



Wind Potential in Coastal Area of Gwadar, Balochistan, Pakistan

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Abstract: Wind energy represents a vital renewable resource for addressing Pakistan's energy crisis, particularly in coastal regions like Gwadar, Baluchistan, which offer substantial untapped potential due to favorable geographical and wind conditions. This study assesses the wind energy viability in four key coastal sites Ormara, Pasni, Gwadar City, and Jiwani, using one year of wind speed data (2021–2022) recorded at 10 meters' height by the Pakistan Meteorological Department. Employing the Hellmann exponent law for height extrapolation and standard power density equations ($P = 1/2 \rho V^3$, with air density $\rho = 1.225 \text{ kg/m}^3$ and Betz limit considerations), monthly wind speeds, power outputs, and energy potentials were calculated. Results indicate varying potentials across sites. Ormara shows power ranging from 5 W/m^2 to 34.3 W/m^2 , Pasni from 35.4 W/m^2 to 116.7 W/m^2 , Gwadar City from 19.2 W/m^2 to 111.9 W/m^2 , and Jiwani exhibits similar seasonal patterns with peaks in April–July and lows in December. These findings underscore Gwadar's role in enhancing national energy security, reducing fossil fuel dependence, and supporting sustainable development goals through job creation and emission reductions. The study highlights the need for policy support, infrastructure investment, and further long-term monitoring to realize large-scale wind farm deployment.

Keywords: *Wind energy, Ormara, Pakistan's energy crisis, Pakistan Meteorological Department*

1.1. Introduction

It is a common fact that wind energy is actually, is a quickly advance technology and has acquired popularity due to its low and stable cost in contrast to traditional fossil fuels (Dabbaghiyan *et al.*, 2016). The total accessible wind energy amounts to about 10 million MW, which can meet 39% of the total global demand. Global installed wind energy capacity reached 1243 giga watts (GW) by the end of 2024 (Fazelpour *et al.*, 2015). Installations in 2023 exceeded 850 GW, which represents a significant increase compared to 2022, when installations totaled 850 GW (GWEC-GLOBAL WIND REPORT ANNUAL MARKET UPDATE, 2015). The Global Wind Energy Council (GWEC), is the international trade association for the wind energy industry and is committed to ensuring that wind energy clears all barriers to deliver substantial environmental and economic advantages. China captured 51% of the annual market with 33 GW of installations in 2019, according to the GWEC report. China currently leads the market with a total installed capacity of 214 GW. With total installations of 75 GW and 59 GW respectively, the US and Germany are the second and third largest markets. Cumulative installed capacity is forecast to reach 1066 GW by the end of 2023. (Nepal *et al.*, 2025). It is crucial to Pakistan's future energy pattern. It can lessen the energy crisis and help in the sustainable development of the country. There is a significant gap in demand and supply of electricity in Pakistan, which is estimated to be around 5000 to 8000 megawatts. It is also estimated that demand of energy will grow 6-8% annually (Raheem *et al.* 2016; Xin *et al.* 2022). Many countries rely heavily on imported fossil fuels. This has resulted in economic and environmental challenges such as increased local fuel price and increasing circular debt (Hulio *et al.*, 2022). In response, renewable energy includes solar energy, wind energy, hydropower and biomass which can meet growing energy demand. Moreover, they do not contribute to environmental pollution and enhance energy security (Kanwa *et al.*, 2020).

Wind energy is quite a great option due to the geographical conditions of Pakistan. The country has a lot of potential for wind energy. It has areas with suitable wind speed, as well as large areas of land for wind farms (Saulat *et al.*, 2020). As per some estimates, as much as 3% of the land of Pakistan could produce almost 132 gigawatts of power. Thus, emphasizing the potential of wind energy development (Asghar *et al.*, 2022). The coastal areas of Pakistan, especially Sindh and Baluchistan, have a lot of potential for wind power generation. Some

projects have installed wind energy systems mainly for rural electrification and job creation (Malik *et al.* 2020; Raza *et al.* 2019).

