Analysis and Distribution of Wind Speed in Saudi Arabia

Y. Al-Douri (yaldouri@yahoo.com)
University of Malaya: Universiti Malaya

S. A. Waheeb
Umm Al-Qura University

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Abstract

Background: the purpose of this study is to estimate the winds, its erosion and wind power of Kingdom of Saudi Arabia. The additional value is to details wind energy in Saudi Arabia indulging updated wind speed analysis, wind speed frequency distribution and mean wind power density variation to present novel work could be added to the literature providing recent data helping for future researches and studies.

Results: the updated analysis and distribution of wind energy are presented in six sites; Al Jouf, Hafar Al Batin, Riyadh, Al Wajh, Jeddah South and Sharurah of Saudi Arabia. The winds and wind energy are elaborated. The long-term annual mean values of wind speeds are found to vary between year 2000 and 2020. The annual values of wind power density are varied between year 2006 and 2020. Also, the wind speeds are researched over the entire geography of Saudi Arabia. The percent frequency distribution at different wind speeds for the mentioned six sites at 12 m for two decades is displayed.

Conclusions: the long-term values of wind speed were found between 3.3 m/s in 2000 and 5 m/s in 2020. The annual wind power density values were varied between 44 W/m\(^2\) in 2006 and 88 W/m\(^2\) in 2020. In addition, the wind speeds were researched over the entire Saudi Arabia for east, north, west and south. The deduced percent frequency distribution was less than 18% of the time at 12 m.

1. Introduction

One of the growing and fastest types of renewable energy is the wind energy that is attributed to its cost-effective and environmentally-friendly compared to fossil fuels and distinguished technology to harness wind power. The wind energy is more appropriate resource to conserve and address the environment and its issues. It is noticed apparently that the wind power projects are increased dramatically worldwide due to novel installation being commissioned on the globe [1]. The united states are the leader for wind power projects regarding to international wind power capacity [2]. The middle-east has reported different wind power and speed efforts [3].

Recently, Bahaj et al. [4] have developed a system of geographical information to solve the spatial siting for offshore wind farms taking into account appropriate conflicting factors/constraints. They have presented new approach for solving the conflicting factors for offshore wind farms. The mentioned approach has been tested through determining the offshore wind energy potential at the Arabian Peninsula including good results for offshore wind farms. Mahbub et al. [5] have assessed the hub height effect, wind shear exponent, wind power, energy yield, air turbulence intensity and plant capacity factor for yielding energy. They have measured wind speeds at different heights. Atieh et al. [6] have demonstrated new wind tunnel with elevation structure and conical to generate the power. They have utilized 48 cm diameter blades of aluminum for wind turbine that is made from galvanized aluminum with square front and back ends with side length of 0.75 m and 0.5 m, respectively. Also, they have conducted simulations for calculating speed of wind at different positions in Saudi Arabia (KSA). Shawon et al. [7] have highlighted the potential of wind energy including detailed analysis on the economics beyond deploying technologies of wind energy. Shaahid [8] has analyzed wind speed in KSA to test the technological and economical potential of wind farm. He has proved that the average wind speed ranges, 3.3–5.6 m/s, while the simulation results refer for 100 kW wind capacity. And, Allhibi et al. [9] have focused on the KSA’s vision 2030 including its plan to target 20% of producing power with focusing on wind energy. There is an impetus to produce electricity by investing in wind farms. Salim and Alsyouf [10] have assessed the
renewable energy potential including wind energy as an essential future energy source in the Gulf Cooperation Council (GCC) region including KSA. They have discussed better understanding for the future and status of wind energy including potentials, projects, targets and strategies. Bassyouni et al. [11] have studied eleven years (2002–2012) to determine wind characteristics of Jeddah in KSA. They have measured the minimum and maximum wind power potential in different month of the year. They have found that wind is blowing predominantly from south east direction. While, Farh et al. [12] have introduced a computer program applied in KSA for choosing the appropriate wind turbines according to economical and technical assessment. They have showed that two wind turbines with same performance but different rated powers get same capacity factor in the same site providing feasible economical awards. Finally, Alharbi and Csala [13] have employed Monte-Carlo simulation and Brownian Motion approaches to predict future behaviors of wind energy in KSA for providing wide options for future results. They have proved that the north-western of KSA is the most highly recommended region for deployment wind energy due to abundance of wind energy resources with low temperature along the year. They have declared a roadmap for climate goals of wind energy of long-term future analysis.

The aim of this paper is to assess the winds, its erosion and wind power of KSA. The additional study is to elaborate wind energy in KSA indulging updated wind speed analysis, wind speed frequency distribution and mean wind power density variation to present novel work could be added to the literature providing recent data helping for future researches and studies.

