}{2}\rho c^3 \Gamma(1+\frac{3}{k}) \quad \text{........(8)}$$

Where:

c is the Weibull scale factor (m/s).

The two significant parameters k and C are closely related to the mean value of the wind speed v_m [6,7].

$$v_m = c\ \Gamma(1+\frac{1}{k}) \quad \text{................ (9)}$$

For *k*=2, the following is obtained from equation (9),

$$v_m = c\ \sqrt{\frac{\pi}{4}} \quad \text{.....................(10)}$$

By extracting C from Eq. (10) and setting k equal to 2, the power density for the Rayleigh model is found to be[4, 6],

$$P_R = \frac{3}{\pi}\rho\ v_m^3 \quad \text{...........(11)}$$

However, the errors in calculating the power densities using the distributions in comparison to those using the measured probability density distributions can be found using the following equation[7]:

$$\text{Error (\%)} = \frac{P_{W,R} - P_{m,R}}{P_{m,R}} \quad \text{........... (12)}$$

Where:

$P_{W,R}$ is the mean power density calculated from either the Weibull or Rayleigh function used in calculation of the error and $P_{m,R}$ is the wind power density for the measured probability density distribution, which serves as 'the reference mean power density'.

The yearly average error value in calculating the power density using the Weibull function is found by using the following equation

$$\text{Error(\%)} = \frac{1}{12}\sum_{i=1}^{12}\left[\frac{P_{W,R} - P_{m,R}}{P_{m,R}}\right] \quad \text{.(13)}$$

In real measurement, the wind speed tends to increase with height in most locations and depends mainly on atmospheric mixing and terrain roughness. Therefore, to calculate the total wind energy potential, the measured surface wind speed must be modified for an altitude different from the normalized height (i.e. 10 m) for this reason the following equation was used[8,9].

$$v = v_i \left(\frac{Z}{Z_i}\right)^{m} \quad \text{............... (14)}$$

Where:

v_i is the wind speed at normalized height, m/s
z_i is the normalized height, m
Z is the turbine height, m

The exponent m depends on factors as surface roughness and atmospheric stability. Numerically, it lies in the range of 0.05–0.5, with the most frequently adopted value being 0.14 (widely applicable to low surfaces and well exposed sites).

RESULTS AND DISCUSSION:

The present data of the wind speed were taken from the National Water Recourses Information Center, Taiz.

Hourly time-series wind speed data measured for the year 2000 have been statistically analyzed. The wind speed data were recorded at a height of 10 m above the ground.

The values were taken every 15 min and stored in data logger. The 15 min averaged data were further averaged over 1 h, which is the most common time step interval used in hourly simulations and in the statistics.

The distribution of wind speeds is important for the design of wind farms, Power generators and agricultural applications like irrigation.

The monthly means wind speed values and the standard deviations are presented in table (1). It is found that the highest wind speed values occur in the months of March and August.

The Weibull parameters seen from the table (1) show that while the scale factor varies between 3.41 and 6.37 m/s, the shape factor ranges from 3.05 to 7.61 for the location under consideration. Figure (1), however, shows that the lowest wind speed occurs in September and October.

The monthly average of wind speed data plotted in Fig. (1) show that the wind speed has the lowest value in the month of October and the maximum in the months of March and August and that the general annual average value is 4.4 m/s.

Effective utilization of wind energy entails a detailed knowledge for the wind characteristics at the specified location. The wind speed data in time-series format is usually arranged in the frequency distribution format where it is more convenient for statistical analysis. Therefore, in the current study the available time-series data were arranged to annual frequency distribution format. The percentage annual frequencies of occurrence of wind speed are depicted in Fig. (2).

As shown in Fig. (2), the maximum value of annual frequency of wind speed occurs at 3.5 m/s and the minimum of this value at 10.5 m/s. The wind speed frequency which occupies the interval between 4 and 5.5 attains about 50% of the total wind spectrum for this location.

The power densities calculated from the measured probability density distributions and those obtained from the models are shown in Fig.(3). The power density shows a large variation among months. The minimum power densities occur in September and October, with 25.78 and 23.53 W/m^2, respectively. It is interesting to note that the highest power density values occur in the months of March, April, July and August, with the maximum value of 157.90 W/m^2 in March.