To fully realize and use wind energy, investment and policy are important to support the industry. Wind farm construction increases the variety of energy sources as well as supports economic development by improving the local economy through job creation (Adnan *et al.* 2021). Moreover, wind energy projects can markedly lower dependence on imported fuels, lessen reliance on fossil fuels, and reduce greenhouse gas emissions (Baloch *et al.*, 2021). To fully harness the wind energy resources, there are challenges such as policy implementation, infrastructure, and finance that need to be addressed. To ensure the large-scale deployment of wind energy, it is essential for the government and other stakeholders to improve investments, technology integration, and policy barriers (Saulat *et al.*, 2020; Xin *et al.*, 2022). There are several reasons that make the coastal area of Gwadar in Baluchistan, Pakistan significant for wind energy exploration. One of the reason this one is its geographical location. It has a long coastline area along with that has good wind which is still not explored well. Due to the China Pakistan Economic Corridor (CPEC), and others, this region has become the apple of investors' eye. Especially, various initiatives are taken to harness and develop alternate energy resources like wind energy to curb the energy crisis in the country (Zahid *et al.*, 2021). Various research works done through geospatial technologies and GIS show that the location of Gwadar is suitable for wind farms. The wind characteristics of the area are conducive for energy generation projects. Such studies have carried out detailed analyses on the wind generation capacities at different sites in Gwadar showing the area's huge potential to contribute well to the grid both locally and nationally (Zahid *et al.*, 2021).

A comparison of wind potentials between Gwadar and other locations suggest Gwadar perhaps does not peak in power generation but it has enough wind to enable useful and economical power generation. Abbas and colleagues (2022) also evaluated the installation and turbine costs, which confirm that Gwadar is suitable for wind energy. The main aim of the assessment of wind potential in Gwadar is to determine the capacity of the area to generate wind energy. This will help in the planning and development of the wind energy projects. This is the assessment of wind speed distributions directions and power density in order to check the feasibility of erecting wind turbines and building windfarms. A good evaluation supports the choice of suitable turbine types and their optimum site for best energy output (Huang *et al.*,

2024; Shi *et al.*, 2021). Investigating wind capacity in Gwadar can greatly enhance the energy security and sustainable development of Pakistan. Wind energy is a clean and renewable energy source. It helps to reduce our dependence on fossil fuels. Further, it helps to cut greenhouse gas emissions. The development of wind energy infrastructure in Gwadar can facilitate access to energy source, enhance economic development and also create jobs, thereby contributing to SDGs, especially decent work and economic growth and sustainable cities and communities (Aceleanu *et al.*, 2017; Lagili *et al.*, 2023; Olabi *et al.*, 2023). By enhancing wind energy capacity, improvements in energy infrastructure, financial de-risking policy incentives, and capacity building may not only be envisaged in renewable energy. The local and national efforts towards attaining energy security and sustainable economic development are further supported by this strategic development (Wabukala *et al.*, 2021).

1.2. Research Methodology

1.2.1. Data and Methodology

To conduct the study, the data was taken by the Karachi Meteorological Department, Pakistan. The statistics include one year (2021 to 2022), the average wind velocity at the height of 10 meters is recorded.

1.2.2. Hellmann Exponent Law

In fact, windmills need a constant wind speed to produce electricity. This is difficult to achieve because the wind is not constant in nature and does not blow at a constant speed, but changes in a short period of time. Wind speed also depends on the height above the ground. We use the Hellmann index rule, Estimation of wind speed at any height (Yaniktepe *et al.*, 2013).

$$V(h)/V_{10}=(h/10)^{\alpha} \quad (1)$$

$V(h)$ is the wind speed at a height, h , V_{10} is the wind speed at a height of 10 m and the Hellmann index is represented by 3. In flat and open surfaces $1/7$. The amount of available wind given a wind speed to a region can be estimated (Gökçek *et al.*, 2007).

$$P = 1/2\rho V^3 \quad (2)$$

Among these are ρ as density of air that is presupposed, 1.225 Kg-m^{-3} , and average monthly velocity of the wind V in m/sec^{-1} . No wind turbine could tap so much energy. The Betz relation suggests the limit of the maximum power of the wind turbine, supplying the possible coefficient of $C = 16/27$ as the most efficient one of the wind turbine (Turkmenler *et al.*, 2015).