2. Winds

Despite of KSA's perceptions of geography and weather, KSA regards not a windy country. The pressures of atmosphere are high but the difference of seasonal pressures is relatively little. The seasonal situation is given in Table 1. The Arabian Gulf is not windy although of *shamal* winds. Riyadh has relatively low mean monthly wind speeds, 2 m/s including monthly maximum is not high [14]. Hafar Al Batin on the different region in north-east of KSA is windier and monthly maximum is double than Gulf coast. Different diverged sites, Al Wajh is on the northern part and Sharurah on its southern part demonstrate wind speed declining from north to south. And although of its altitude, Jeddah South is much less windy than Hafar Al Batin or Al Jouf.
Table 1
Mean monthly wind speed (m/s) of six sites of KSA [23].

|                | Hafar Al Batin | Al Jouf | Jeddah South | Al Wajh | Sharurah | Riyadh |
|----------------|---------------|---------|--------------|---------|----------|--------|
|                | Mean | Max.  | Mean | Max.  | Mean | Max.  | Mean | Max.  | Mean | Max.  |
| Jan            | 2.1  | 13.8 | 2.2  | 10.7  | 2.4  | 7.4   | 1.5  | 4.9   | 2.2  | 9.1   | 2.0  | 6.3   |
| Feb            | 2.4  | 13.5 | 2.5  | 11.7  | 2.6  | 10.2  | 1.5  | 7.4   | 2.2  | 9.8   | 2.0  | 4.6   |
| Mar            | 2.7  | 16.0 | 2.6  | 14.5  | 2.5  | 9.3   | 1.6  | 7.4   | 2.5  | 10.9  | 2.1  | 5.7   |
| Apr            | 3.1  | 14.9 | 2.8  | 13.8  | 2.1  | 8.2   | 1.7  | 7.1   | 2.4  | 9.9   | 2.1  | 4.9   |
| May            | 3.0  | 14.6 | 2.7  | 13.8  | 2.0  | 7.6   | 1.8  | 7.1   | 2.3  | 9.1   | 2.1  | 7.8   |
| Jun            | 3.1  | 13.2 | 5.2  | 9.9   | 2.1  | 8.0   | 1.8  | 6.8   | 2.8  | 9.5   | 2.6  | 7.7   |
| Jul            | 3.0  | 11.6 | 2.6  | 9.6   | 2.3  | 8.2   | 2.0  | 6.8   | 2.7  | 8.5   | 2.2  | 6.7   |
| Aug            | 2.5  | 9.3  | 2.3  | 8.8   | 2.1  | 8.2   | 1.9  | 6.6   | 2.3  | 8.0   | 2.1  | 7.0   |
| Sep            | 2.3  | 9.9  | 2.0  | 8.8   | 2.1  | 9.9   | 1.6  | 5.2   | 1.8  | 8.2   | 1.7  | 7.1   |
| Oct            | 1.9  | 22.1 | 2.1  | 9.3   | 2.0  | 8.0   | 1.3  | 4.3   | 1.7  | 8.5   | 1.6  | 6.7   |
| Nov            | 1.8  | 12.7 | 2.0  | 11.0  | 2.0  | 6.0   | 1.2  | 4.1   | 1.8  | 8.8   | 1.8  | 5.4   |
| Dec            | 1.7  | 13.2 | 2.0  | 12.1  | 2.0  | 6.0   | 1.3  | 3.5   | 2.0  | 8.5   | 2.1  | 6.7   |

The intense low pressure over the east creates big anticlockwise winds displaying northerly winds as shown in Fig. 1. Additionally, there is one or more seasonal winds affecting the KSA. It is as known that there is *aziab*, a wind, hot, strong and dry sourced south-west as happened in May–September a year. It handles dusts to Jeddah including thunderstorms. The disturbances are created by low-pressure and fronts sourced west or north-east regions.

This is leading us to know much more about the wind erosion that is playing an important role in the KSA's landforms development. Clearly, wind erosion has been effective in the dune areas where the sand grains are frosted due to high impact collisions. Nowadays, KSA is not a windy environment but there is abundant evidence of wind erosion relating to former palaeoclimates.

### 3. Wind Energy In Saudi Arabia

KSA has an alternative renewable energy such as wind energy to be attractive technology contributing to KSA's vision 2030. The KSA's wind map is defined by red sea and Arabian Gulf. It is researched that speed of wind is almost 6–8 m/s. However, it does not include a potential analysis of wind power to reflect distribution of wind speed. The central, northeast and western mountains are familiar with big speed of winds. Saudi Arabia's wind speed map is illustrated in Fig. 2. Moreover, KSA has good potential of wind speed, 7.5-8 m/s (east), 7-7.5 m/s (west) and 5-6.5 m/s (center) [15]. Figure 3 illustrates the updated average wind speeds of six sites of KSA within the year 2020 that are distributed geographically for the east, north, west and south. For your knowledge, the lowest wind speed is available in the capital Riyadh and second city Jeddah that is attributed to natural...
landscape. While, the highest wind speed is available at Al Wajh. Meanwhile, Hafar Al Batin and Sharurah are inner areas having average wind speed