The errors in calculating the power densities using the models in comparison to those using the measured probability density distributions are presented in Fig. (4).

The highest error value occurs in February and June with 11.23% and 17.63% for the Weibull model, respectively. The power density is estimated by the Weibull model with a very small error value of 2.8% in July. The yearly average error value in calculating the power density using the Weibull function is 8.44%.

The monthly analysis shows that the error values in calculating the power density using the Rayleigh model are relatively higher, over 17.42% in some months, such as April and July. The smallest error in the power density calculation using the Rayleigh model is 1.24% in November. The yearly average error value in estimating the power density using the Rayleigh model is 1.89%.

Table (1) : Distributions parameters on monthly basis, calculated from measured hourly time-series wind speed data in Taiz, Yemen

Month	v_m (m/s)	σ(m/s)	C (m/s)	k
January	4.50	1.31	5.00	3.82
February	4.58	0.98	4.97	5.34
March	5.71	1.91	6.37	3.28
April	4.75	1.70	5.32	3.05
May	4.22	1.01	4.76	4.72
June	4.28	0.66	4.56	7.61
July	4.71	1.67	5.27	3.08

August	**4.96**	**0.88**	**5.32**	**6.54**
September	**3.13**	**0.94**	**3.47**	**3.69**
October	**3.11**	**0.78**	**3.41**	**4.49**
November	**4.63**	**1.30**	**5.13**	**3.99**
December	**4.32**	**0.99**	**4.32**	**4.95**

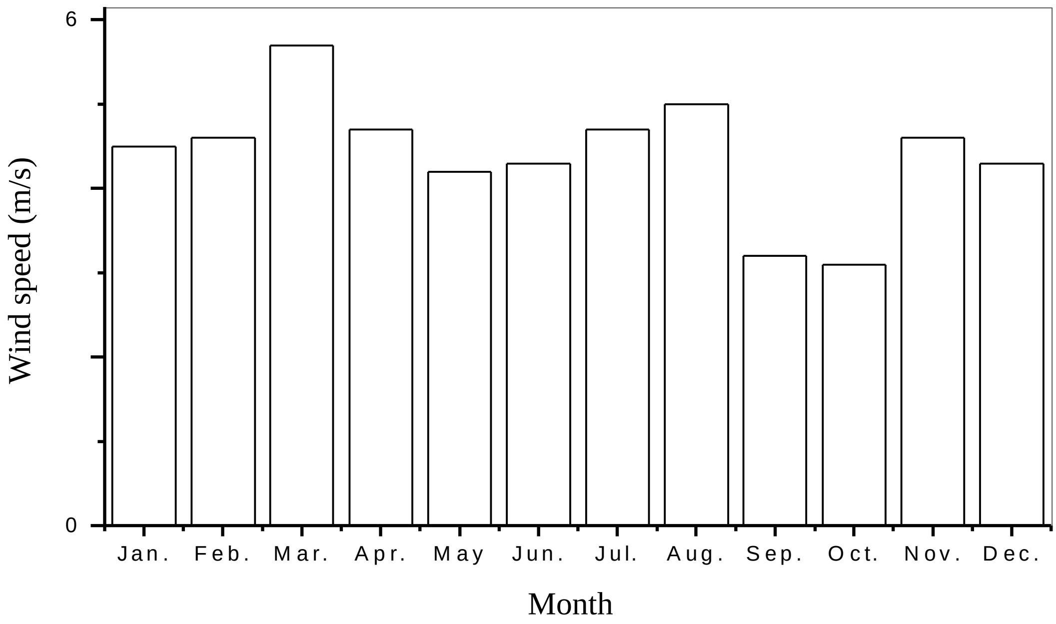

Fig .1.Monthly mean of wind speed in Taiz,Yemen in the Year 2000 .