Power output:

$$P_{\max} = 1/2\rho C_p V^3 W \text{m}^{-2} \quad (3)$$

In this article we shall employ equation (2) to compute data on the speed of the winds and this will be done in terms of square meter of area covered by the rotor:

$$P = 0.1 \times V^3 \quad (\text{W m}^{-2}) \quad (4)$$

1.3. Results and Discussions

1.3.1. Study Area

The coastal area of Gwadar, Baluchistan, Pakistan, near the Arabian Sea, is discussed in this section. Being geographically close to the coast of the Arabian Sea, strong and moderate winds prevail in spring and summer. That is because the difference between the temperature of the sea and land is high during winter, and the storms occur during the day, and the land wind occurs at night. Nonetheless, as an aid to comprehend the wind patterns related to the site, long-term monitoring research will also assist in the realization of potential locations of wind parks as depicted in (Figure.1), Alternative Energy Development Board (AEDB), of Pakistan government was formed in May 2002, and became the core body in the formulation of renewable energy source identification and wind power potential in Pakistan (Fazelpour *et al.*, 2015).

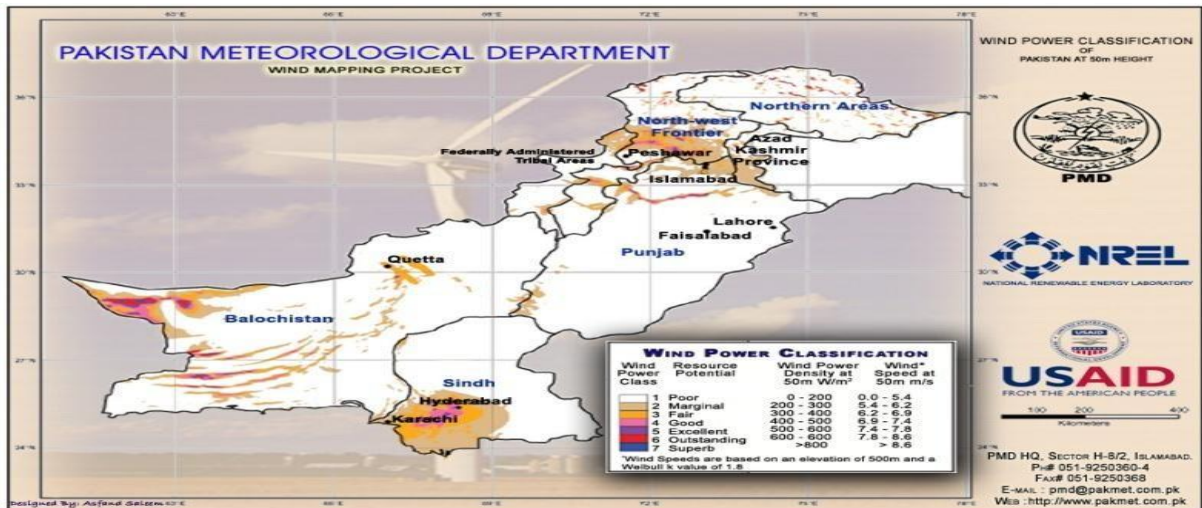


Figure.1: Wind Map of Pakistan.

Coast monitoring stations are located on land or over 02 km from the sea. Four regions along the Arabian coast have been studied for their wind energy potential. These areas include Ormara, Pasani, Gwadar City and Jiwani in Gwadar, Baluchistan province, Pakistan. The record set on the wind speed was done every year with an elevation of 10 meters since 2021 to 2022. The wind map under study is shown in (figure.2).



Figure .2: Wind Maps from Gwadar, Pakistan.

Wind speed data at four coastal stations in Gwadar, Baluchistan (i.e. Ormara, Gwadar City, Pasani and Jiwani) were obtained from the Pakistan Metrology Department (PMD), Government of Pakistan. Wind speed data for these locations were recorded at 10m during 2021-2022.

1.3.2. Tables Description

The results of the calculations for all four research areas are presented in several tables, including descriptive statistics, monthly wind and electricity, energy and energy intensity and potential. In this section, the structure of these tables is explained. The monthly table consists of 12 columns.