Most of the oil countries including KSA is relying on oil, coal and gas causing emission of CO$_2$ to affect the global warming. Paris convention is commissioned to reduce naphtha and carbon dioxide emissions as signed in 2015 [16, 17]. Its aim is to control the temperature of globe below 2 °C yearly. KSA plays an important role in the mentioned treaty. Due to KSA is 11th international rank of CO$_2$ emission [18], it produces M 494.82 ton of CO$_2$ [19]. The expected production is expected to be twice by 2023 [20]. Moreover, KSA has announced a KSA’s vision 2030 to increase using renewable energy more than fossil fuels.

4. Results And Discussion

This updated wind speed analysis, wind speed frequency distribution and mean wind power density variation are interpreted and discussed as the followings:

4.1 Wind speed analysis

The long-term, smooth and economic conversion of wind energy systems are an important for annual variation study. The long-term is necessary for studying wind speed, let us say for 10 to 20 years [21]. The wind strength information and wind power availability are necessary for annual mean wind speed [22]. The annual wind power density and wind speed are calculated. The wind speed increases dramatically along long-term to provide confidence to develop wind farms designers and financers. Figure 4 illustrates for six sites of KSA the mean wind speed at 12 m varies between the minimum, 3.3 m/s in 2000 and maximum, 5 m/s in 2020. It is known that every 10 years, the wind speed shows a cyclic change. Along two decades, it is cleared obviously a variation of wind speed that is attributed to the weather reasons. In general, there is an increasing for the mentioned long-term. The seasonal monthly wind speed calculated at 12 m follows specific trend for the capital Riyadh as shown in Fig. 5. As seen, the bigger mean wind speed is observed in 2020, otherside, the lowest one is in 2000. It is observed a variation of monthly mean wind speed along two decades. Otherside, the collected data are helped for the overall mean monthly values along the mentioned period of time but do not reflect seasonal change. At 12 m, the average monthly mean values are found 4 m/s.

4.2 Mean wind power density variation

The mean density of wind power is studied for six sites of KSA using the daily values of wind speed and density as illustrated in Fig. 6. There is semi-matching of variation of wind power density values and wind speed as illustrated in Fig. 4. The lowest density value of wind power is 44 W/m$^2$ in 2006 in comparison with the lowest wind speed in 2002. This is ascribed to error percentage of calculations. While, the highest value is 88 W/m$^2$ in 2020 in comparison with the highest value of wind speed in 2020 too. It is noticed from Figs. 6 hat density values are almost high at 12 m. For studying seasonal behavior of wind power density for the capital Riyadh, the mean value is calculated at 12 m as depicted in Fig. 7. It is seen a vibration of wind power density values along two decades. The values are found in the range, 20–85 W/m$^2$ at 12 m.

4.3 Wind speed frequency distribution
The distribution of percent frequency distribution of mean wind speed at many wind speeds for six sites of KSA at 12 m along 20 years is displayed in Fig. 8. The distribution of frequency at 12 m is acquired. At 12 m, the wind value is found to remain zero for less than 18% of the time for different speeds. It is normal to notice that the commercial wind turbine starts to produce energy at 3.5 m/s. It proves the wind machine produces energy for 18% of time at 12 m. As a result, Hafar Al Batin is within existed wind data and turbines produce energy within the mentioned percent. At 12 m/s, the machine of wind gives power during whole collected data.

5. Conclusions

The wind energy in six sites of KSA was analyzed and distributed with updated data. The discussion was focused on winds and wind energy. The long-term values of wind speed were found between 3.3 m/s in 2000 and 5 m/s in 2020. The annual wind power density values were varied between 44 W/m$^2$ in 2006 and 88 W/m$^2$ in 2020. Also, the wind speeds were researched over the entire KSA and distributed geographically for east, north, west and south. The deduced percent frequency distribution was less than 18% of the time at 12 m.

Declarations

- **Data availability statement:**

  Data openly available in a public repository that issues datasets with DOIs

  The data that support the findings of this study are openly available in figures captions at reference numbers [13,24].

- **Ethics approval and consent to participate:**

  The authors declare their approval

- **Consent for publication:**

  The authors declare their consent

- **Availability of supporting data:**

  The data that support the findings of this study are openly available in figures captions at reference numbers [13,24].

- **Competing interests:**
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

- **Funding:**

Not applicable

- **Authors' contributions:**

Y. A. wrote, characterized, edited and review original draft. S. A. W. analyzed, verified data and edited the manuscript.

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Figures
Figure 1

Intense low pressure over the east creates big anticlockwise winds [13].
Figure 2

KSA's wind speed map [24].
Figure 5

Seasonal variation wind speed at 12 m for the capital Riyadh.