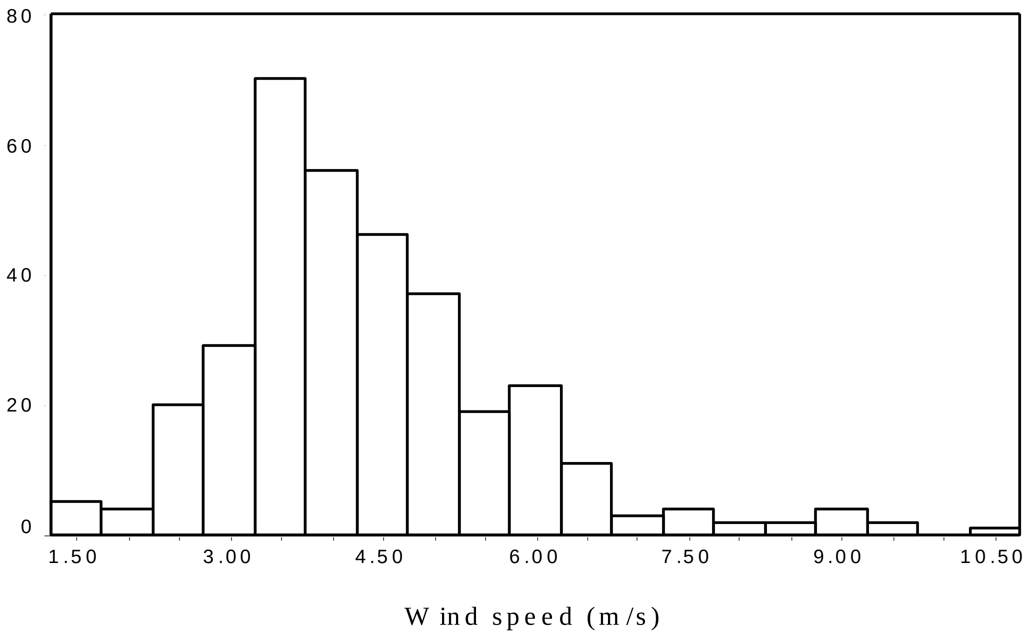

Fig. (2) :Frequency diagrams of the wind speed

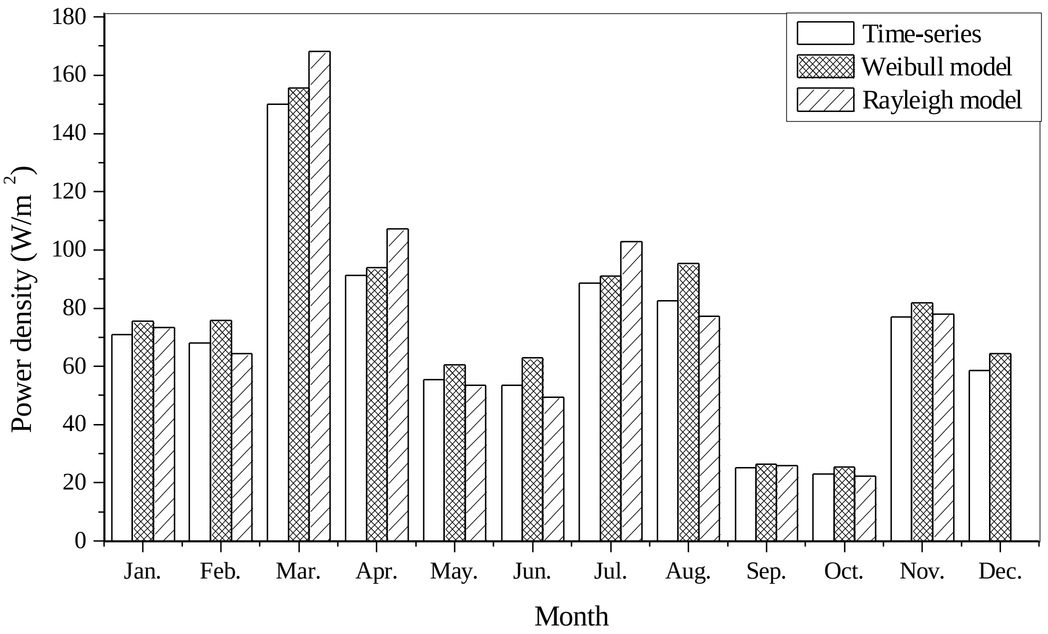

Fig. (3) : Wind power density obtained from the measured data versus those obtained from the Weibull and Rayleigh models, on a monthly basis