1.3.3. Case 01: Ormara (Gwadar, Baluchistan)

Ormara lies cad way in province of Baluchistan in Pakistan located district of Gwadar. Ormara is a port town of the Makran coast, which is located 360 km west of Karachi. We have got the daily values of the wind speed of the Pakistan Meteorological Department (PMD), and it has been measured at a height of 10 meters above ground level. Its location is $25^{\circ}13' N$ and $64^{\circ}37' E$. The map of Ormara as depicted in (Figure. 3), reveals that the town is on its way towards the future, apart from the right arm of the sea disk that is trapped in the school of force.



Figure. 3: Map of Ormara, located in Gwadar District, Baluchistan, Pakistan.

1.3.4. Descriptive Statistics

To estimate wind speed, first convert wind speed from knots to m/s. By using the power per square meter swept by the standard rotor, the wind speed, wind energy and wind power estimates are shown (Table.1 and figure 4.3.2).

Table .1: Annual wind speed for Ormara

Months	Wind Speed [m/s]	Power Watts	Energy Kwhm⁻¹
January	5.3	15.4	46.2
February	4.5	9.1	27.3
March	5.3	14.9	44.7
April	5.8	19.5	58.5
May	7	34.3	102.9
June	6.4	26.2	78.6
July	5	12.5	37.5
August	4.7	10.4	31.2
September	4.1	6.9	20.7
October	4	6.4	19.2

November	3.9	5.9	17.7
December	3.7	5	15

Figure 4. Indicates the months of the year in the horizontal axis and the vertical axis indicates the wind speed, power and energy.

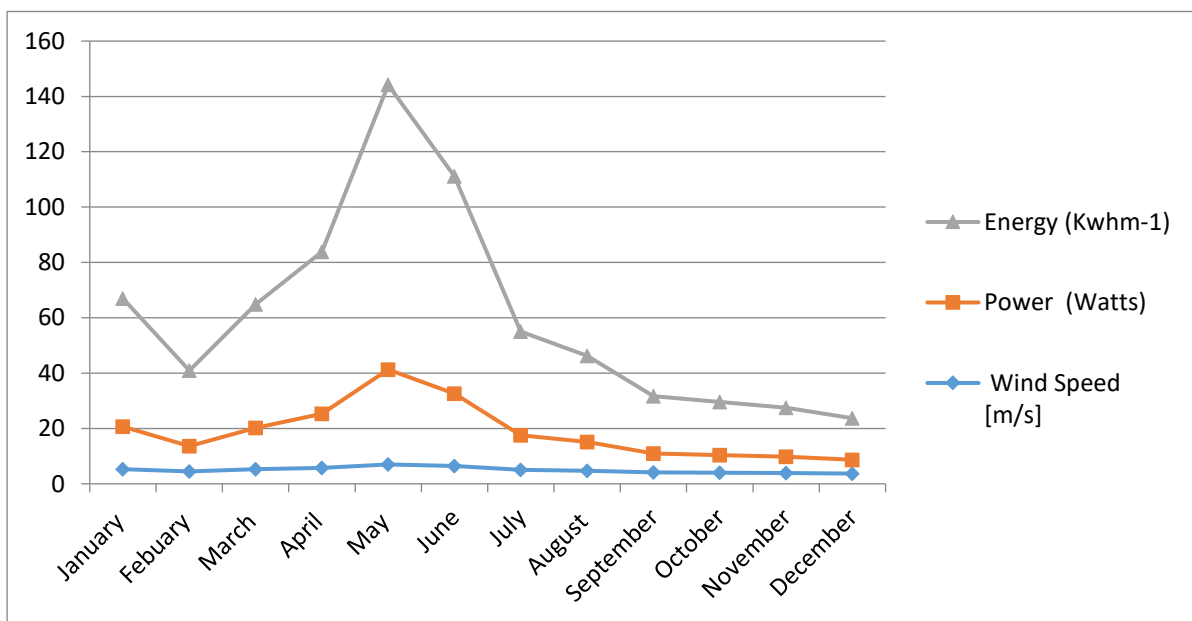


Figure. 4: shows the speed duration curves for Ormara station.

1.3.5. Wind Potential Energy for Ormara

Figure. 3.Presents monthly wind power and power at 10m height within the years 2021-2022. The wind speeds become higher between the months of April through July and the lowest rate of the speed will be witnessed during the month of December. The power varies from 5 watts to 34.3 watts.

1.3.6. Case 02: Pasni (Gwadar, Baluchistan)

In the province of Baluchistan in Pakistan, the town of Pasni is a fishing port in the Gwadar district. It lies approximately 450 kilometers from Karachi on the Makran coast of the Arabian

Sea. The dominant activity of the inhabitants around the city is fishing, and the city has a modern fishing port, the Pasni port. Pasni is situated at 25°13' 2N and 64°37' 2E. A total of 1 year coverage of wind speed was recorded between 2021 and 2022. Location of the map: Pasni is in a district of Gwadar in Baluchistan in Pakistan, as (figure. 4 shows).



Figure. 5: Map of Pasni located in district of Gwadar, Baluchistan, Pakistan.

1.3.7. Descriptive Statistics

The recorded wind speeds in knots are first converted to meters per second in order to estimate the wind potential. One year data from 2021 to 2022 from the observatories are analyzed. The energy and power potential of wind are obtained by using the power per square meter area swept by the rotor. The wind speed, wind energy and wind power estimates are shown (Table. 2 and figure. 5).

Table .2: Annual wind speed for Pasni station

Months	Wind Speed [m/s]	Power Watts	EnergyKwhm ⁻¹
January	5.5	16.6	49.8

February	4.9	11.8	35.4
March	5.4	15.7	47.4
April	6.2	23.8	71.4
May	7.4	38.9	116.7
June	6.8	31.4	94
July	6.6	30	90
August	5.4	15.7	47.1
September	5	12.5	37.5
October	4.2	7.4	22.4
November	4.21	7.4	22.2
December	4.1	6.9	18.9

In figure 6. The x axis is a representation of the months of the year. The speed of wind, power and energy are denoted on the vertical axis.

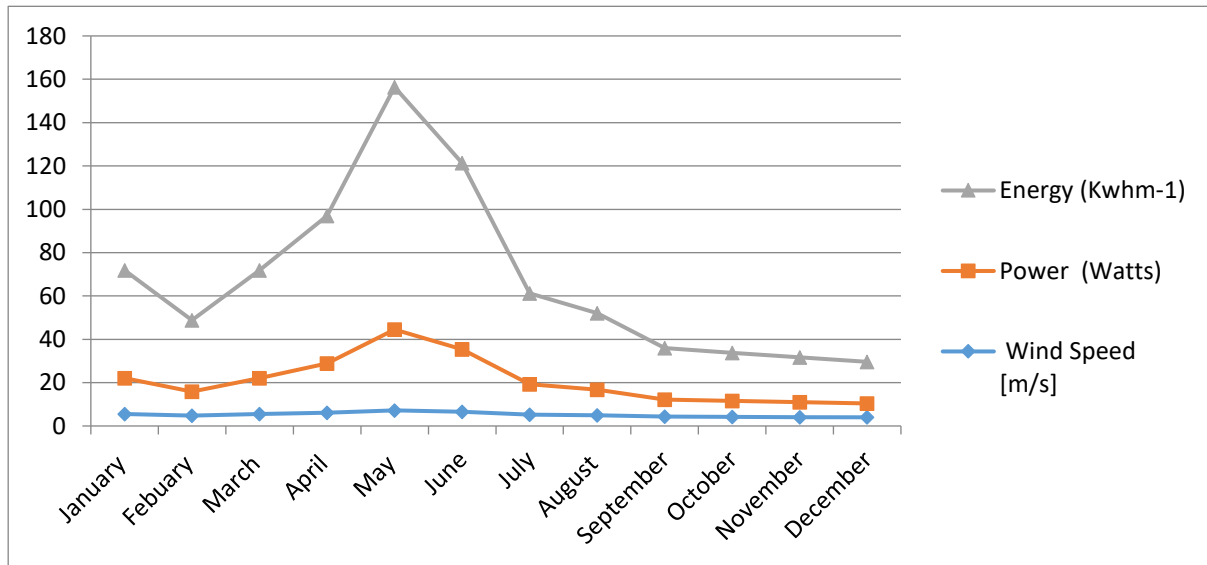


Figure. 6: shows the speed duration curves for Pasni station

1.3.8. The potential of wind energy for Pasni

Figure 4.4.2 reflects the monthly wind power and energy computed at 10m height within the period 2021 to 2022. The wind speed is found to be the lowest in month December. Power: The product is operated between 35.4-watts and 116.7 -watts.