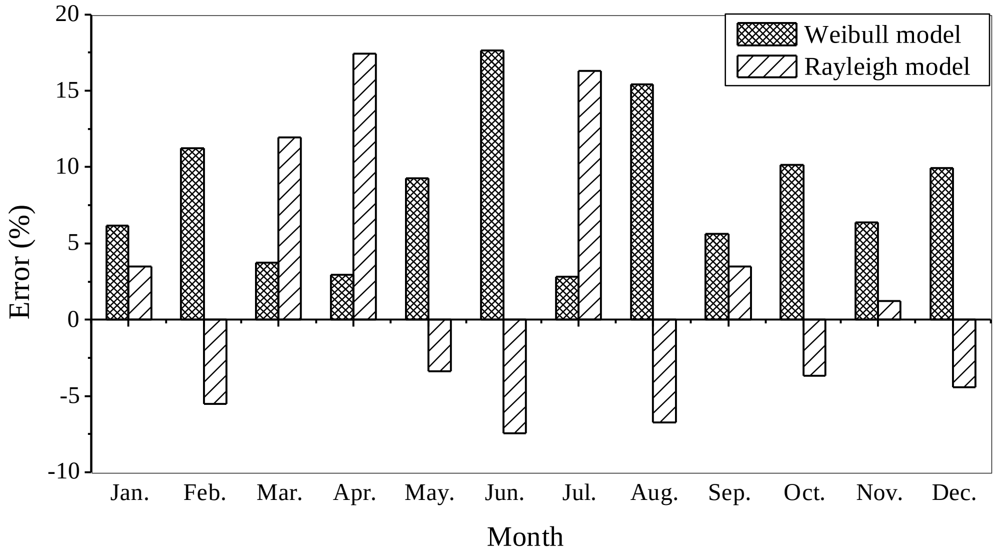

Fig. (4) : Error values in calculating the wind power density obtained from the Weibull and Rayleigh models in reference to the wind power density obtained from the measured data, on monthly basis.

CONCLUSIONS:

In the present study, the hourly measured time series wind speed data of Taiz have been statistically analyzed. The power density distributions have been derived from the time series data and the distributional parameters were identified. The wind energy potential of the location has been studied using the Weibull and the Rayleigh models. The most important outcomes of the study can be summarized as follows:

1-The data show that the distributions of wind speed depict relatively reasonable annual average of 4.4 m/s, which indicates that the area can be explored for wind energy applications. The data also show that the maximum monthly wind speed occurs in the month of March while the month of October has the lowest mean wind speed.

2-The wind speed frequency which occupies the interval between 4 and 5.5 attains about 50% of the total wind spectrum for this location.

3-The yearly average wind power density value of 72.41 W/m^2 indicates that this level of power density is adequate for connected electrical and mechanical applications.

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تحليل وتقييم كثافة طاقة الرياح في تعز- الجمهورية اليمنية

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يمكن استغلال الطاقات المتجددة في اليمن، مثل طاقة الرياح والطاقة الشمسية، ليس فقط للحد من زيادة الطلب على الطاقة، ولكن أيضا لأسبابٍ بيئيةٍ، لذا فإن هذه الورقة تستعرض نَتائِجَ التحليلِ لبياناتِ سرعةِ الرياحِ لسَنة تقويمية (٢٠٠٠) م المقاساة كمتوالية زمنيةٍ لكل ساعةٍ في مدينةِ تعز الواقعة جنوب غرب اليمن خط عرضَ -٣٥ ١٣° شمالا وخط طول َ٤٤°٠١ شرقاً والتي ترتفع عن سطح البحر بحوالي ١٣١١ متر، وطبقاً للتحليل الإحصائي فإن المتوسط السنوي لسرعة الرياح حوالي ٤.٤ م/ث وتكون أكثر تكرارا بين القيمتين ٣ و ٦.٥ م/ث، كما بينت الدراسة أن القيمة الشهرية القصوى لسرعة الرياح تكون في شهر مارس، كما تم تقييم طاقة الرياح استنادا على نموذج Rayleigh و Weibull ويستنتج أنه من الممكن الاستفادة من طاقة الرياح في موقع الدراسة.