1.3.9. Case 03: Gwadar City (Gwadar, Baluchistan)

Gwadar city is a port city on the southwest coast of Baluchistan province, Pakistan and capital of Baluchistan South region, which is the Gwadar district of Baluchistan province, Pakistan. Data on the daily values of wind speed in knots were obtained by Pakistan Meteorological Department (PMD). The mast is installed 10m above ground level. The mast coordinates are 25°13' N and 64°37' E. The data on the wind speed is gathered during the year 2021-2022. The map of Gwadar City (shown in figure.7) includes locations such as the Lashkar Gah City (which happens to be the main source of tension between the Islamic Republic of Pakistan and Afghanistan), Bajo Inferior, and Bajo Superior.



Figure. 7: Gwadar City map, located in district of Gwadar, Baluchistan, Pakistan

1.3.10. Descriptive Statistics

In order to determine the wind potential, we are to convert the wind speeds recorded in knots to the equivalent in meters per second. The data from two years, 2021-2022, is analyzed in one year of the observatories. The wind energy and the wind power can be estimated on the basis of the power per square meter of rotor swept area as follows. The estimated values of wind speed, wind energy, and wind power are in (Table. 3 and Figure 4.5.2).

Table. 3: Annual wind speed for Gwadar City

Months	Wind Speed [m/s]	Power Watts	Energy Kwhm ⁻¹
January	5.5	16.6	49.8
February	4.8	11	33
March	5.5	16.6	49.8

April	6.1	22.7	68.1
May	7.2	37.3	111.9
June	6.6	28.7	86.1
July	5.2	14	42
August	4.9	11.8	35.4
September	4.3	7.9	23.7
October	4.2	7.4	22.2
November	4.1	6.9	20.7
December	4	6.4	19.2

In figure 8, the horizontal axis shows months of the year and the vertical axis shows wind speed, power and energy.

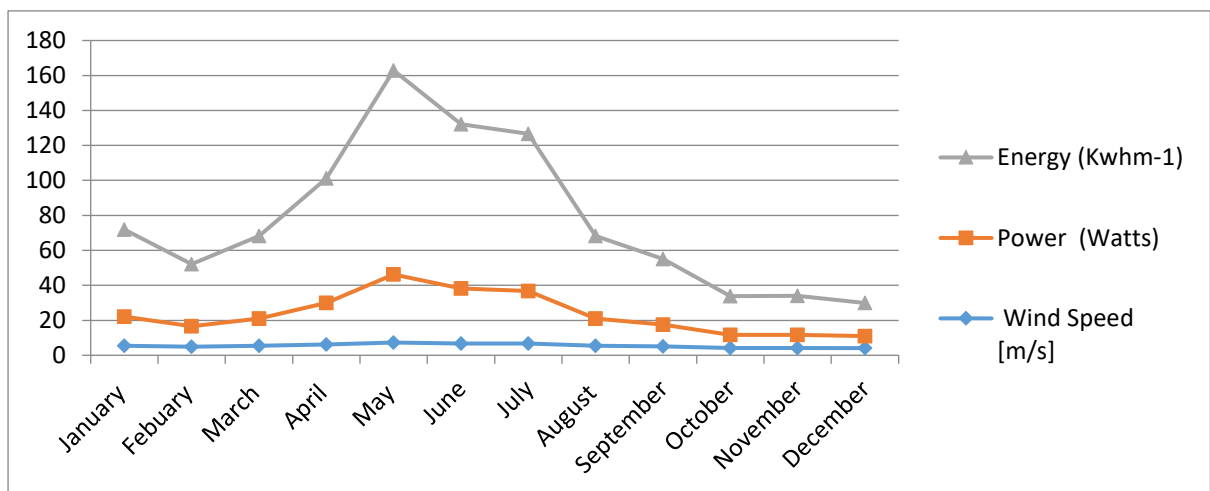


Figure. 8: Shows the speed duration curves for Gwadar City station.

1.3.11. Wind energy potential for the city of Gwadar

Figure 9. Illustrates the monthly wind power and energy obtained at a height of 10m between the years 2021 and 2022. The wind is high between April to July and the lowest wind speed will be recorded during December. The power ranges between 19.2W and 111.9W.

1.3.12. Case 04: Jiwani (Gwadar, Baluchistan)

Jiwani Jiwani is located in the Gwadar District of Baluchistan Province of Pakistan. Jiwani is the location of the Gulf of Oman, but it is a principal commercial port and also a town. It is also bordering Iran and Pakistan. Jiwani is a port town at the Makran coast. All the data of wind speeds measured in knots were provided by the Meteorological Department of Pakistan and measured at a height of 10 m above the land. The coordinates of the mast are 25°13' N 64°37' ES. The wind speed data were observed during the five years 2021 and 2022. In Figure 4.6, a map of the Jiwani site is depicted.

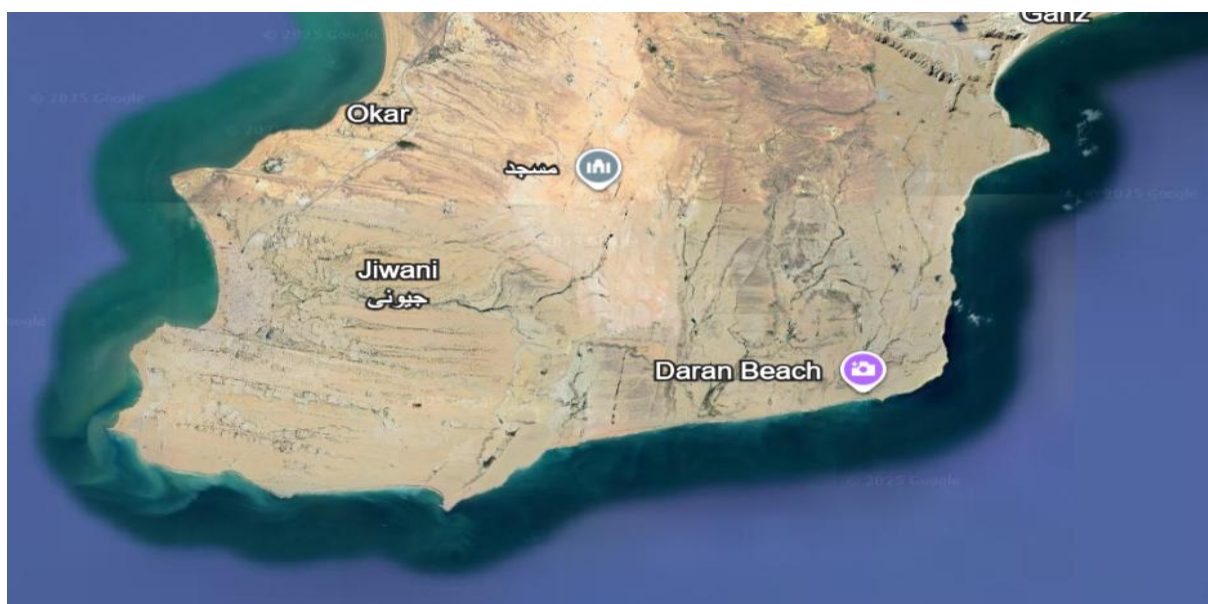


Figure. 9: Jiwani Map, located in district of Gwadar, Baluchistan, Pakistan.

1.3.13. Descriptive Statistics

The flow speed as recorded in knots is then converted to meters per second to give a wind speed so as to calculate wind potential. The data of 2021-2022 observed in the observatories are analyzed over one year. The estimation of wind power and wind energy is provided with the formula of power per square meter of rotor swept area; The estimated wind

speed, wind energy and wind power are given in (Table 4. and figure. 9).

Table No. 4.: Annual wind speed for Jiwani

Months	Wind Speed [m/s]	Power Watts	Energy Kwhm ⁻¹
January	5.6	17.56	52.68
February	4.95	12.13	36.39
March	5.5	16.6	49.8
April	6.3	25	75
May	7.4	40.5	121.5
June	6.96	33.6	100.8
July	6.85	32.1	96.3
August	5.5	16.6	49.8
September	5.1	13.3	39.9
October	4.4	8.5	25.5
November	4.275	7.8	23.4
December	4.3	7.9	23.7

In figure. 10 Horizontal axes show months and vertical axes show wind speeds, power and energy.

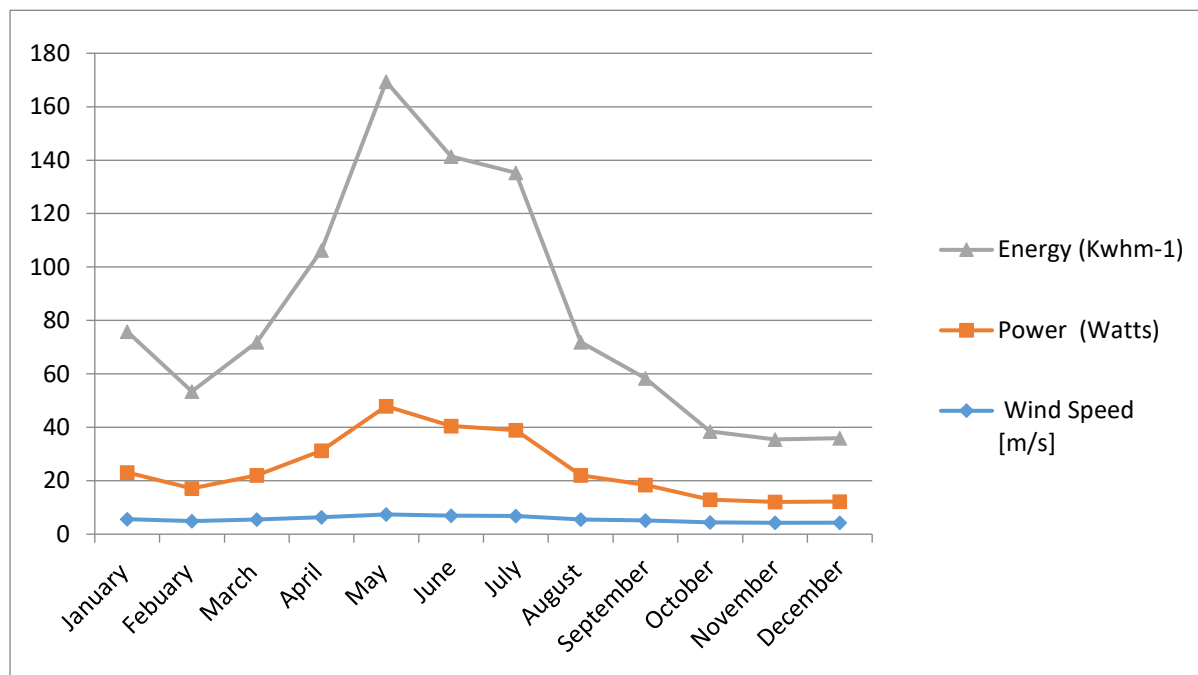


Figure. 10: Shows the speed duration curves for Jiwani station.

1.4. Conclusion

This investigation into the wind energy potential of Gwadar's coastal areas in Baluchistan, Pakistan, demonstrates significant opportunities for renewable energy generation, particularly in Ormara, Pasni, Gwadar City, and Jiwani. Based on analyzed wind speed data from 2021–2022 and applying established methodologies like the Hellmann exponent law and wind power density calculations, the sites exhibit promising seasonal wind patterns, with higher speeds and power outputs during spring and summer months, sufficient for economical wind turbine installations. Pasni and Gwadar City emerge as particularly viable, with peak powers exceeding 100 W/m², while all locations contribute to diversifying Pakistan's energy mix amid a growing demand-supply gap of 5,000–8,000 MW. Integrating wind energy in Gwadar not only addresses the nation's reliance on imported fossil fuels and mounting circular debt but also aligns with global sustainability efforts by curbing greenhouse gas emissions and fostering economic growth through rural electrification and employment. However, challenges such as policy barriers, financing, and infrastructure limitations must be overcome through collaborative efforts by the government, the Alternative Energy Development Board (AEDB), and investors, potentially leveraging initiatives like the China-Pakistan Economic Corridor

(CPEC). Future research should incorporate multi-year data, advanced geospatial modeling, and turbine-specific simulations to optimize site selection and capacity. Ultimately, harnessing Gwadar's wind resources can propel Pakistan toward energy independence, environmental resilience, and alignment with Sustainable Development Goals, paving the way for a greener energy future.

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